SCOTTISH MARKET CROSSES:

THE DEVELOPMENT OF A RISK ASSESSMENT MODEL

BY

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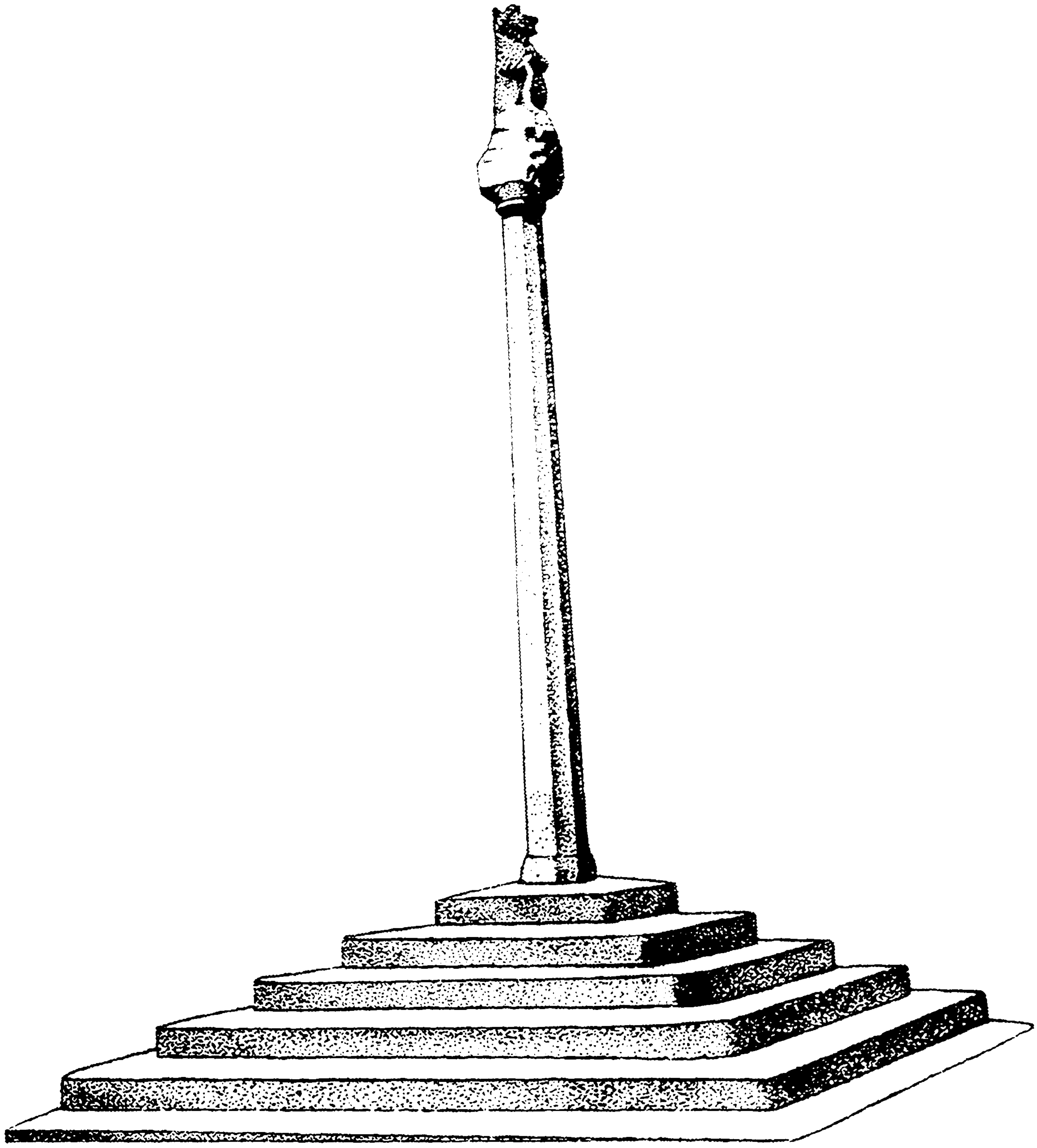
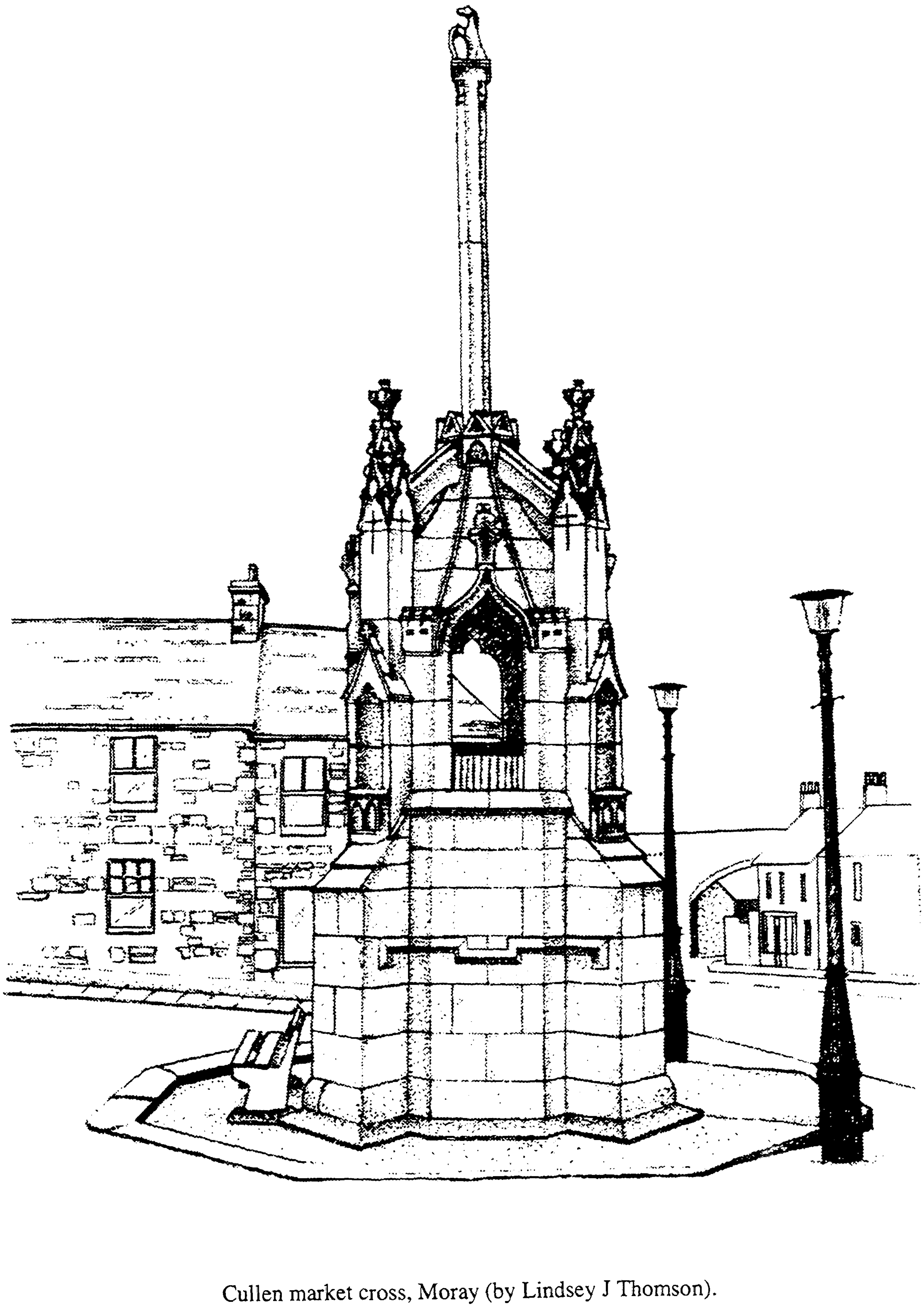


Doune market cross, Stirlingshire (by Lindsey J Thomson).



Cullen market cross, Moray (by Lindsey J Thomson).

Declaration

The candidate has not, while registered for this PhD submission, been registered for another award of a university during this research programme.

None of the original material in this thesis has been used in any other submission for an academic award. Acknowledgements for assistance received are given under the heading "Acknowledgements" and any other work has been acknowledged by its source and author.

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Abstract

The purpose of the research was to investigate the causes and effects of stone decay and soiling upon Scottish market crosses, and to develop a risk assessment model for this monument type. Risk assessment methods are otherwise used in spheres of business and industry. This research is unique in exploring the possibility of applying these techniques to the study and prediction of monument degradation. Additionally, the research is the first synthesised study of market crosses since 1928. A mapping methodology was developed in order to record the condition of a sample of Scottish market crosses. Visible evidence of the erosion, soiling and conservation of these monuments was collected and analysed in relation to various associated weathering factors. A risk assessment model was then developed for predicting the future condition of such monuments. Integrated with this, intervention criteria and conservation guidelines were also produced aimed at those charged with the care of market crosses. The model was applied to a case study to assess the risk of degradation of the tested monument. The method was found to work in practice, and could be used by practitioners in the future.

The methodology for the research can be summarised as follows. Based upon the literature review, hypotheses were formulated regarding the effect of various weathering factors upon decay and soiling patterns. Data for all surviving market crosses in Scotland was collected from archives and publications. A pro-forma and relational database were designed to hold all of the gathered data. A sample of 27 crosses was selected for detailed analysis. An increased level of data was collected for the sampled crosses, and a programme of intensive fieldwork was undertaken at these. Evidence for all visible decay, soiling and conservation treatment was mapped onto a detailed elevation sketch of each facade of every sampled cross. The decay and soiling were also classified according to intensity level and surface extent, based upon evidence from visual observation. In addition to the drafted mappings, the visited monuments were subject to a photographic survey. The collected data were analysed by interrogating the database and by applying a variety of statistical tests. A number of significant relationships were indicated between the various decay/soiling types and weathering agents. It was found that the patterns of decay, and particularly soiling, were greatly influenced by the monument characteristics, primarily due to the degree to which the stone was exposed to moisture ingress. Environmental factors were also found to have some influence, particularly the nature of the ground surface and the land-use type. Surprisingly, the level of nearby traffic was found to have little effect. Climatic factors were shown to be significant in relation to a few decay/soiling types. However, the contradictory nature of these trends suggested that the ranges within Scotland may be too limited to have much real effect upon the observed variations in decay/soiling. Previous intervention was found to have some significant effects, particularly in the case of chemical stone cleaning.

Risk levels for each significant relationship were calculated from the rate of occurrence and the amount of stone degradation observed in the sample. The sample risk model was developed to produce a pro-forma designed for use by practitioners involved in managing Scottish market crosses. Practitioners could use the designed system to regularly record the condition of other crosses and assess the extent to which they are at risk from decay/soiling due to various weathering agents existing at each site. Intervention criteria were also produced in order to advise the practitioner on when and how to intervene to stall the current decay or to reduce the risks of future degradation of crosses in their care. Methods were also suggested for interpreting and promoting market crosses to the public.

1. INTRODUCTION

1.1 An introduction to the characteristics of the market cross

Market crosses (Scots = *mercat crosses*) are a common landmark in Scottish town centres. Surviving examples frequently have an interesting history, both at a local level and sometimes even at a national level when they have been associated with well-known historical episodes. Their origins are less than clear; however, they have evolved from at least the twelfth century in the UK. Surviving market crosses in Scotland date from as early as the fourteenth century (and from the eighth century in the case of one re-used slab), although seventeenth and eighteenth century examples are more common. They are frequently small monuments and their design ranges from plain to elaborately carved. In spite of their name, their design frequently does *not* incorporate a cross or other religious imagery. Instead, heraldic or other secular themes of ornament are often favoured.

The original function of the market cross was mainly as a symbol of the burghs' right to trade. Occupying a central position within the market place, they formed the physical focus of trading activity. However, their prominent site, as well as civic associations, also made them an ideal landmark to be associated with other official burgh business. Thus they became the public points at which state celebrations and royal visits were centred, proclamations were issued and offenders punished. The continuity of market crosses upon these historic sites, as a feature of interest and aesthetic value in the townscape, thus deserves to be maintained.

1.2 The need for research

1.2.1 Lack of previous and current research into market crosses

Scottish market crosses have received little attention as a subject of study in recent decades. A flurry of interest in their history and architectural style was inspired around the mid-1800's and a few articles appeared in Scottish journals around this time. In 1900 a catalogue of Scottish market crosses was compiled, along with an investigation of their history and stylistic development (Small 1900). Subsequent publications dealt with the historical evidence and architectural characteristics (Black 1928), and proposed their relationship to Belgian 'perron' monuments (d'Alviella 1914; Black 1928). While these authors made reference to recent demolition of market crosses, they made little comment regarding the condition and environment of the remaining examples. Subsequently there has been no 'first-hand' research into this monument class as a whole. While the surviving examples are currently all protected by legislation, none are in State care. Due to this, Scottish market crosses fall outwith the group of monument types currently being researched by Historic Scotland with regard to carved stone decay.

1.2.2 Lack of existing data on the condition of market crosses

Archived data held by the National Monuments Record for Scotland and the regional Sites and Monuments Records usually describes the general degree of survival of individual crosses. However, specific evidence of stone decay is less frequently referred to and information on condition is generally scant due to infrequent site visits and limited resources. In several cases the crosses have been subject to conservation efforts through the intervention of Historic Scotland. The 'before' and 'after' records of the condition of such crosses is nowadays fairly detailed, although documented detail decreases with the age of the records. For the sake of future research and conservation work, the benefits of accurately recording details of monument condition and conservation treatment are now being recognised (Gordon, Historic Scotland 1996, pers comm). Conservation records now usually comprise a collection of letters, memos and reports. Photography is used to illustrate the monument condition; however, there are generally no mapped illustrations to detail the forms and distributions of decay interpreted across the stone surfaces.

1.2.3 Limitations of existing recording and mapping methods

Surveyors have previously been more concerned with recording architectural form rather than the condition of stonework. The recording of detailed data on stone condition could ultimately offer an improved level of interpretation and understanding. Drafted mappings of stone surfaces are one means of effectively conveying this data, and could allow a greater understanding in the future of decay and soiling mechanisms and the rate at which these occur. There are also advantages to be gained from mapping the nature and extent of conservation treatments applied to the monuments. The long-term effects of certain conservation materials are unknown, but records made will allow future conservators to more readily interpret their effect. In certain cases the drafted data could be digitised for posterity and, indeed, digital mapping has recently been trialled upon stone facades to recording their condition on-site. Currently, statutory bodies charged with the care and recording of historical buildings and monuments do not use mapping techniques. There is a gap in knowledge regarding methods for mapping the condition of stone surfaces. Pioneering attempts were recently made to produce classification and mapping techniques for weathering forms (NORMAL 1988; Fitzner & Kownatzki 1989; Fitzner et al 1992 & 1995; Heinrichs & Fitzner 2000). However, criticisms of these systems are that their application is time-consuming and requires rather specialised geological knowledge (Houston, BRE 1997, pers comm; Ball & Young 2000). The present research will attempt to develop such a mapping system and apply it to recording the condition of market crosses.

1.2.4 Stone weathering risks

Most market crosses are built of sandstone, which can be relatively vulnerable to weathering in certain circumstances. Sandstone decays naturally due to factors of moisture, temperature, solar incidence, and natural salts, which interact to cause physical and chemical weathering. Decay is generally measured by the degree of fragmentation and stone loss. Locational and environmental factors affect the type and rate of weathering. Even the morphology of the monument itself and the degree of shelter affect the microclimate experienced by a monument, contributing to the weathering pattern. Pollution emitted from motor vehicle exhausts, as well as from industrial and domestic fuel burning, can also introduce salts and particulate soiling to stonework. The literature review revealed that one of the most damaging agents of stone weathering is considered to be salts, derived particularly from atmospheric pollution, de-icing salts and coastal environments. The location of market crosses is such that they are likely to be at risk from damaging salts from all of these sources, and particularly from motor vehicle emissions. The research will allow further insight into the effects of salt weathering, an area that is currently not fully understood. The decay of carved stone is a subject of current concern and research in Scotland, reflected by the recent research programme launched by Historic Scotland (Yates et al 1999). Thus the present research into Scottish market crosses is topical and complementary to the research by Historic Scotland.

1.2.5 Complexity of intervention history

Market crosses are unique among monument classes due to the extent to which they have been modified and moved around. Most examples have an enormously complex history of intervention. Many examples have been uprooted and moved to a succession of different urban sites, and thus subjected to varying environmental conditions as well as to risks of damage incurred in the course of removal. Additionally, many crosses have had components within them replaced at various times since their construction. The resulting patchwork of components carved at different periods and with different stone properties can cause differences in the weathering patterns seen across individual monuments. Furthermore, the juxtaposition of incompatible stone types can introduce other decay risks. These factors of previous intervention have influenced the current condition of each market cross and an appreciation of these is therefore important in analysing the visible weathering in addition to the current prevailing environmental factors.

1.2.6 Conservation methods and materials

The use of inappropriate conservation materials or methods can introduce new sources of degradation to the stonework. In certain cases, well-intentioned restoration and conservation projects have in fact posed a risk to the crosses. For example, many repairs in the first half of the twentieth century made use of hard cement mortar which has introduced problems in moisture retention in the stone and caused increased erosion of stone at masonry joints. The corrosion of iron dowels and cramps formerly used has also caused fracturing of the surrounding stonework in some cases. Even today there are hints that the involvement of less experienced persons during intervention may inadvertently be adding to the damage of market crosses in certain cases, due to the multitude of local authorities involved in the care of these monuments across Scotland. Furthermore, the long-term performance and effects of some modern conservation materials on stone is not fully known. Substances such as consolidants, water-repellents and epoxy resin are currently applied in sparing doses to historical stonework as a last resort measure to combat decay. Epoxy resin is also used as a strengthener for fastening key structural joints. The effect of these materials on historical stonework ought to be monitored. However, there is generally no system in place for regularly checking the condition of historical monuments.

1.3 Objectives and aims of research

The ultimate aims of the research are to increase the profile of Scottish market crosses as a monument type worthy of long-term preservation, and to gain an increased understanding of the relationships between their condition, their environment and human intervention. The end product is the design of an improved management strategy for the care and promotion of market crosses. The research also aims to explore generally the value of applying risk assessment methods to historical monument preservation. Other aims are to improve knowledge about the scale and rate of stone weathering generally, and the effects of various types of intervention. The proposed objectives of the research are as follows:

1) **To develop a methodology for mapping stone surfaces, in order to record the nature and level of their decay**

By means of:

- Reviewing methodologies used to record and map data by other researchers and statutory bodies
- Developing a pro-forma for recording details of monument condition, to use both during the archival research and fieldwork phases of data collection
- Designing a database to record the information gathered by the pro-forma
- Undertaking fieldwork on a sample of monuments using the developed mapping method
- Evaluating the effectiveness of the developed method following the fieldwork

2) **To establish a record of the current condition of a representative sample of market crosses in Scotland**

By means of:

- Selecting a sample of market crosses based upon archived data, with regard to aspects such as monument age, survival, architectural design, environment, geographical location and history of intervention

- Undertaking fieldwork to record in detail the current condition of each monument within this sample
- Compiling an archive, consisting of drafted mappings, photographs and data logged in an electronic database

3) To assess the extent to which market crosses are at risk from weathering and from human agency

By means of:

- Exploring the extent of damage to the sampled monuments, and to the monument class in general
- Examining the collected data to identify trends that indicate possible causes of decay and soiling, (eg the relationship of various decay and soiling patterns to factors such as aspect or the proximity to passing motor vehicles)
- Comparing the gathered data of current condition with evidence from the past (old photographs and drawings), with a view to gauging the rates of decay
- Evaluating the effectiveness of intervention treatments made to the crosses

4) To propose effective strategies for the care of Scottish market crosses, based upon a risk assessment model

By means of:

- Developing a predictive model of stone weathering on market crosses given various environments and other factors of influence, based upon analysis of the gathered data
- Producing a digitised pro-forma which can be applied by practitioners to unsampled crosses and other similar monument types
- Producing a set of recommendations of intervention methods and materials
- Recommending criteria for gauging when various types of intervention are required
- Suggesting suitable management strategies for the future treatment of market crosses as a heritage resource within the context of historic burgh centres

An understanding of the scale of decay and soiling and factors influencing this on market crosses will allow future predictions to be made regarding the dynamics of their condition in various environments. The developed risk assessment will therefore be an original contribution to knowledge in the field of conservation. The methodology for evaluating the condition of the crosses is basic and inexpensive, and based upon visual observation. The system used for mapping will therefore be accessible to most professionals, in recognition of the fact that most bodies do not have access to expensive, high-tech equipment.

1.4 Hypotheses

The general hypothesis which forms the basis of this research is that the condition of market crosses and other monuments can be related to their material properties, their environment, and acts of intervention. In particular, it is thought that the *rate* of stone decay is determined by environmental factors (Yates et al 1999). The literature review indicates a number of hypotheses regarding specific factors that are considered to cause or contribute towards various decay and soiling types. The extent to which the market cross sample data supports, or in some cases opposes, these hypotheses are discussed in the data analysis in Chapter 4. Some of the main hypotheses investigated are:

- Motor vehicle emissions contribute significantly towards salt weathering and particulate soiling of stonework
- Coastal proximity is also a significant factor in the salt weathering of stonework
- Climatic differences across Scotland, particularly the levels of moisture and frost, affect patterns of decay and soiling upon stonework
- The orientation of monument facades has a major effect upon biological soiling patterns
- Stones carved at earlier dates tend to exhibit greater decay
- The use of certain conservation materials may be damaging to stonework
- Market crosses are particularly vulnerable to vandalism and graffiti due to the nature of their siting

1.5 Inter-disciplinary nature of the research

The present researcher has an archaeological background, and the research undertaken spans a number of disciplinary fields, namely history, heritage management, conservation, geology, surveying and risk assessment. Often archaeology and conservation seem to be segregated disciplines. The task of the archaeologist is usually to interpret the vestiges of the past in an attempt to throw some light upon the various activities and beliefs of past societies. The present research has therefore allowed the candidate an introduction to the mechanisms of monument degradation, and to the professional realms of stone erosion, conservation and risk analysis generally. There is increasing recognition now of the benefit of inter-disciplinary projects and the advantages are that it encourages a broader understanding of issues, the integration of all interests and greater co-operation between professions.

1.6 Structure of the thesis

The thesis begins with a literature review in Chapter 2, structured according to six main themes relevant to the research: the history, architecture and survival of market crosses in Scotland; a critical review of research previously undertaken into market crosses, and other available data sources; stone properties, soiling and weathering agents, and the physical effects of these; monument conservation policies, methods and materials; the needs and methods for recording and mapping stone condition; and risk assessment techniques and applications. Chapter 3 presents the methodology designed for the market cross sample selection, data collection and recording. The analysis of the collected data is presented in Chapter 4. This includes discussion of the application of statistical techniques to the data, and presents the results of the tests applied to examine the relationships between the observed decay and soiling and the potential factors of influence. The risk assessment model is developed in Chapter 5. A method for risk assessment is presented, adapted from the general formula used in other fields of study. The formula was first applied to the sampled market crosses to determine the degree of risk represented by their exposure to various factors of influence. The results from the sample are presented and discussed. A further risk assessment method was developed from this, designed for use by practitioners on other, individual market crosses and similar monument types. Example data is presented to illustrate the procedure of application. A set of intervention guidelines and criteria is also presented for the use of practitioners. The significant findings of the research are summarised in the conclusion in Chapter 6.

2. LITERATURE REVIEW

The structure of the following literature review is thematic. Sections 2.1 and 2.2 are specific to market crosses, in which their historical context, architectural characteristics and survival are explored. The chronological development of market cross research in the nineteenth and twentieth centuries is discussed, with reference to published and archival data. Evidence for market crosses elsewhere in the U.K. and Europe has also been sought for comparison. The subsequent sections contain reviews of the effects and mechanisms of stone weathering and soiling (2.3), stone conservation practice and policy (2.4), techniques for recording and mapping stone condition (2.5), and risk assessment methods (2.6).

2.1 Introduction to the literature review: The history, architecture and survival of market crosses

2.1.1 Historical context

The market cross (Scots = *mercat cross*) was a characteristic feature of historic burghs in Scotland. To set the scene, this section will explore the historical background to the use of these monuments in Scottish burghs.

2.1.1.1 The establishment and characteristics of Scottish burghs

Prior to the twelfth century there is very little evidence for urban settlements in Scotland. Castles at the royal centres of Edinburgh and Stirling may have had small settlements adjacent, but little is known of these. However, in the twelfth century a systematic programme began in Scotland of establishing towns, known as 'burghs'. King David I of Scotland, who reigned from 1124 to 1153, had observed the feudal system in place in England, and introduced it into Scotland. His agenda of enfuedalisation also included the establishment and maintenance of law and order, the development of the Church, particularly with regard to its educational role, and the promotion of local and foreign trade. In addition to the establishment of royal burghs, some monastic foundations and barons were also given the right to erect a burgh. It is possible that some small communities already existed on the sites which were given the status of burgh. However, in the case of some royal burghs King David's planners designed the layout, including the street patterns and building plots, eg at Perth, Aberdeen, Haddington and Peebles (Simpson 1972). In every burgh a market cross was erected in the market place as a symbol of the right to trade. King David's successors continued to erect burghs such that by the death of King William in 1214 over 30 royal burghs had been founded, and by the year 1500 around 150 burghs existed in Scotland (Simpson 1972). Burghs continued to multiply and prosper, finding particular commercial success in the sixteenth and seventeenth centuries. The layout and buildings, including market crosses, have often survived from this period.

The privileges granted to the burghs included the right to elect a town council with magistrates, the right to make by-laws, to form merchants guilds and trade incorporations with exclusive rights of manufacture and trade within the burgh and its 'liberties'. Burghs were also granted the right to hold markets, weekly or twice weekly, and fairs, annually or more frequently, and the right to charge tolls. Only the royal burghs had the privilege of self-government and the right to trade overseas and in imported goods, and later they also acquired the right to attend parliament. In return the monarchy expected loyalty from the burgesses and nobility, the observation of Royal Law, the maintenance of peace within the burgh (through 'watch and ward' duty), and military support when required (MacMillan 1992).

Following the Union of the Crowns in 1707, new burghs were no longer founded, and alternative forces continued to shape urban development in Britain. After 1746 with the 'pacification' of the Highlands, a wave of new town building spread through Scotland, beginning in Edinburgh, stimulated by the flow of wealth from the Act of Union. A new era of prosperity came in, stimulated by agricultural improvement and wider access to markets. This flowering encouraged fashionable building construction within the burghs. As a useful summary, MacMillan identified five different periods within burgh history each with its own characteristic urban and architectural forms (1992, 9-10): *Medieval* (thirteenth and fourteenth centuries), the main period of castles, churches and cathedrals, when burghs were founded strategically with the aim of developing the feudal system and providing income and loyalty to the monarchy; *Renaissance* (sixteenth and seventeenth centuries), *'when the burghs achieved their most characteristic form'*, including buildings with a vernacular character and occasional elaborate public and nobles' buildings; *Georgian* (eighteenth and early nineteenth centuries), increasing urban density and a more formal, classical type of building; *Victorian* (later nineteenth century) rapid growth following the advent of the railways and the expansion of industry. This period also saw the beginning of the destruction of the older remains in some burghs; *Modern* (between and after the two World Wars), increasing expansion and urban sprawl engendered by cars, massive destruction of historic town centres, but also a more recent increase in the awareness of heritage.

2.1.1.2 Historical functions of the market cross

The primary function of the market cross was as a symbol of the right to trade granted to a burgh. However, documentary sources refer to all manner of announcements, celebrations and grisly punishments which took place at market crosses, due largely to the civic associations and the prominent, central location of these monuments. These various roles are examined below.

Trading

The market cross was usually located centrally in a town's marketplace. Here burghal law set the standard for traded units of weight and measurement, which could vary from one burgh to another. In the market place there was also a burgh 'tron', or public weighing apparatus, for ensuring such standards were adhered to. Few examples of these mostly wooden structures survive; however, their tradition is often preserved in street names, such as 'Trongate' in Glasgow. Some market crosses had units of measurement incorporated into them, for example the cross at Fettercairn has an 'ell' (a unit of measurement for cloth) marked by an incised line running down the shaft. The market cross was a symbol of controlled market activity where fair-trading was enforced and taxes were exacted. The payments were administrated at the burgh tolbooth. These buildings often still survive, at least in part, in town centres today, and were usually found at the market place near to the cross. Documentary evidence indicates that some burghs had two crosses in their marketplace to distinguish the areas where certain produce was traded. For example, Aberdeen Castlegate had both a 'Fish Cross' and a 'Flesh Cross', and Thurso similarly had a 'Fish Stone' and a 'Cocky Stane', the latter for use by the farm wives (Mair 1988). Indeed the location of stalls for different crafts or foodstuffs was often defined by reference to the cross, where areas were designated in relation to it. In some places markets were held regularly in churchyards in the Middle Ages, and some market crosses were therefore located next to churches for this purpose. A law was issued by Parliament in 1503 forbidding the holding of fairs within churchyards; however, the practice was well-established and the new law could not be enforced (Love 1989). This law was re-issued in 1579 with stiffer penalties, thus the practice ceased to some extent and these markets were transferred to other village sites. Nevertheless, at Dallas cross (Moray) Sunday markets were held in the churchyard until another law in 1692 made Sunday trading illegal. However, markets continued on weekdays in some churchyards until the eighteenth century (Willsher 1985).

Proclamations

The market cross was also used as a point from which announcements were made, including royal and burghal edicts. For example, a reference was made in 1830 to a *'brieve'* at Glasgow cross, served both verbally and by affixing the notice to the cross *'that none might plead ignorance in the premises'* (Black 1928, 8). Coronations were also proclaimed and celebrated at market crosses, eg a record exists of an announcement made at Glasgow cross in 1649 that King Charles II had succeeded to the throne. If the content of proclamations made at the market cross was equivalent to what we might today read about in the press, we need only consider the less literate nature of the population in that period to realise the importance of such a practice. New laws were also announced at market crosses in the royal burghs; however, in 1581 the Scottish parliament enacted that this practice need only be continued at the cross in

Edinburgh (Grant 1930). At Airth market cross (Falkirk), the practice of announcing deaths and funerals persisted until the early 1900's (Rennie & Gordon 1966).

State celebrations and royal visits

Market crosses sometimes provided the ideal site for historically significant occasions and documentary evidence paints a vivid picture of the involvement of some crosses. The tower-based crosses in the larger burghs were used as a decorated focal point for burghal celebrations, particularly during royal visits. On such occasions, they were used as ceremonial platforms and as centrepieces for festive decoration. During a royal ceremony at Edinburgh High Street market cross in 1561, four ladies representing Fortune, Prudence, Justice and Policie greeted Mary Queen of Scots from the elevated platform and wine was engineered to gush forth from the cross gargoyles. Wine also flowed from the gargoyles of the Aberdeen Castlegate cross during a visit by Queen Margaret (the wife of James IV) in 1511 (Hutcheson 1900). Edinburgh market cross was hung with tapestry in 1600 for a visit by King James VI, and the king sat upon the elevated cross platform during the ceremony. In 1660 the burgh council and heralds in all their regalia announced the restoration of the monarchy from the elevated platform of the *'richly clad'* cross (Howard 1995, 125-6). At Stirling the market cross and tolbooth were decorated with gold leaves for a visit by King James VI in 1617 (Mair 1988).

Punishment

Documentary evidence refers to many punishments carried out at market crosses. This darker side of their function prompted Hutcheson (1900) to describe their site evocatively as *'the dreaded theatre of public punishment and shame'*. Victims were flogged, branded, burned, hanged, or placed in the stocks, branks or jougs at the cross. No doubt this function can be largely attributed to the nature of the market cross as being symbolic of civic authority and justice, and also to its position in a central, open and public space. Humiliating forms of punishment were often favoured in the Middle Ages, and stocks, branks and jougs were all contraptions designed to humiliate and entrap the wrong-doer, exposing them to the taunts and missiles of the populace. In some cases, the jougs and branks were attached to the market cross, and some examples still bear the remains of iron chain links or anchoring devices attached to their shaft as testimony to this, as at Fowlis Wester and Inverkeithing.

2.1.2 Architectural characteristics

The essential element of surviving market crosses is *not* a cross, but a shaft crowned more frequently with a heraldic sculpture. Religious iconography is less frequently used, and only rarely is the monument in the form of a cross.

2.1.2.1 Traditional, shaft-upon-steps form

The earliest surviving market crosses tend to be the simplest in construction and consist usually of a shaft crowned with a capital and finial, arising from a plain, stepped, square or polygonal base (see example in Plate 2.1). This allowed the cross to be more easily visible over a crowd of heads (Mair 1988). The steps are undecorated and often roughly hewn. The cross shafts are usually square with stop-chamfers, octagonal, hexagonal, or occasionally round in section. In a very few cases a heraldic shield is carved upon part of the shaft in relief (eg Ormiston). Prior to this, the earliest crosses seem to have consisted of a wooden shaft set upon stone steps and crowned with a decorated finial; however, none of these early wooden pillars survive (Naismith 1989).

Plate 2.1 Culross market cross, Fife. Traditional, shaft-upon-steps type.

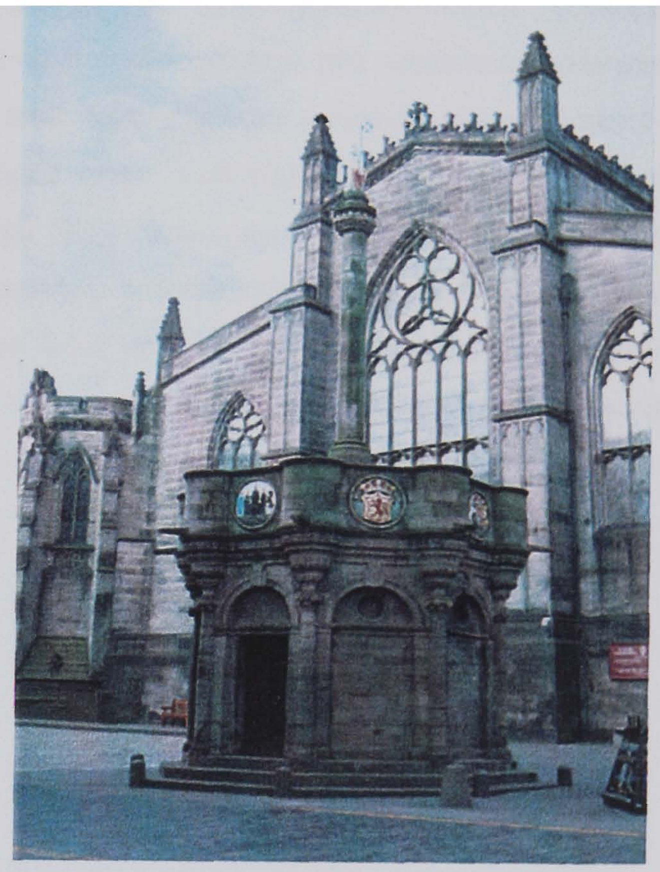


Plate 2.2 Edinburgh High Street market cross. Tower-based type.

2.1.2.2 Tower-based designs

Depending upon the funding originally available in the burgh for their construction, some market crosses were relatively elaborate. During the 1600's (and even earlier in the case of Glasgow) a few 'tower-based' market crosses were constructed. Seven of this type can be seen today, at Aberdeen, Edinburgh, Elgin, Glasgow, Prestonpans, Perth and Selkirk (see example in Plate 2.2). The example at Prestonpans survives from 1617; however, the other tower-bases are later reconstructions based upon earlier evidence. These crosses consist of a shaft crowned with a capital and finial surmounting a substantial, roofed, octagonal understructure (or square in the case of Selkirk). This tower-base normally incorporates a doorway and internal staircase spiralling around the central shaft, providing access to an elevated platform from which announcements could be made upon a safe, elevated position. This design of an internal stairway to an elevated platform makes this type of market cross unique to Scotland. At Prestonpans cross, a separate chamber in one half of the tower-base was used to detain prisoners, and in some instances the tower-bases of these crosses may have provided some shelter to night wardens, eg for wardens of Edinburgh tolbooth (Howard 1995). Drummond (1860) likened the design of such crosses to a parapetted castle wall and thus well-suited to symbolise the stability and power of the authorities. The Glasgow reconstruction is rather conjectural, although a reference in the Burgh Records in 1582 regarding payment for a door indicates that there was once a tower-based cross here (Hutcheson 1900). The Aberdeen Castlegate cross (built 1686) has been largely modified from its original form, transformed in 1837 into an open vaulted structure with no surviving provision for access to its upper part.

The more substantial nature of these structures afforded room for architectural elaboration. Thus the tower-based crosses are adorned with features such as cornices, pilasters and ornamental rainwater goods. The relief carvings are elaborate, including medallions depicting monarchs and renaissance-style fruit and floral designs on Aberdeen Castlegate cross, shell-headed alcoves on Elgin and Prestonpans crosses, and heraldic arms on Edinburgh High Street cross. In the case of Aberdeen Castlegate cross, even the shaft is intricately ornamented with renaissance design. Documentary evidence indicates that some of the carved features were painted and gilded, and the nineteenth century reconstruction of Edinburgh High Street cross today has well-maintained, gaily-painted heraldic arms adorning its parapet wall.

Plate 2.3 Turriff market cross, Aberdeenshire. Gothic Revival style.

Plate 2.4 Heraldry on Inverkeithing market cross, Fife.

2.1.2.3 Victorian, Gothic Revival designs

In the eighteenth and particularly the nineteenth century, there was an attempt in Britain to recreate the decoration and atmosphere of Gothic architecture. Correspondingly there are several architecturally elaborate, Gothic Revival designs of market crosses built during the 1800's. For these crosses the fashion favoured a large pedestal base, usually mounted upon just one or two steps (see example in Plate 2.3). Some more substantial examples are constructed of diminishing tiers, as at Cullen and Forres, which are elaborately carved with pinnacles and crocketting. Although the design of these crosses are *'pure Victorian fantasy'* (Mair 1988, 57) they often mark the site of the preceding crosses.

2.1.2.4 Modern constructions

A few other monuments built at around 1920 but listed as 'market crosses' were constructed primarily as war memorials. These structures at Abernethy and Kelso attempt to replicate the traditional shaft-upon-steps style of market cross. At Bowden the war memorial actually incorporates former elements of the original market cross.

2.1.2.5 Use of religious iconography

As described above, the term 'cross' is a misnomer, since the cross ecclesiastical is a relatively rare element of market cross design. Where it occurs it usually indicates the re-use of an earlier cross removed from a burial ground, as at Inveraray, Campbeltown and Ormiston. However, some other market crosses are adorned with stylised cross finials (eg Dallas, dating from the early 1500's), and the Banff cross unusually incorporates a sculpted Calvary scene (replicated from a fifteenth or sixteenth century original). On the whole, however, religious iconography is less significant than heraldic features upon Scottish market crosses. This could perhaps be explained, to some extent, by the effects of the Reformation in sixteenth century Scotland. It is thus possible that market crosses carved and used prior to this time exhibited a greater element of religious iconography, although there is little evidence to confirm this.

2.1.2.6 Use of heraldry

Heraldic beasts are common subjects for the market cross finials, thus a unicorn or lion can often be seen crowning these monuments (see example in Plate 2.4). Shields of arms are another common feature of the crosses, frequently adorning the capital or clasped by the crowning animal. No doubt these devices were intended to reinforce visually the legitimacy of civic authority over the community, perhaps another element in the *'cultivation of deference'* proposed by Tittler in his study of the symbolism of late Medieval English town halls (1991, 98-128). To the uneducated viewer, heraldic imagery exudes mystical metaphors, higher knowledge, a higher ranking system, establishment and tradition. It is a time-honoured badge, a remote embodiment of royal or baronial power. Such crests and arms express themselves through puns and symbols, and by reference to a broader complex heraldic 'language' or coding system, thus mystifying the basis of the seat of power. This symbolism is beyond the comprehension of the masses even today, and is at once demonstrative but also exclusive in the level of knowledge required to interpret it. It suggests an office supported by a greater, unintelligible, time-honoured system, and in this pretence the particular authority is thus presented as a force not open to challenge. The royal burghs in particular often had heraldic beasts and armorial shields (sometimes painted or gilded), for example at Stirling and Crail (Mair 1988).

2.1.2.7 Other finial designs

Another common subject for the capital is a sundial, in which lines and numbers are incised and copper gnoma bedded in the stone (eg Houston and Airth crosses). Sundials were also commonly carved upon the masonry of houses of the time, and their carving persisted even after clocks and watches became relatively popular possessions (Scott-Moncrieff 1938). No doubt the sundials on market crosses were useful for both citizens and traders organising their day's business. Sometimes the sundial is found in combination with armorial bearings, eg at Peebles and Inverkeithing (Dunbar 1966). Some crosses bear a finial of more modest design, eg a stone ball, urn shape or other plain terminal (eg Inverbervie and Clackmannan). At Wigtown the finial of the older cross is unusually carved in the shape of a 'pineapple', in reference to the heraldry of a local burgh patron.

2.1.2.8 Stylistic evolution of market crosses in Scotland

Hutcheson (1900) outlined the different forms of market crosses and suggested a possible line of stylistic development. The oldest specimens featured the Cross Ecclesiastic, followed by constructions with a plain, splayed or octagonal shaft and ornate finial with heraldic insignia (typified by Stirling and Inverkeithing crosses). Later the shafts were treated classically with some examples of round shafts (Hutcheson 1900). Moulded bases and classic capitals are characteristic of this class, mostly from the seventeenth century, and to a lesser extent from the eighteenth (eg Dunfermline, Fettercairn and Rossie). The larger tower-based market crosses were usually limited to larger towns, and were built in the early seventeenth century. The unicorn was used as a subject for finials from as early as 1400, eg at Inverkeithing (Hutcheson 1900), but became less common in the eighteenth century, when other sculpted shapes such as urns or even weather vanes were mounted on top of cross shafts (Scott-Moncrieff 1938).

2.1.2.9 Use of inscriptions

Some market crosses bear inscriptions, of which the most common forms are incised dates and initials. Where they exist, the dates are particularly useful for indicating when the crosses were erected, or alternatively when they were restored. The initials usually refer to the benefactor responsible for such works. Such inscriptions are usually placed upon the shaft or capital. In some cases, modern plaques with inscriptions including dates are now affixed to the cross bases.

2.1.3 Market crosses outwith Scotland

Comparative data from outwith Scotland has been sought to allow a wider context in which to view the properties of the Scottish examples. Market crosses are common in England, and are also found in some towns in Wales and Northern Ireland (eg Newtonards). In Europe, Belgian perrons and German Roland statues are other market-place monuments, which are suggested to have fulfilled a similar role to British market crosses.

2.1.3.1 English market crosses

The earlier English market crosses had the basic morphology of a shaft-upon-steps. However, growing crowds and increasing business encouraged the development of a covered structure in the fifteenth century (Harper 1979). Thus the English crosses evolved into more substantial structures, often comprising a roofed but open-sided structure which could be used for shelter. In contrast, none of the Scottish market crosses were designed for public shelter (with the exception of Aberdeen Castlegate cross which is a late re-modelling). These sizeable, arcaded shelters, were constructed of stone and/or timber framing, with stone, slate or tiled roofs, crowned with a lantern or cross finial. John Leland (c.1505-1525) described the late fifteenth century cross at Malmesbury in Wiltshire as '*a right fair and costely peace of worke in the market place made al of stone and curiusly voultid for poore market folkes to stande dry when rayne cummith*' (Friar 1991). Messent (1936) described the church as being the chief influence on the origin of English market crosses and proposed two purposes for their erection: to mark the meeting place of religious assemblies and to stand as a Christian witness of trading and business. Other functions included use for the annual election of the mayor, for mystery plays and for the burning of books (Vallance 1920). Many markets belonged to monasteries and the monks at times harangued the populace from the market cross (Britton 1807). In Wales they were also used as a point for labour hire. In some of the more wealthy commercial centres, late medieval and Tudor benefactors funded the construction of these roofed shelters or 'butter crosses' (Friar 1991; Harper 1979). Indeed, the building and rebuilding of these monuments was often viewed as an act of civic piety in the two centuries preceding 1640 (Everitt 1976). An expansion of markets in the sixteenth century led to the erection in some English towns of up to as many as four or five crosses, corresponding to the sale of various commodities such as fish, cheese, poultry, hemp and butter (Everitt 1976).

It has been suggested that the design of the canopied English market cross evolved from earlier existing cross types such as churchyard, wayside and preaching crosses (eg Messent 1936; Vallance 1920). Vallance (1920) proposed a line of evolution for the design of the English market crosses, quite distinct from the Scottish examples. The basic forerunner was the shaft-upon-steps type of Christian cross, found in churchyards, on waysides and on village greens or squares. The steps of these were typically unornamented, the shafts usually tapered, with a plain capital and cross finial.

Later cross designs were more elaborate, with diminishing tiers and the shaft taking the form of a pinnacle or spire, crowned by a small cross or finial (eg the so-called 'Eleanor crosses'). Following this, crosses took on a more utilitarian direction and preaching crosses were constructed incorporating a small shelter for one or very few people, and crowned with a soaring superstructure. The classic, canopied English market cross may have been an expansion of this idea in the fifteenth century, for the comfort and convenience of people gathered at the cross for market business (Vallance 1920). Market crosses generally seem to have taken on a more secular aspect following the Reformation (Messent 1936). From the seventeenth century, there was further architectural divergence in which cross-shaped finials were abandoned in favour of sundials or an allegorical figure of justice to emphasise fair dealing. Furthermore, some crosses acquired an upper, enclosed chamber above the open, ground level shelter. In some cases the original circular or polygonal plan of the market cross was totally abandoned in favour of an oblong plan, in which greater accommodation could be provided for civic machinations, and thus the market hall developed (Vallance 1920).

As early as 1936, Messent called for the preservation of the English market crosses to prevent them falling into decay and advised that they should not be moved unless they are causing acute traffic problems.

2.1.3.2 Belgian 'perrons'

D'Alviella (1914) discussed the similarity between Scottish market crosses and Belgian 'perrons'. Perrons are stone monuments composed of elements that can be traced to various eras. Their design variously includes: a base consisting of a flight of steps; a cylindrical (or more rarely polygonal) column, of pagan, Germanic origin; a pine cone, of Gallo-Roman influence; sometimes a cross, indicating Christian endorsement; heraldic emblems, such as a lion and a crown, dating from feudal times; and sculptures of the group of three Graces, influenced by seventeenth century art. Perrons were a symbol of jurisdiction, used as a place for oath-taking, auctions, formalities relative to the transfer of property, official proclamations and the announcement of edicts. The *'cry du peron'* was equivalent to the news which we might today publish in the press. They were the point from which crimes were denounced and sentences of banishment were dealt out. The site of the perron, or even the monument itself, could be used as a pillory for whippings or to carry out a variety of humiliating punishments. The later eighteenth century use of one perron at Sart lez-Spa was preserved in local memory as including all occasions of rejoicing such as carnivals, marriages and public feasts, and the perron was sometimes even decorated with greenery. A 1591 edict granting permission to the citizens of Spa to open a market and erect a perron there is very similar to those given in Scotland in the same period for rights to hold a market and erect a market cross. The use of the image of perrons on Belgian civic insignia attests the importance of their role in civic and public affairs. The functions of the perron, and also some elements of its appearance, therefore sound remarkably similar to those of the market cross in Scotland.

2.1.3.3 German 'Roland statues'

The so-called 'Roland statues' in Germany have been suggested as serving a function equivalent to that of market crosses (D'Alviella 1914; Black 1928). Roland was a semi-legendary French knight who, according to tradition, lived until about 778AD. He is the most celebrated of the paladins of Charlemagne and was the ideal of a Christian knight. A Roland 'cult' emerged in later centuries, when Charles IV revived the tradition of Charlemagne and the legend of Roland in the Empire. From about 1240, and particularly in the fourteenth and fifteenth centuries, gigantic statues of Roland were erected all over the Germanic Empire, including Prague. The earliest examples carved from wood, set up in the thirteenth and fourteenth centuries, no longer survive although in some cases replicas stand in their place. Their greatest concentration is in Brandenburg and around the Elbe. The practice of their erection spread from town to town and the statues are all of a similar style. Each represents the huge figure of a knight, brandishing a so-called 'sword of justice'. They are completely secular in subject matter, and explanations for their erection are that they were symbolic of imperial justice, civic rights, commercial privileges and freedom of trade (Lejeune & Stiennon 1971). In this sense they are similar to market crosses which were also symbolic of justice and trading conventions within the market place. Roland statues symbolised burghal authority and protection, and the safeguarding of civic rights, although the exact nature of the freedoms and privileges may have varied from place to place. Like market crosses, they also usually stand in the market place in close proximity to the town hall. Documentary evidence, although vague, suggests that there were further Roland statues elsewhere in Germany and Holland (although the Scandinavian Roland statues can be attributed to the arrival of a later fashion). Some writers have questioned whether such statues do in fact represent Roland, seeing them as perhaps portraying other princes, kings or judges, or even the *Spielroland*, a wooden dummy used in the game of the quintain. A further theory is that they might have evolved from the *Irminsûl* or Irmin-columns, images or pillars symbolic of a mythological deity. Many of these were destroyed, hidden or modified with the spread of Christianity across Germanic lands. Research by Gatken concluded that the interpretation of each Roland statue needed to be considered in its own particular historical context (Lejeune & Stiennon 1971). Whatever the origin of these statues they do appear to have served a similar function to market crosses within the late medieval market places of Germany.

2.1.4 Origins of Use

Differing opinions prevail regarding the appearance and iconography of the early examples of market crosses. Since the earliest market crosses referred to in documentary sources do not survive, it is thought that they were made from wood (Hutcheson 1900). The uncertainly about the physical appearance of the early examples has given rise to speculation about the origin of market crosses in the British Isles. In Scotland, historical documents refer to market crosses from the twelfth century onwards. There is little evidence to elucidate the origins of this monument prior to this; however, a few authors have explored some possible lines of evolution (Drummond 1860: Hutcheson in Small 1900; Black 1928).

Many writers have suggested that early market crosses were in the form of the Cross Ecclesiastical, and that the idea of the market cross developed from a tradition of using wayside and churchyard crosses for making deals and oaths in medieval times. Such crosses could also have acted as prominent landmarks useful as places of meeting or assembly. Early Christian crosses were erected for prayer and memorial purposes, set up at places such as waysides, wells, boundaries, churchyards and at points of rest along funerary paths (Britton 1807). These Christian crosses may have been used for bargain striking (Drummond 1860). Thus a pact could have been considered particularly binding if made at a cross due to its sacred connotations. The bargainer may even have touched the cross with his hand during this for added emphasis (Drummond 1860; Harper 1979). The idea of the market cross may have evolved from this tradition, with the religious significance of the cross becoming somehow less involved. Such crosses came to form the focus for inhabitants to meet, buy, sell or exchange goods, a *'rendezvous for gossips and idlers'*, and the site thence became the scene of regular markets, such that the cross came to take on the name of 'market cross' (Kidd 1901, 1-2). Drummond (1860) suggested that the cruciform thus mutated into what we now consider to be the traditional market cross form, the shaft-upon-steps type of structure, with appropriate secular finial. There are some examples of market crosses that have been cited as supporting this idea of transition. Crosses at Preston in Kirkcudbrightshire (unknown date of construction), Dallas (early 1500's), Duffus (1350) and possibly Crawford (unknown date) bear the remains of cross-shaped finials (Hutcheson 1900). The large crucifix at Ormiston (1400's), and the Cockburnspath finial (date unknown) have also been cited as supporting this theory (Drummond 1860). The dates of other secular finials suggest that the iconography of the market cross must have evolved from a Christian cross to secular subjects including heraldry, sundials and other plainer terminals by the 1600's.

Some authors envisaged an even more ancient link between the functions of the market cross and those of the prehistoric monoliths of the pre-Christian era. It is suggested that the practice of using market crosses for oath-making, proclamation, points of assembly, and for meting out punishment may stem from an ancient, pre-Christian tradition (eg Hutcheson 1900; d'Alviella 1914; Hamilton-Grierson, 1914; Black 1928). According to this idea, some pagan monuments were endorsed by adherents to the Christian faith who carved a simple cross onto them and used them as wayside crosses. As such, the pre-Christian use of monoliths for marking points in the land and for trading and punishment may have persisted through time, manifested in the Middle Ages by the market cross. Such a theory would therefore see a pagan practice christianised, and then de-christianised. The use of prehistoric monoliths during the spread of Christianity in Western Europe is documented by chronicles and council records, and further evidence is provided by archaeology and folklore traditions. In ancient Germanic usage, it is thought that standing stones were used for the jurisdiction of court of law, held in the open air (d'Alviella 1914; Black 1928). The argument runs that assemblies for communal business and pronouncements of judgement were held around these ancient 'stones of justice', such that they came to symbolise collective interests. Tacitus provides documentary evidence that the populations of the Lower Rhine, the Frisians and perhaps also the Franks, venerated columns dedicated to certain of their gods. The pillars could originally have been the symbol of a pagan god, probably Tiews, the god who presided over wars and at assemblies (d'Alviella 1914; Hamilton-Grierson 1914). Immediately prior to the spread of Christianity these symbolic pillars may have had the image of god with the insignia of an individual army carved on top. However, during Charles the Great's conquest and conversion of the Saxons in the eighth century, many of these 'Irmin-pillars' were destroyed, hidden or buried, while some were preserved in their traditional role subject to the addition of some symbol of the new authority, such as a shield or crown. D'Alviella argued that '*when the meaning of these figurines was forgotten, popular imagination gave them the name of 'paladin' in full popularity and the Irminsäulen became the Rolandsäulen*', or Roland statue. In supporting the idea of a prehistoric precursor to market crosses, perrons and Roland-columns, Hamilton-Grierson (1914) drew upon world-wide historical and anthropological evidence. This indicated the use of borderland as holy or neutral territory, in which people met to trade, often in the shadow of a stone boundary marker. Hamilton-Grierson suggested that many market crosses were originally either pagan monoliths that had been Christianised or new monuments that had been planted by the church as substitutes for the pagan monuments.

D'Alviella (1914), Hamilton-Grierson (1914) and Black (1928) did not envisage a *direct* link between perrons, Roland statues and market crosses. Rather they suggested that these three monuments types were each the result of a parallel evolution from a common, Western European precursor, ie pagan monoliths. Scotland indeed exhibits numerous remains of both prehistoric monoliths and Christian crosses. It may be significant that Clackmannan market cross (built in the 1600's) shares its town centre site with an ancient capped monolith which could have acted as a predecessor to the market cross. Hutcheson (1900) identified further examples of market crosses located next to boulders of pagan significance at Athelstaneford, Bowden and Minnigaff. However, whether a general continuity of practice can be stretched from recent centuries back to as far as prehistory is rather speculative. The origins of the market cross may well be lost irretrievably in the mists of time. We are on uncertain territory in seeking to research pagan practice and belief with regard to standing stones. It was the spread of Christianity that introduced to the West the practice of making written records in the early medieval period, and Christian writers have little to say about the earlier pagan practices. Prior to this, Roman writers offer us only tantalising glimpses of this Celtic past, based upon observations made for the most part in Continental Europe.

2.1.5 Survival

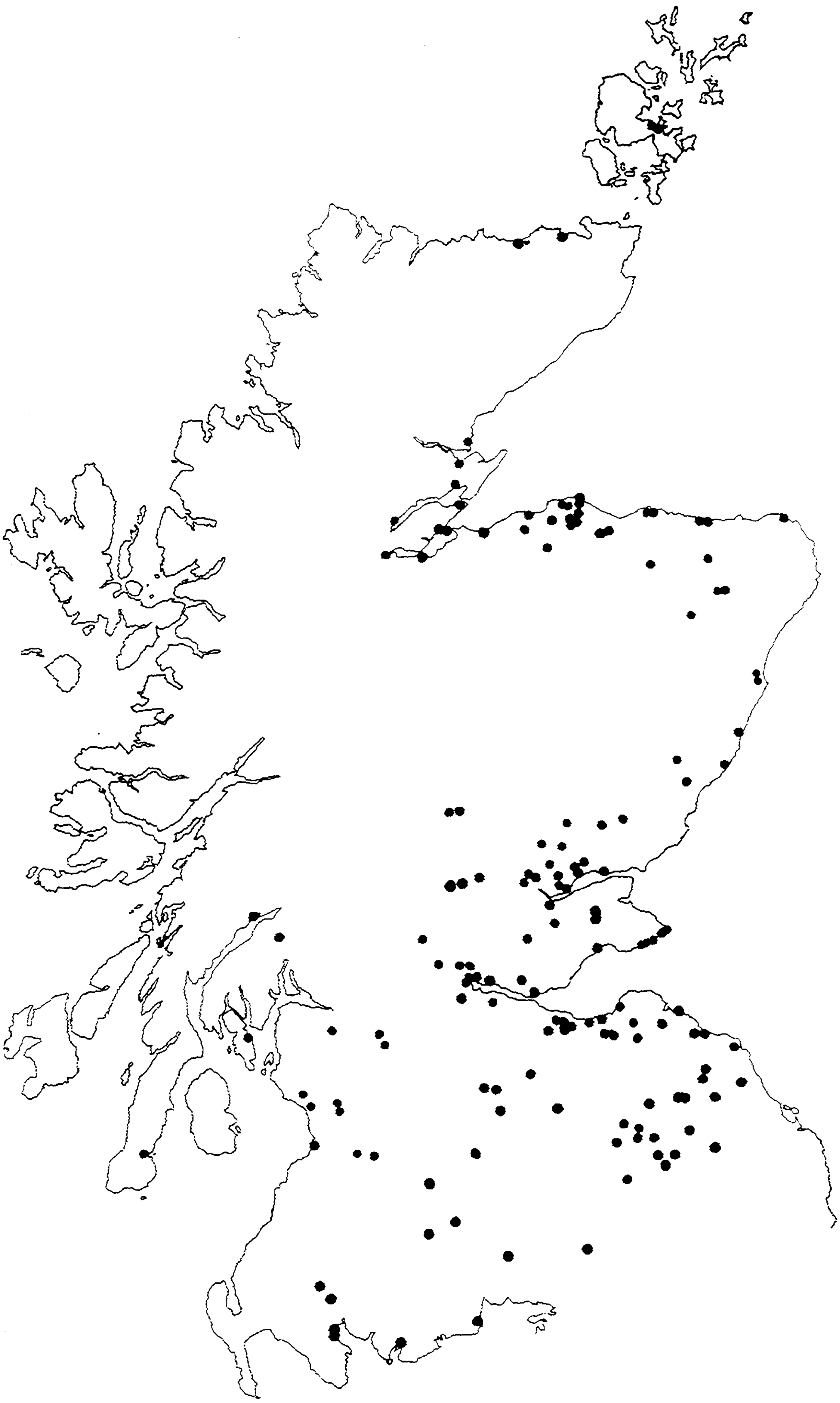
There are 151 market crosses surviving in Scotland today, including some fragmentary examples. There are further examples recorded by documentary evidence that have not survived. Many crosses have been wholly or partly replaced by replicas over the centuries. In a few cases, eg Marykirk, the cross survives as a mere stump. The construction date is known for 110 of the surviving crosses, and spans the late 1300's to the 1900's (with a further cross being re-used from the 700's). Most (84%) date from the period between AD1500-1900, and particularly the 1600's. The location and date of all surviving examples is listed in Appendix A.

2.1.5.1 Geographical location

In Scotland, market crosses are today mostly located in town centres, and distributed largely in the eastern and southern areas of the mainland (see distribution map in Figure 2.1). This distribution largely reflects that of burghs historically. Then, as now, the Highlands of Scotland were less populated than the Lowlands and, indeed, the nature of settlement in the Highlands conformed to a different set of economic and social values. Around 86% of the surviving market crosses still stand in town centres, 6% are located in churchyards or cemeteries, 5% are situated on rural land, and 3% have been moved indoors.

In some instances market crosses can be found in locations outside of town centres. As mentioned above, some late medieval markets were held in churchyards and in a few cases market crosses can still be found at these locations (eg Dallas and Duffus in Moray). In the past a few market crosses were actually purchased on occasions when they were being dismantled, and the acquired pieces were moved into the grounds of affluent local individuals for preservation or simply as curios. For example, Banff cross was bought by a local landowner in 1768, who mounted the shaft and finial upon a dovecot building. Similarly, Longforgan cross was moved to Huntly Castle in 1790, the remains of Perth cross were moved to Fingask Castle (probably during the 1700's), and the remains of the Edinburgh High Street cross were moved to Drum Castle at nearby Gilmerton in 1756. A few crosses are located in a rural setting on the original site of deserted medieval settlements, eg at Old Airth (Falkirk), Old Fochabers (Moray), Old Scone (Perthshire), Ness (Ross & Cromarty), and Rossie (Perthshire). Additionally, the remains of a few crosses have been moved indoors into museums or churches, eg Fowlis Wester, Thurso, Liberton (Edinburgh) and Kirkwall.

Figure 2.1 Map showing the distribution of surviving market crosses in Scotland.



2.1.5.2 Relocation

Market crosses have often been moved around, sometimes to inappropriate sites, over the years in the course of urban redevelopment. This practice occurred even as early as the sixteenth and seventeenth centuries eg in cases where towns became larger. It is usually the case that the relocation of crosses was only over very short distances within town centres, particularly if the removal was simply to provide more room for traffic. For example, the present and two previous sites of Inverkeithing market cross are all within a very short distance of each other. Other crosses were relocated because the burghs they originally served had become extinct eg - Rossie, Longforgan and Kincardine (Mair 1988). In some cases market crosses were demolished rather than relocated, because they blocked high street traffic or because they offended the eye of Victorian improvers (Mair 1988). For example, the former Edinburgh High Street cross was subject to a complex history regarding the replacement of its parts and removal prior to its eventual demolition in 1756. It came to be considered, along with certain other historic buildings, as blight upon the architectural surroundings and an *'incumbrance to the street'*. However the sites of demolished crosses are usually commemorated, eg by a wall plaque at Hawick, or by stone setts embedded in the street, as at Lanark, Montrose and Brechin. At Biggar the surviving cross fragment is built into the wall of the Exchange, close to the former site of the cross. Later in the nineteenth century and in the first half of the twentieth century, towns expanded and developed rapidly due to industry and the advent of the motor car. In accommodating these changes and improving the building and housing standards, the fabric of many of the historic burghs was ripped out. The historic remains and street layouts in many of the larger towns were affected by this to varying degrees (Dundee, for example, was a particular casualty). This increasing redevelopment also encouraged the relocation or dismantling of market crosses in some cases.

2.1.5.3 Replacement

The state of survival is known for 111 of the crosses. The condition of the others could not be established from the information recorded in the consulted sources, and site visits would be required to confirm this. Of those for which the degree of survival is known, 22% still consist entirely of all of their original parts (note that this includes a few later examples built in the twentieth century). A further 24% have been largely or completely modified or replaced with replica parts. The other 54% have been subject to varying degrees of repair and *partial* replacement. Therefore, most market crosses have had at least part of their structure replaced since their original construction (for further information see the Data Analysis chapter, Section 4.2.3). For example, since its original construction in the late fifteenth or early sixteenth century, Banff market cross has been completely renewed through the piecemeal replacement of its component parts, and this situation is quite common among market crosses. A few other market crosses have been replaced with Gothic or Victorian substitutes, which look nothing like the originals. These are included in the present research, since they are nonetheless categorised as market crosses in the archives consulted and because they represent another dimension in the history of the construction of this monument type, no less valuable.

2.1.5.4 Current risks to survival

The market cross today is frequently still located in town centres and is thus vulnerable to a range of sources of damage additional to the natural weathering processes. Human agencies such as vandalism, re-siting, well-meaning but inappropriate conservation methods and materials, motor vehicle emissions and other atmospheric pollutants can all cause damage to the stonework.

The crosses are usually designated as Listed Buildings, and sometimes as Scheduled Ancient Monuments, and are thus subject to development control by legislation. However, these designations do not come with any system of regular monitoring, nor can they guarantee good practice with regard to methods of intervention. The multitude of local authorities involved in the care of these monuments across Scotland may in the past have led to misguided intervention and mishandling, albeit good-intentioned, by unqualified persons. It is likely that the practice of moving many of the market crosses may have accelerated the damage in some cases. Inappropriate conservation materials or methods also have the potential to introduce new sources of degradation. For example, many repairs in the first half of the twentieth century made use of cement mortar which has introduced problems in moisture retention in the stone and caused increased erosion of stone at masonry joints. Rusting iron parts, intended to stabilise the crosses or strengthen their joints, have also caused the fracture of stone where they have corroded and expanded. Even the long-term effects of conservation materials currently used (eg epoxy resins, consolidants and water repellents) are still not fully understood. In town centre locations motor vehicles are a major hazard in terms of both emissions (see Section 2.3) and the risk of impact to the crosses. In towns there are also risks from sporadic vandalism. Several market crosses are situated in churchyards and may be exposed to other types of damage, eg impacts due to grass-cutting equipment. Crosses located on arable land (eg Rossie) could be exposed to higher levels of nitrate from fertilisers. In addition to the anthropogenic sources of damage, the stonework is deteriorating due to natural weathering, primarily through the effects of salts and moisture. The various weathering types and mechanisms are discussed in detail in Section 2.3. In practice, the environmental and anthropogenic decay factors interact as a set of conditions in the weathering process.

2.2 Market cross research

2.2.1 Previous research

In the latter half of the 1800's, there emerged a surge of interest in Scottish market crosses, evident in various journals. This appears to have been stimulated by the growing support for proposals to erect a reconstruction of the former Edinburgh market cross (subsequently reconstructed in 1885). A call to gather information about both destroyed and surviving examples of market crosses prompted readers of a number of journals to send in details of their local market crosses. Thus, discussion about Scottish market crosses took place in the *Proceedings of the Society of Antiquaries of Scotland, Transactions of the Stirling Natural History and Archaeological Society, Scottish Notes and Queries,* and in *The Scotsman* newspaper. This culminated in the publication of an inventory of this monument type in 1900. Further key papers followed in 1914 and 1928; however, there has been little synthesised research into market crosses since this time.

Nineteenth Century Research

An early attempt to elucidate the origins and to assert the architectural and historical value of the market cross was made by Britton (1807). Here ideas were presented regarding the evolution of the crosses, in which their architecture and use were discussed and associated events from history were cited. However, no reference was made to any Scottish examples.

McCulloch (c.1854) presented a paper describing the architecture of the former Edinburgh market cross and celebrating its role in a number of significant historical events. Abundant examples of documentary evidence were drawn upon to describe the *'noble and ignoble'* historical events that had taken place at the cross. McCulloch expressed concern at the removal of the cross along with other historical buildings from Edinburgh High Street, and made a case for the erection of a reconstruction of the cross. His reasoning for such a project was to allow compliance with the age-old injunctions which require royal proclamations to be made at the market cross in Edinburgh, also for the benefit of visitors to the city, and more generally because of the celebrated role of the cross in history.

A few years later, plans were indeed announced to build a reconstruction of the Edinburgh cross. In response to the recent interest generated by this, Drummond (1860) presented an article on Scottish crosses, which focused particularly upon market crosses. The discussion was a meandering appreciation of this monument type, which touched upon various aspects of their design, use and survival. Drummond asserted the essence and superior form of the Scottish tower-base type of market cross and discussed the design options for the proposed new Edinburgh market cross. He sought to describe the likely appearance and location of the earliest recorded Edinburgh cross by reference to documentary evidence. During his research Drummond made sketches of several market crosses; however, their value for the purposes of research is limited since they are not very detailed.

In 1885 the reconstructed Edinburgh market cross was erected, and Arnold (1885) published a paper recounting the history of Edinburgh's market crosses up to the present, describing their design and the importance of their role in Edinburgh historically. Yet another paper followed in 1886, regarding the former location and appearance of the earliest known of the Edinburgh market crosses, which had been dismantled in 1617 (Miller 1886). Drummond's earlier interpretations (1860) were criticised for being inaccurate and not based upon the full evidence available. Thus Miller presented further evidence and attempted to elucidate details of the site and appearance of the former Edinburgh market cross during the period 1365 to 1617.

A survey by MacGibbon and Ross of *"The Castellated and Domestic Architecture of Scotland"* (1887-92) included a description of selected market crosses. Ten market crosses bearing sundials plus two of the tower-based examples were described, with brief notes regarding their architecture, carvings, date and site history, accompanied by rough sketches.

In 1890 an article on *"Scottish Market Crosses"* was presented in a Stirling local society journal (Small 1890). The aim was to make note of the surviving market crosses following the interest created by the recent reconstruction of the Edinburgh cross. Their origins, historical use and architecture of market crosses were discussed and a list of 37 known market crosses was included (of which three were no longer even upstanding). Small stated that the distribution of nearly all the known examples fell within a forty-five mile radius of Edinburgh, and almost all were located east of Stirling. This early observation was due to a bias in the gathered data, which was rectified during Small's subsequent research. In the wake of this paper an effort ensued in the 1890's to gather information on the surviving examples of market crosses. A request appeared in *Scottish Notes and Queries:*

"MARKET CROSS - Will some of your correspondents gather together in Scottish Notes and Queries the names of the places where the old market cross is still standing? I remember Old Rayne, Bervie, and Fettercairn, although the last-named has been removed to a new site. Since the end of the last century the cross at Turriff has been twice changed, and that at Aberdeen has been renewed and shifted. It is of no little importance that all information be collected upon these that remain and those that have disappeared" (Gammack 1891).

A correspondence lasting for around six months followed in the same journal, in which data was submitted regarding examples of both surviving and demolished market crosses. An anonymous article in *The Scotsman* the next year stated that the writer had been able to draw up a list of market crosses surviving in Scotland based upon information sent to him by various readers. A list of 78 surviving Scottish market crosses was presented, including examples that had not previously been recognised by Drummond (1860) and Small (1890), accompanied by some brief notes on the date and architecture of some. The writer supported Small's (1890) observation that their distribution appeared to be largely confined to the eastern part of Scotland, and added that:

"*...As was naturally to be expected there are but a few north of the Grampians, for a population continually at strife, and one might also say nomadic, was not likely to trouble itself with the erection of market crosses*"!

This statement can be refuted, as it is now known that several examples were erected in the less urbanised Highland region from as early as the 1400's up to the 1700's. The description of the population as "*nomadic*" can also certainly be argued. However, the anonymous paper ends with the invitation:

"*...Any one might make a valuable volume, both as regards letterpress and illustrations, concerning these interesting relics*".

This article gave rise to further correspondence leading to the publication of a yet another list of market crosses (Calder-Ross 1892). The listed examples included some which were previously uncited, and some that were no longer even surviving. These were accompanied by selected notes based upon those sent in by the correspondents regarding cross dates and removal incidents. Calder-Ross' list of crosses was further expanded upon in 1895-6 in Small's second published paper on the subject. Small listed 97 market crosses in this article, with brief notes of the architecture and date of selected cases.

To summarise the work in the 1900's, it seems that proposals to reconstruct Edinburgh market cross sparked discussion on its history and design, which in turn fuelled an interest in the remains of this monument type more generally. Some writers such as McCulloch and Miller chose to write about the history of the Edinburgh Cross only, while other research by Calder-Ross, MacGibbon & Ross, and various correspondents, culminated in notes regarding the history and architecture of other individual examples. Drummond and Small each attempted to provide a synthesised study of this monument type, including investigation into their use and origins.

Small continued to gather data and in 1900 published his third and most extensive piece of research upon the subject culminating from his previous investigations, in the form of a large volume entitled *Scottish Market Crosses.* This key publication consists of an inventory of this monument type in Scotland, and includes an introductory chapter by Hutcheson exploring the origins, architecture and use of Scottish market crosses. Hutcheson noted that market crosses had hitherto received scant treatment in publications. He acknowledged the value of investigations by Drummond (1860), but identified a lack of study of this monument type, whereby previous references made to market crosses had generally only been in relation to associated historical events. Rather, an aim of this inventory was to convey the merits of the crosses themselves, particularly with regard to their architecture and their survival. Hutcheson noted that many market crosses had perished in recent years, not only through neglect, but also due to drastic decisions to demolish certain examples, particularly in the 1700's. Many had been *'razed to the foundations as cumberers of the ground and obstructions in the march of civilisation'*. The attached inventory by Small presented 118 market crosses, of which many were included on the criterion of their being known in the town or village as *'the cross'*. Thus some unconventional examples were included, such as a transplanted sundial and certain wells and fountains which variously incorporate parts of old market crosses in their structure. Small included all recently constructed market crosses in his inventory (eg the Jedburgh example was built in 1887 to commemorate the Jubilee of Queen Victoria). Although Hutcheson had outlined his own view of the stylistic development of market crosses in the *Introduction*, Small's inventory was not subject to any typological classification in its arrangement. Entries for each market cross are generally brief, from a couple of sentences up to three paragraphs outlining selected data regarding their date, historical details and architectural form. Small did not undertake any photographic recording; however, each cross is illustrated by a rough profile sketch, with an occasional more detailed inset of an ornate part. These sketches are adequate in conveying the composition of the monuments; however, the proportions are sometimes misrepresented and detail is often lacking. Further market crosses not recorded by Small were discovered in the archives consulted during the present research, indicating that Small had missed out about 26 examples (a few further crosses have also been built since his publication). Some of the crosses which Small overlooked are fully upstanding, although others survive only as fragments. Many of them are located in the north and north-east of Scotland, and the ignorance of their existence may have been due in part to their distance from the modern population centres and centralised administration systems.

Although Hutcheson alluded briefly to the recent destruction of market crosses, no comments on the stone condition, stone type, land-use or environmental features were provided either in a general sense in the *Introduction*, or for individual examples in the inventory. The provision of sketches rather than photographs inhibits any attempts to gauge the rates of decay and soiling of market crosses through comparing photographs from *'then'* and *'now'*. However, Small did much to promote the cause of the market cross through his publications, and he was even responsible for designing the finial of the Culross market cross in 1902.

Twentieth century research

In 1914 a Belgian author published a paper in which he suggested links between Belgian *perrons* and Scottish market crosses (d'Alviella 1914). The arguments which were advanced to demonstrate the similarities in appearance and function of the two monument types are described above in Section 2.1.3. D'Alviella pointed to the disappearance of some perrons, due to a lack of concern for these antiquities amongst the local authorities. Certain other perrons had been preserved through adaptation to decorate public fountains. This represents a fate similar to the later mutation of some Scottish market crosses into objects such as wells and even street lamps. D'Alviella highlighted a difficulty in determining the extent to which surviving perrons had retained their original form, subsequent to the various restorations and modifications that they had undergone. He emphasised the value of seal dies and imprints in providing a datable image, but also acknowledged the possibility of inaccurate depiction in some cases.

In the same year, another paper was written exploring the possible origins of the market cross, which investigated d'Alviella's suggestions that prehistoric monoliths were the common precursor of various Western European market place monuments (Hamilton-Grierson 1914). This investigation actually drew upon worldwide historical and anthropological evidence in seeking to explain their evolution.

Following the First World War, two papers were published which proposed the market cross as one possible monument type which could be used as a model for the design of war memorials. Along with table-tombs, headstones, wall tablets, almshouses and halls, Godfrey (1919, 66) described the possibilities of using the market cross as a subject:

"We desire to erect something simple to bear a recording sentence, the names of the fallen, the symbols and badges of ourselves and our Allies; we desire this something to stand where we can all see it, to be a focus of the village life, and withal to beautify the scene and not to intrude as a stranger. And for all these things we have a precedent in the village or market cross, which regardless of its beauty, we have very nearly banished from the land".

Godfrey believed that market crosses *"always possessed a memorial or public character, as well as religious significance"*. Regarding the Renaissance-style market cross in Aberdeen Castlegate, he suggested:

"...One need only imagine the carved panels of the Aberdeen cross filled with the heraldry and insignia of the War, and the central column inscribed with names, to conjure up a perfectly ideal memorial for a country town" (1919, 67).

Vallance (1920) expressed a similar aim in his research into *Old Crosses and Lychgates*. He criticised modern art for its '*bankruptcy*' and its unsuitability for serving memorial needs. His investigation of these monuments, which included market crosses, aimed to assess *"the most appropriate form of monuments for reproduction or adaptation to the needs of the present"*. However, the market cross examples described are all English and Vallance felt that *"to obtain a sufficiently representative series there has been no occasion to go beyond the confines of England and Wales"*. We can certainly challenge that viewpoint and indeed, as described above, Drummond (1860) had already asserted the unique characteristics of some of the Scottish market crosses.

In due course, the idea of using the market cross as a model on which to base the design of war memorials was indeed taken up in certain towns in Scotland. This can be seen at Abernethy, Bowden and Kelso.

In 1928 Black described the appearance and fate of the former Glasgow market cross, and explored the possible origins, architectural characteristics and historical evidence of market crosses in general. He expounded the earlier theory of their relationship to Belgian perrons. Black also pointed to areas of work that he felt needed to be pursued for this monument type. This included recording, especially through photography, the exact location of surviving examples, conducting a literature search for individual examples, and exploring the evidence from sources such as local traditions and municipal seals. These lines of enquiry have not been followed up by any subsequent research. He noted that other authors were guilty of not indicating the position of the crosses in relation to their surroundings and claimed that the market cross had not been satisfactorily treated by archaeologists. Black highlighted the fact that 'The Sculptured Stones of Scotland' (Stuart 1856-67) featured few market crosses because only a few were 'sculptured' (Stuart had made early illustrations of market crosses at Campbeltown, Dull, Fowlis Wester and Inveraray - see Section 3.9.1 in the next chapter for a discussion of these). Black also noted that Small's sketches (1900) were not always comprehensive and that no measurements had been given. He referred to the trend for market cross demolition and hinted at the inappropriate way in which some market crosses had been restored, advising greater care in the study of monuments prior to such works.

Therefore, the published works to this point demonstrate a growing concern for the conservation and detailed recording of market crosses. However there was still little comment upon the actual condition and environment of the remaining monuments. Since Black (1928) there has been no synthesised study of Scottish market crosses. Rather, points of interest regarding the architecture and historical use of certain market crosses have merely been outlined within publications and gazetteers concerned more generally with the architecture and socio-economic history of the Scottish burgh. Some examples of these publications are referred to below, and they are useful in indicating recent perceptions by authors of the significance of the market cross.

With regard to placing the market cross within its socio-economic context, numerous historians have written about Scottish burghs, and such publications offer a useful historical backdrop to the market cross. Adams (1978), Gordon and Dicks (1983), Lynch, Spearman and Stell (1988), Mair (1988), Naismith (1989) and Ewan (1990) have all discussed various aspects of life in historic Scottish burghs. However, in most cases there is no in-depth discussion of the role of market crosses within this. Gordon and Dicks (1983) highlighted that there had previously been a lack of historical research into the urban character of Scottish society, and highlighted a bias in which research had instead been more focused upon the Scottish Highlands and Islands. Mair (1988) aimed to reach a broad audience and discussed aspects of daily life in seventeenth century Scottish burghs. This publication was geared towards stimulating public interest in historical town life and architecture, and aimed to encourage the reader to look for the clues in their local surroundings. Despite the prominence given to the market cross in the publication title *('Mercat Cross and Tolbooth: Understanding Scotland's Old Burghs')*, the discussion dealt relatively briefly with their architecture, location, function, survival and removal, with reference to several examples. However, Mair also noted that the sandstone of which market crosses are mostly built varies in durability across the country, and he remains the only author to make reference to this vulnerability of their material. Although the discussion is not in-depth, this section of the publication represents the lengthiest treatment accorded to the market cross since Black (1928). Other studies of Scottish churchyards by Willsher (1985) and Love (1989) included explanations for the presence of market crosses at these locations.

Tittler (1991) investigated the symbolism and intent of English civic architecture rather than Scottish. However, some of his ideas could well be applied to Scottish burgh architecture and the control systems that operated to maintain and exploit daily urban life in the period 1500-1640. He presented a detailed study of the sociology of the English town hall and what it revealed about the contemporary social system. He was interested in analysing symbols of authority and status, as portrayed through the architecture and use of town halls, their fixtures and fittings, the organisation of space, the mayor's role and associated paraphernalia. He presented evidence from both documentary sources and physical remains in exploring the symbolism used in this *'cultivation of deference'*. The discussion is analytical and insightful, with a Marxist slant. His analysis of the market place is particularly interesting, and he described the town hall in relation to this. Representative of *'the restrained, disciplined, and bourgeois values of contemporary ruling elites, the hall looked out on the spontaneous and potentially disruptive activities of the market-place below. It stood between order and disorder, hierarchy and inversion'* (131). He also described how the symbolism of the hall linked the present with the past, by the display of images of the town's heritage, even folkloric or mythical heritage. This would probably be of increased importance in a society less literate than today. Such imagery was used in *'celebrating the foundations of the community or to perpetuate the memory of its important citizens and benefactors. In so doing, the civic leaders of our period tried to grace their own brows with the laurels of their forebears, whether mythical or historical'* (131). The heraldic devices on market crosses must surely have been intended to serve the same function. None of the discussion refers to Scottish burghs, and nothing is said on the subject of market crosses other than that the name and site of the cross has been continued, in some cases, in that of the later town hall. However, some of the general observations made can be applied to Scottish market crosses, particularly regarding the use made of devices such as heraldry and portraiture in an attempt to legitimise the powers of the burgh authorities. If one extrapolates from Tittler's line of reasoning, the very presence of the market cross itself must have been viewed as a visible symbol of the presence of royal, baronial or monastic control in the market place. Here, standards and measurements were maintained and, in effect, the consumer rights of the day were protected. This symbolism indeed must have been obvious in the past, in the association of the market cross with acts such as formal punishment and proclamations, indicating their official endorsement.

There are a large number of published studies on historic Scottish burgh architecture. Scott-Moncrieff (1938), Lindsay (1948), Dunbar (1966; 1976), Petzch (1971), McWilliam (1975), MacMillan (1992) and Howard (1995) each presented studies of the architecture in Scottish burghs. However in most cases the references to market crosses comprise but a brief outline of their use and general architectural character. Notably, McWilliam (1975) highlighted their frequent removal with the growing threat of impinging motor traffic.

In one of a series of thematic studies, the Royal Commission on the Ancient and Historical Monuments of Scotland (RCAHMS 1996) published a study of Scotland's pre-1833 tolbooths. This discussed the architecture and historical use of tolbooths, and included a descriptive gazetteer of 87 selected examples. Occasional note was made of market crosses where they survive in close proximity to the listed tolbooths. They aimed to heighten public awareness of tolbooths and to highlight the quality of information available in the National Monuments Record for Scotland. The current series of thematic recording by the RCAHMS generally aims to focus upon '*building and monument types that are redundant in terms of their original functions and are particularly representative of Scottish architecture and society*'. Market crosses could also be thought of as meeting this criteria and the data gathered during the course of the present research could potentially allow the production of a similar study and gazetteer, complementary to that of the tolbooths. The related factors are that tolbooths and market crosses are both contemporary, civic buildings, which are primary features of Scottish burghs, usually to be found in very close proximity to one another on the market place. The architecture of each attempted to symbolise the fact of burghal status, burghal powers, and the heritage of the burghal authority or benefactors. In recognition of this association, one of the authors expressed the desire to include market crosses in this study along with tolbooths, but resources had not allowed a thorough investigation of the crosses during this project (Fisher, RCAHMS 1996, pers comm).

Individual publications in the *Scottish Burgh Survey* series (eg '*Historic Aberdeen*', Dennison & Stones 1997), commissioned by Historic Scotland, aim to highlight the historical development and archaeological potential of specific historic towns. These publications are intended to help inform planning and development works, generally to raise awareness of the urban heritage, and ultimately to better preserve the remaining historic core of the burghs. Fifty-six burghs were surveyed during the period 1978-1990, and the present phase of survey began again in 1994 with more widespread publication. This source includes a brief description of the market cross in each burgh, eg indicating the original site and construction date, and outlining the architectural characteristics.

A vast number of popular gazetteers are widely available which include entries for individual examples of market crosses. Their coverage of the crosses is a brief outline of the architectural composition and date of construction and, occasionally, details of their removal, points of historical interest and photographic illustration. Their condition is generally not referred to. Regional gazetteers providing a limited source of data on particular market crosses are the *'Buildings of Scotland'* series (Gifford 1988, 1992, 1996; Gifford et al 1984; Williamson et al 1990) including summaries of the local building stone types; the *'...An Illustrated Architectural Guide'* series published by RIAS (McKean 1985, 1990; McKean, Walker & Walker 1989; Swan 1987; Pride 1990; Beaton 1992, 1996; Close 1992; Strang 1994), and the series *'Exploring Scotland's Heritage...'* published by the RCAHMS (Stevenson 1995; Ritchie 1996; Ritchie & Harman 1996; Shepherd 1996; Stell 1996; Walker & Ritchie 1996; Baldwin 1997). Various other local history studies include reference to particular market crosses, eg in Dundee (Kidd 1901; McKean & Walker 1984), NE Scotland (Tranter 1974), Moray (Douglas 1936), Stonehaven (Watt c.1960), Aberdeen (Fraser 1908; Munro 1910) and St Andrews (Robertson 1973).

Finally, published inventories are another source of data on particular market crosses. The *'Old'*, *'New'* and *'Third'* *'Statistical Account of Scotland'*, (eg MacKenzie 1953; Rennie & Gordon 1966) contain brief inventory-type information about the local monuments, including market crosses, and associated traditions in various localities. Other key inventories are the Department of Environment's *Ancient Monuments of Scotland*, the RCAHMS regional *Inventories* and *Lists of Archaeological Sites and Monuments*, and the *Original Name Books* of the Ordnance Survey. The RCAHMS regional *Inventories* occasionally comment upon previous attempts at intervention (eg for Airth cross, RCAHMS 1963, 402). Data from these latter sources was not exhaustively sought during the present research, since the National Monuments Record for Scotland has often already extracted information from them for its own archived record of each monument.

2.2.2 Archived data

The archives of the National Monuments Record for Scotland (NMRS) and the Listed Buildings data provided the bulk of the preliminary data used in this research. For the 151 surviving market crosses, data regarding their location, architectural characteristics, construction date, protective designations and any other details that happened to be recorded were extracted from these sources. Limited snatches of data were also extracted from the published sources reviewed above. In the case of the sampled crosses, Restoration Reports archived at Historic Scotland were consulted to extract data for an increased range of variables. The contents of these archives in relation to market crosses is summarised below.

The National Monuments Record for Scotland (NMRS)

Market crosses were first recorded as historical monuments by the archaeological division of the Ordnance Survey; however, this responsibility was subsequently taken over by the NMRS. The archived records comprise a national register of the historical sites and monuments in Scotland and they vary in content, although all recorded monuments are at least represented by data indicating their location and the general class of monument. Usually monument records also include a description of the architectural composition, a general indication of the state of survival and references to additional external sources of data. Site visits, infrequent and irregular, are variously recorded in these records. The field observation notes from these sometimes record tantalisingly brief details of the monument condition, and generally there are no specific details on the decay characteristics of the stone. Photographic evidence and drawings often supplement the records. The monument records were kept initially as a card file system by the Ordnance Survey, and subsequently developed in paper format by the NMRS, who inherited the responsibility. The written data has now been largely digitised for ease of retrieval and physical longevity, although the pictorial and map data remain as a paper record. The NMRS usefully stores information for all areas of Scotland, therefore their archives were the primary resource used in the present research for selecting the sample of market crosses which would be subject to more detailed analysis. The NMRS records can be queried remotely, by use of the CANMORE database on the Internet. A fact to be born in mind by future researchers recovering data is that some confusion is caused by the various filing of market crosses under either 'buildings' or 'archaeological monuments', and that they are also listed variably as 'market cross', 'mercat cross' or even 'town cross'. A few further examples defined as market crosses in Small's inventory (1900) are not even identified as such within the NMRS.

Regional Sites and Monuments Records (SMR)

Regional Councils also maintain an archive of data relating to local monuments, known as the Sites and Monuments Record. The regional SMR's were established piecemeal at various dates from the 1970's with the aim of making the data more immediately accessible. This was particularly intended to ease the processing of planning requirements, in which archaeological evaluation had come to play an official role. The SMR data was transferred directly from the contents of the NMRS archive, but Regional Council archaeology staff have since built upon this basis by making further updates to various monuments in their SMR. These additions have often been random and usually when monuments have been affected by development proposals. New discoveries of monuments, and new protective designations (particularly with regard to twentieth century remains, such as wartime defensive monuments) have also resulted in continued growth in the number of records in the SMR's. Recent changes within the RCAHMS have seen certain responsibilities regarding the upkeep of monument records being delegated to the regional Sites and Monuments Records. Data from the regional SMR's was not exhaustively sought during the research because in many cases the monument records simply duplicate that which can be found in the NMRS. However, some data was obtained from the SMR's for crosses in the regions of Aberdeenshire, Moray and the Scottish Borders.

Listed Buildings Record

Most market crosses (66%) have been designated as Listed Buildings, which offers statutory protection during any works of alteration. The Listed Building Record is maintained by Historic Scotland and contains a brief physical and historical description of each Listed cross. The records are ordered according to the street in which the cross is located. Data was exhaustively sought for all surviving market crosses contained in this archive.

Historic Scotland Restoration Records

Historic Scotland's Conservation Laboratory maintains a paper archive of Restoration Records in which details of conservation work undertaken by Historic Scotland are recorded and supplemented by photography. This provided a valuable source of data for the present research. Conservation data for sixteen market crosses is included in this archive, consisting variously of letters, memos, conservation reports, photocopied extracts, sketches and photographs. The details of monument condition before and after conservation are often included. Although earlier recording of the condition and conservation of monuments is less detailed, the recorded data has been much more comprehensive in recent years (Gordon, Historic Scotland 1996, pers comm). Details are now recorded of the conservation programme, costing, methodology and materials used. However, there are no mapped illustrations to detail the conservation and the types and distributions of decay interpreted upon stonework. Instead, photography is currently used extensively to show the monument or monument parts before, during and after conservation. For the sake of future research and conservation work, the benefits of accurately recording details of monument condition and conservation treatment are increasingly being recognised.

Historic burgh records

In previous centuries many burghs maintained records including such details as expenses and court procedures. Occasional references are made to the market crosses in these burghs where they featured in relation to punishment procedures or building works. The language contained within them is antiquated and the coverage is patchy. Records pre-dating 1500 are rare; however, exceptions are Aberdeen (which has the earliest series of burgh records beginning in 1398), Ayr (records kept from 1428) and Newburgh in Fife (records kept from 1457) (Simpson 1972). However, most burghs have no surviving records from before the sixteenth or even the seventeenth century, with the exception of some charters. Some details relating to market crosses have been extracted from this source by other authors who were consulted during the present research.

2.2.3 Summary of the literature and data on market crosses

Early research into Scottish market crosses investigated their origins, their relation to other monument types in continental Europe, and their architecture, history and use in Scottish burghs. However, the subject has been a static area of research for decades. No synthesised research has been undertaken into market crosses since Black (1928). The number of known surviving market crosses has actually expanded since those listed by Small (1900). Recent publications discussing Scottish late medieval burgh life and historical architecture are aimed variously at historians (social and economic) or those interested in historical architecture or local history. They have dealt only in passing with market crosses, outlining their functional and stylistic aspects with descriptive, rather than analytical, accounts. Nobody has discussed the extent and rate of decay on market crosses, or considered this degradation in relation to factors such as the prevailing environmental features. Published sources contain no details of the condition of market crosses; however, some details of decay and intervention are recorded in Historic Scotland's Restoration Records if conservation work has been undertaken.

The lack of recent research into this monument type could be due to a combination of the following factors: market crosses are small, discreet monuments; many are simple in construction with little architectural detail; the stylistic elements of their architecture are similar, in some cases, to that which can be found upon some other small monuments or buildings, thus there may be a feeling that they can be dealt with under a more general category; their function was basically as markers, and due to this it may be that little mystique is perceived to surround them; many are relatively recent monuments within the timescale of history and archaeology; many have been modified or are reconstructions.

However, there is room for reviewing the management strategy of this monument type, and also for raising its profile as an element of the heritage resource worthy of public promotion and of conservation. In addition to stone weathering, their condition is further at risk in town centre locations from a number of anthropogenic factors, including atmospheric pollution, mechanical damage and inappropriate intervention. Generally, market crosses would seem to all suffer from a similar set of problems (Gordon, Historic Scotland 1996 pers comm). There is a vast body of literature dealing with decay processes and conservation ethics and practice for dressed stone surfaces in general, which has recently developed in line with increasing conservation concerns (reviewed in Sections 2.3 and 2.4). However, little or no attention has been paid specifically to the market cross with regard to this. Therefore, current and future investigation of this monument type could look at their survival, condition, intervention treatment, and their promotion and interpretation as a heritage asset. The present research attempts to address these issues.

2.3 Stone Weathering

The following section reviews the characteristics of stone types and soiling, the mechanisms of stone weathering and the decay effects upon stone. The role of architectural morphology and mortars in stone decay is also examined.

2.3.1 Stone types

The most common stone type used in the construction of Scottish market crosses is sandstone. Other stone types much less used include granite, schist, marble and whinstone. Although there are some limestone pockets in the Highlands it is not generally used for building in Scotland. The stone types described in this section relate to those that occur amongst the sampled crosses only, namely sandstone, granite and chlorite schist.

2.3.1.1 Sandstone

This section presents a summary of the fundamentals of sandstone formation processes and properties. Sandstone is composed of mineral grains and cementing material, permeated by pore spaces. Mineral composition, texture, fabric, structure, pore spaces, and grain cement can all affect stone durability (Winkler 1994). These properties vary between different types of sandstone. Furthermore, due to the physical and chemical heterogeneity of stone, even masonry blocks from the same quarry can exhibit some variation in properties.

Bedding

The process of sandstone formation produces layering within the stone, known as stratification or bedding. Layers vary in thickness and can differ in grain size, mineral composition, porosity, cementation and sorting. The layers can be differentially eroded due to their varying properties. The bedding alignment of sandstone needs to be taken into account when laying pieces of masonry during construction, since face-bedded sandstone is vulnerable to decay by delamination.

Granular composition

The granular element of sandstone consists of durable minerals inherited from a primary rock type. The grains are mostly quartz and feldspar, although they can also consist of other mineral types such as calcite, mica and hornblende. These grains are generally more durable mineral types capable of enduring the physical forces incurred during transportation prior to their reconstitution as sandstone.

Quartz is a very durable mineral and can resist most chemical attack (Winkler 1994). Although the primary rock source for the sand grains can be sedimentary, igneous or metamorphic, the resulting sandstone is classed as a 'sedimentary' rock type. That is, it consists of a series of sediments deposited by the action of wind, water or ice and subsequently infiltrated by a cementing material.

Granular properties

The variability between the coarseness or grain size of the layers is known as the degree of 'sorting' and it indicates the nature of the transporting agent. For example, a layer composed of a wide variety of grain sizes can represent a period of relatively rapid deposition during flooding. Larger grains can be seen by the naked eye; however, most granular characteristics can only be gauged by use of a microscope. 'Packing' is a measure of how closely spaced the grains are, and the relationship of the grains to the spaces. The degree of abrasion of individual sand grains is known as the 'roundness'. The sandstone 'fabric' refers to the orientation of grains within the stone, and 'texture' describes the relationship between the shapes and sizes of grains.

Porosity

The porosity value is the ratio of pore space volume to the total volume of the stone in percent. For sandstone the typical porosity range is 8-25% (Leary 1986). However, the degree of pore fineness is a more important indicator of weathering susceptibility than the overall porous volume (Honeyborne 1990). With regard to the growth of salt and ice crystals within a stone, larger pores are more physically tolerant than micro-pores. This will be further discussed in Section 2.3.3.3 in relation to salt weathering and frost damage. Smaller pores also demonstrate greater capillarity action, that is, they can attract and hold water more readily thus encouraging decay (see next paragraph). An understanding of porosity is important, as it affects stone strength and durability, and can allow estimates to be made of moisture content and movement through the masonry (Winkler 1994). However, the role of porosity is only one factor in the complex equation of stone decay. Although stone porosity and saturation coefficient measurements cannot indicate the overall stone durability, their values may be useful in selecting stones for replacement (Leary 1986).

Capillarity

Capillarity refers to the degree to which surface tension forces dominate the behaviour of liquid water in the stone pores. Capillary action can allow moisture to be transferred upwards from the ground and the effect can also be evidenced horizontally in the stone. The conduction takes place through interconnecting pore spaces of varying pore diameters, although smaller pores exhibit greater capillarity action. Salts can be introduced into the masonry through the ingress of moisture by capillarity. The height reached by moisture through capillary rise can be quite substantial and may be greater in thicker walls (Torraca 1988). Capillary moisture can be concealed by surface lichens and mosses, thereby posing a greater risk to the stone. These biological growths retain moisture and inhibit its evaporation from the open channel ends of capillaries.

Cement

The sandstone grains are bonded together by a natural cement, which is a major factor in the weathering susceptibility of a sandstone. The composition of the cement and the degree of cementation affect the strength and durability of stone. The cement consists of minerals deposited from solution, such as calcium carbonate, silica, ferrous iron and clay minerals, often combined together in various proportions. Other rarer cement types may include dolomite (calcium magnesium carbonate) and gypsum (calcium sulphate). The main cement types are described below, and all are found in the sandstones of which market crosses are constructed.

Siliceous sandstone contains silica as the dominant cement and is a strong rock type. Silica can be dissolved only in conditions of high temperature and pH (Winkler 1994). Indeed, a pure silica cement results in a very hard stone called quartzite.

Calcareous cements are composed of calcium carbonate (calcite). Such sandstones are vulnerable to attack from the carbonic acid in rainwater, particularly if the stone is poorly compacted. Calcareous sandstones represent only a small minority of building stones used in the UK due to their poor durability (Honeyborne 1990). The resistance of the cementing material to acid is a significant factor in sandstone durability. Where pockets of calcareous cement occur within a sandstone consisting predominantly of a stronger cement type, the calcareous pockets are more readily eroded and can result in pitting of the stone surface. Calcareous cemented sandstones are best suited to rural environments as they are more vulnerable to decay in a polluted atmosphere (Leary 1986).

Ferruginous sandstone is cemented with ferric oxides and ferric hydroxides and tends to be red in colour. The iron coats the individual grains, and sometimes small, black specks are apparent. When the iron has been changed to the insoluble ferric form the cement is virtually insoluble by the normal range of acid rainwater (Winkler 1994). Ferruginous cements often occur along with more dominant siliceous cements and these sandstones are normally very durable.

Argillaceous sandstones are cemented with clay producing a stone very vulnerable to weathering, liable to weaken through mere wetting and drying. The most common types of clay in sandstone are kaolinite, illite and smectite. Smectite clays expand when wet and detach from the underlying grains, leading to multiple spalls on outer weathering layers of sandstones. Smectite can be present in the grains as well as the cement. This is the case with many of the local Dundee and Arbroath sandstones where smectite forms by degradation of grains from volcanic basalts.

Sandstone colour

Pure calcareous and silica cements are white. The colour in sandstone results from other minerals present in the cement or grains. The colours mostly arise from the concentration and degree of iron oxidation to ferric oxides (Winkler 1994). These oxides of iron can result in a range of stone colour. They produce shades of red, orange, yellow and brown, and they can even add green, blue and black tones. Where the iron is in a reduced form it can appear grey/green. Ferruginous sandstone can sometimes appear blotchy, with both reddish and grey mottles (eg sandstone from the Arbroath area). A pale pink tint can be caused by manganese as a trace element. Argillaceous sandstones tend to be grey-coloured; however, the clay content can also result in dark brown or greenish stone.

The Munsell colour system (1975) is widely used to measure stone colour by visual comparison. It was devised in 1915, and enables measurement of the three attributes of hue, chroma and value. Hue is a measure of the instance of red, yellow, green, blue or purple. Further classifications represent transitions between each of these, eg yellow-red, or further subdivisions such as red-yellow-red. Chroma refers to the strength, saturation, or degree of departure of a particular hue from neutral grey of the same value (Winkler 1994). The value records the degree of lightness or darkness, in relation to a neutral grey scale. The Munsell system was used to measure the colour of stone in the sample of market crosses.

Thermal properties

Thermal properties refer to the degree to which the stone absorbs and conducts heat, which can produce differential expansion and contraction throughout a piece of masonry. In direct sunlight, the heat generated on a stone surface is greater than that experienced internally, thus stresses can result. Heat conductivity and retention are greater in less porous stone (Winkler 1994).

2.3.1.2 Granite

Only a small proportion of the stones making up Scottish market crosses are carved from granite, and the sampled crosses only include one granite component (the steps of Turriff cross). The properties of granite can be summarised as follows.

Granite is an igneous rock, formed by the crystallisation of molten rock. It contains quartz, feldspar, mica and other minerals in lesser quantities. The grains are usually medium- to coarse-sized, and individual minerals are visible without magnification. The colour varies from pale grey to blue-grey and red. Granite has no bedding planes, although there may be some alignment of the crystals. However, these alignments do not represent significant planes of weakness. Pores occur both within and between the mineral grains; however, the porosity of granite is low compared to other stone types. Porosity is commonly <1.5% (compared to 8-25% in sandstone). The pore spaces may be largely caused by mineral alteration during subsequent weathering, and micro-fracturing, eg due to quarrying, working processes and stresses in the building (Urquhart et al 1997). Granite is widely considered to be a very durable stone type; however, it is nonetheless vulnerable to decay. It exhibits a range of decay and soiling symptoms similar to sandstone; however, its relatively low porosity means that the decay rate tends to be slower.

2.3.1.3 Schist

Two market crosses in the sample include masonry carved from local chlorite-schist (Campbeltown and Inveraray crosses). Schist is a metamorphic rock, re-crystallised from a muddy, sedimentary rock under conditions of moderate temperature and pressure. The main minerals are mica and quartz, and chlorite-schist additionally contains chlorite crystals (Blythe & Freitas 1984). The grain size is usually medium or coarse and the alignment of minerals generally allows this rock type to be easily split.

2.3.2 Soiling

Biological soiling and other particles can accumulate upon stone surfaces, causing a change in the surface appearance. The characteristics of different types of soiling and the conditions for their occurrence are described below. Their effect upon the stone is discussed later in Sections 2.3.3.4 and 2.3.3.5.

2.3.2.1 Biological

Biological soiling refers to the growth on masonry of microorganisms including algae, bacteria, fungi and lichen, as well as mosses and higher plants. Most new microbial colonisation results from organisms transported onto the stone surface by atmospheric particles, groundwater or from bird droppings. A study of Maltese monuments found that colonisation by microorganisms occurred on surfaces less affected by sunlight (Fitzner 1995). Lichens, algae, fungi and bacteria obtain nutrients from the atmosphere and from bird excrement. Their distribution upon a monument is determined by the architectural morphology, stone type and the microclimate. Indeed, different microcommunities may live within centimetres of each other due to different local light and heat conditions. Biological growths are especially common on building exteriors in rural areas. The diversity and abundance of biological growth is generally less in urban areas due to atmospheric pollutants (Urquhart et al 1996a). This can result in the domination of an urban facade by one particular pollution-tolerant species giving a bland appearance, as opposed to rural growth, which features more of a variety of species together. Some growths may even be thought of as an asset where they are considered to give the building a 'mellow' appearance. However, biological soiling is often considered to reduce the aesthetic value of buildings and monuments. It can obscure the stone surface from view, and it can cause biodeterioration, attacking stone both mechanically and chemically (see discussion of the effects in Section 2.3.3.5). The characteristics of the main classes of biological growth are described below.

Bacteria

Bacteria are a ubiquitous microorganism; however, on stone their colonisation is most prevalent upon weathered surfaces and cracks (Winkler 1994). The bacteria can be autotrophic (taking their energy from sunlight, chemical oxidation and reduction) or heterotrophic (deriving energy from existing organic matter produced by higher organisms, such as lichen). The identification of these is difficult and complex, and their action is unclear. Cyanophyta (also known as *'blue-green algae'*) are a more visible type of bacteria, which can produce a blackened appearance on walls.

Fungi

Fungi include moulds and mildew. These appear as spots or patches, and can spread to form a furry cover upon the stone, grey-green, black or brown in colour. They live off organic material, such as algal and bacterial waste products and dead cells (Honeyborne 1990). Other sources of nutrients can include bird excrement and decaying leaves. They grow upon wet surfaces and indicate, even indoors, the existence of moisture in the masonry, eg from condensation. The black colour on many Mediterranean marbles and limestones has been attributed to a single-celled species known as Dematiaceous fungi (De Leo et al 1996).

Algae

Algae are visible as green, red or brown powders or filaments and can sometimes appear slimy depending upon moisture conditions (Dukes 1972). The type of algae most commonly found on masonry are from the Division Chlorophyta. Algal growth on a facade often appears as sheets or streaks of green. One algal genus, *Trentepohlia*, appear orange due to conditions of high light intensity. Algae do not have roots and leaves like true plants, but rather they exist as individual cells, clumps or colonies, or as long strands or filaments. Moisture and nutrients in the form of mineral salts are required on a surface for algal growth. Algae favour wet conditions and colonise stonework that can retain moisture for sufficiently long periods (Honeyborne 1990). Indeed, desiccation can arrest the growth of algae. Porous stone, such as sandstone, is particularly suitable due to its ability to retain moisture and entrap wind-blown particles. Their growth may be limited on stones with very low porosity (Urquhart et al, 1996a). Algae also require energy from light; however, conditions of high light levels can discourage growth. Slightly acidic conditions are needed by many algae, commonly occurring on the surface of non-calcareous stones. Most species of algae tolerate pH within the range of 5-9. Run-off from lime mortar can inhibit growth on adjacent stone due to its high alkalinity after application, when it has not yet been fully carbonated. Algae can thrive in industrial polluted atmospheres, upon all building surface types. Growth can be relatively rapid, eg a thick coating can grow within as little as 3 to 5 years. In one case, algal colonisation was observed to have occurred on freshly-cut sandstone in the relatively dry climate of Aberdeen after just 30 weeks of exposure (Urquhart et al 1996a). The accumulation of algae on a surface may eventually reach an optimum level when no more new growth can be sustained.

Algal colonisation is influenced by the factors affecting stone surface moisture, ie climate, geographical location, architectural characteristics, orientation of facades, surface roughness or texture of the stone, degree of shade, the level of building maintenance and the extent of existing biological soiling (Urquhart et al 1996a). Patterns of precipitation and sunshine in the course of the year are important in assessing the likely surface wetness of stone. Surfaces exposed to run-off will retain moisture for longer. Thus, projecting string courses, splash zones, window sills, stone parapets above roof level, and free-standing monuments are all vulnerable to algal growth. Tapered structures, eg steeples, pinnacles and historical ruins with large run-off areas are particularly vulnerable (Urquhart et al 1996a). Market crosses are therefore particularly susceptible to algal growth. Surfaces permanently in shadow retain greater moisture. Thus north and east facing walls are more vulnerable to algal growth, due to the reduced solar incidence and the reduced exposure to the prevailing wind respectively. Parts shaded or overhung by trees, recesses and niches will also retain greater moisture and encourage algal growth. The duration of wetness of a stone surface is of more importance for algal growth than the frequency of the wetting (Bravery & Jones 1977). The degree of maintenance is also a factor, because neglected rainwater goods can cause the masonry to be saturated leading to localised algal growth. In addition, any defects in the stonework or pointing could entrap water and also lead to algal growth. Other biomasses, living or dead, upon the stone surface can also help to entrap water. Base courses of masonry are vulnerable to algal growth as they can experience the splash-back of rainwater from the ground, along with nutrients from ground soil and dust. On granite, the low permeability means that algae tend to be restricted to areas where run-off is concentrated.

Lichen

Lichen growth is formed by the symbiosis of fungi and algae. It can be crustlike (crustose), leaflike (foliose), or stalked (fruticose). Lichens are sensitive to air pollution, especially to sulphur and motor vehicle emissions, and cannot tolerate lead in the early stages of their growth. High levels of urban sulphate and soot on a masonry surface prevent lichen colonisation (Winkler 1994). Rural locations exhibit a greater diversity of lichen species due to this (Urquhart et al 1996a). Stone surfaces with little moisture, which are not colonised by the more rapidly growing algae and mosses, may be colonised by lichen. Lichen can tolerate conditions of extreme cold and dryness and nutrient limitation (Urquhart et al 1996a). Their distribution across a stone surface is less predictable than algae and moss, due to the fact that lichens can tolerate less moisture. The growth rate of lichens is very variable, but is often slow. Rings of lichen can increase by around 1mm in diameter each year.

Mosses

Mosses appear as patches of a green, 'furry' growth, and are supported by a system of rhizoids rather than roots. They require soil and moisture for their growth. Thus open joints and ledges where pockets of soil and moisture can collect are particularly vulnerable. The more foliage the moss exhibits, the greater the presence of moisture it indicates. Mosses favour alkaline surfaces, including lime mortars or cement concrete (Torraca 1988). Their growth is therefore often seen in a linear form, following the line of mortared joints. Like lichens, mosses are not very tolerant of high levels of urban sulphate and deposited soot (Winkler 1994).

Higher Plants

Higher plants (eg ferns, grasses and small trees) similarly require pockets of soil and moisture. They can find a foothold on buildings on and between stone blocks, and use the nutrients of simple organisms like bacteria and algae.

2.3.2.2 Non-biological soiling

Particulate soiling

Particulates deposited on stone can cause the surface to take on a blackened appearance, known as particulate soiling. Particulates can be deposited through the mechanisms of dry, wet or occult deposition. Dry deposition is the most prevalent source of soiling and occurs when dry particulate pollutants in the atmosphere are attracted to wet stone surfaces, aided by the hydrophilic tendencies of the surface moisture film. The particles adhere to the stone surface after the moisture has evaporated. Dry deposition of particulates occurs close to emission sources, usually in urban areas, and can consist of particles of soot, fly ash, part-burned coal and oil. Wet deposition occurs when particulates in the atmosphere are picked up by rainwater and deposited as such upon stone surfaces. In occult deposition, films of moisture can form on masonry from condensation and mist or fog. These fine water particles include particulates and gaseous pollutants (Verhoef 1988). Generally, larger particles tend to be deposited locally as soiling, while smaller ones can be transported over greater distances (Verhoef 1988).

From the thirteenth century in SE England, coal began to replace wood as a fuel. However, widespread use of coal as a domestic fuel did not come until the late sixteenth century and the Industrial Revolution saw its use escalate. The burning of coal became a major source of atmospheric pollution in urban areas. This contributed greatly to the development of black, soiled masonry facades, which can still be seen today on some historic, urban buildings. Coal-burning emissions are much reduced today; however, particulates are still produced by the burning of fossil fuels for domestic and industrial use and in motor transport. Regular monitoring of emissions has shown that the decade between 1979 and 1989 saw a significant reduction in coal-burning emissions but a doubling of diesel smoke emissions. Particulate Elemental Carbon (PEC) emissions from diesel vehicles are considered to be the main source of soiling in European towns (Mansfield 1992). Particulates from diesel adhere to stone particularly well due to the sticky nature of the hydrocarbon content and cannot easily be washed away by the rain. Particulate soiling tends to be heaviest upon the most frequently wetted zones of a building, eg horizontal or sloping surfaces and other washed areas. Although it can be considered as disfiguring, it does not tend to cause stone decay. However, gaseous air pollutants transported onto stone surfaces by the same processes and dissolved in water can be damaging (see Section 2.3.3.2 on chemical weathering).

Bird excrement

A further type of soiling is bird excrement. It can be frequent upon buildings and monuments at coastal locations and in town centres, or in other situations where birds are roosting and nesting on the masonry. Nutrients from bird excrement can encourage algal growth on stone surfaces.

Staining

Staining refers to the migration of coloured matter into the stone from adjacent or attached materials (Fitzner et al 1992). The stains can be produced due to rusting iron components attached to the stone or due to bronze- or copper-wash from other attachments (eg plaques). The process of rust deposition on stone surfaces displaced from the exposed iron or steel is still not fully understood. Rust stains can be intense, they are virtually insoluble in water and sometimes impossible to remove (Honeyborne 1990). Bronze and copper eventually form a stable patina on their surface, but during this process some copper solution can be washed away leaving a blue-green stain on mortar or limestone (Honeyborne 1990).

Applied graffiti

Applied graffiti is a further category of soiling, in which pigment types may penetrate the stone surface. The pigment types most commonly found upon historic surfaces are paints, felt-tip markers, correcting fluid, ballpoint pens, waxy substances (eg lipstick and crayon) and chalk (Urquhart 1999). These do not generally cause stone decay; however, they can be considered to be aesthetically damaging to historic monuments and the existence of a little graffiti on a surface can often encourage repeated attacks. It can penetrate the pores of stone causing difficulties for removal. Both sandstone and granite can absorb graffiti pigments in this way. Although granite is less porous than sandstone, the pigments can permeate through the micro-cracks in granite and may even penetrate to a greater depth than sandstone (Urquhart 1999). (Note that *inscribed* graffiti has been treated as a form of mechanical damage, rather than soiling, in classifications made during the present research).

2.3.3 Weathering agents

Stone weathering occurs on the Earth's surface due to a natural tendency towards entropy, ie to revert back into granular form. Sandstones, granites and other rock types were formed at high temperatures and pressures. They are unstable in the environment at the Earth's surface and are therefore subject to degradation, at varying rates, to forms that are chemically more stable. This can involve dissolution of some minerals (eg calcite) and alteration of other minerals (eg feldspar) to clays. Thus all masonry will weather naturally to some degree regardless of how well it is maintained and of how polluted the surrounds may be. Stone 'decay' refers to the loss of material through weathering processes. These processes cannot be stopped or reversed, although they can be slowed down if a building or monument is appropriately maintained. Stone decay occurs through the processes of chemical and physical weathering. Chemical weathering describes the process whereby old minerals are broken down and new ones are developed in chemical reactions, while physical weathering refers to the mechanical disintegration of stone into smaller fragments. These weathering types interact, such that chemical weathering is assisted by mechanical break-up (Winkler 1994). Indeed, weathering could be considered as a 'synergistic' set of phenomena in which decay effects aggravate one another.

Decay processes have the propensity to develop within the stone as a series of conditions interacting until a critical point is reached, when mechanical damage can be manifested quite suddenly and dramatically (Smith et al 1988). Thus a long period of subsurface activity can be followed by rapid and visible surface deterioration, for example through scaling or granular disintegration. These erratic tendencies, in addition to the heterogeneous nature of stone, complicate the investigation of decay rates (Winkler 1994).

Moisture and salts are widely believed to be the most damaging factors in stone decay (Winkler 1994; Smith, Whalley and Fassina 1988). Moisture has a necessary role in all chemical weathering, and is also involved in physical weathering processes such as frost damage. The mechanism of moisture movement in stone in its different states is a complex area and is still not fully understood (Winkler 1994). The crystallisation of salts within stone pores places stress upon the pore structure and can lead to several different types of decay.

The decay of limestone and marble has received much attention in recent years, particularly with regard to atmospheric pollution. This was stimulated by observations that some of the ancient Roman and Greek classical architecture of the Mediterranean was experiencing acute erosion from atmospheric pollutants in certain urban locations. Following on from this, research into sandstone and granite weathering has also been undertaken, focusing upon Northern European architecture, eg field exposure tests of stone samples in the International Materials Exposure Programme (Mirwald 1989), and the UK National Materials Exposure Programme (Butlin 1989). The following section describes the role of various environmental agents in the decay process.

2.3.3.1 Climate and micro-climate

This section will highlight how variables of climate and micro-climate can influence stone decay. Micro-climate refers to the specific climate experienced at various points upon a stone surface and its characteristics are affected by factors of the built environment and topography, and by the morphology of the stone structure itself.

The role of moisture is paramount to an understanding of stone decay mechanisms. The following sections will include examination of its agency through rainfall, atmospheric relative humidity, condensation, fog, and rising ground moisture. Solar incidence, temperature and wind are also significant in their capacity to absorb this moisture and as agencies in thermal activity. The degree to which stone is exposed to these climatic factors is also influenced by the orientation of facades, site aspect, the nature of the built environment and the existence of any sheltering features. Furthermore, urban climates generally differ from that of their rural surroundings. The urban climate is more mild and moist than rural settings (Winkler 1994). It also experiences altered wind patterns due to friction produced by the concentration of buildings. The effects of urban micro-climate are potentially relevant to the setting of some market crosses; however, the effect upon many other crosses may be negligible where they are located within relatively small settlements.

Relative Humidity (RH)

Atmospheric relative humidity is an important factor in the absorption of moisture by stone and in the supply of moisture into masonry. If the atmosphere is undersaturated it will absorb moisture from stone surfaces. Conversely, moisture can be precipitated onto colder masonry if the atmosphere is sufficiently saturated. Stone retains cold and warmth for a longer period than the surrounding air. Thus moisture can be absorbed from warm humid air by cooler masonry walls or by the cooling of air temperature (Winkler 1994). Relative humidity in urban contexts is generally about 5% lower than in rural areas (Winkler 1994).

Wind

The prevailing winds in the UK are from between the SW and W, and wind speed increases towards the north and west of the landmass (BRE 1989). Monuments sited with a W or SW aspect would therefore be more exposed to the prevailing winds. Windward faces experience greater moisture ingress from driving rain, but they also experience greater evaporation. As wind blows from rural land onto urban land, it slows down but is also made more turbulent due to features of the built environment. Urban obstructions can decrease wind speed by up to 25%, and create micro-patterns in wind currents (Winkler 1994). Around market crosses, the height, proximity and orientation of surrounding buildings could affect the wind patterns experienced at the crosses. Local topographic features can also affect wind patterns, eg hills, valleys, cliffs and ridges. Towards summits the wind speed is accelerated and conversely wind speed decelerates in valleys or at the bottom of cliffs. However, the site of most market crosses tends to be relatively flat.

Wind is important in its capacity to affect the movement of precipitation and atmospheric moisture on and around buildings, and in its effect upon temperature and upon drying rates. The movement of wind currents around a building is affected by the building morphology and by the presence of nearby obstacles. Pressure and negative suction can be brought to bear upon masonry surfaces. When wind hits a flat facade face-on, pressure builds up and the wind is deflected and accelerated around the edges and over the top. The consequent reduction of pressure exerts suction on the sides and top of the building and, to a lesser extent, upon the rear face (BRE 1989). With regard to the morphology of market crosses, there is unlikely to be much of a pressure differential produced due to the small size and narrow nature of these monuments. Larger crosses with a tower-base may experience some pressure differential; however, since these are round in plan the effect may be less than that produced around other angular buildings.

Solar incidence and temperature

The sun can act as a thermal agent directly or indirectly upon masonry. The potential damage that can be caused by thermal stresses is described later in Section 2.3.3.3, but additionally solar radiation has an obvious affect upon ambient temperatures and upon the character of the prevailing weather as a whole. Temperatures affect the activity of moisture, ice and salts within masonry. The incidence of solar radiation upon masonry is dictated by the time of day and season, the orientation of facades and site aspect, and the degree to which the built environment and cloud cover provide shade. Solar heating effects are also more significant on darker stones, which absorb more energy than lighter coloured stones. Temperatures tend to be higher in urban areas, due to additional heat sources. The higher temperatures are aided due to the proliferation of light reflection surfaces, although an increase in the incidence of smoke and haze can absorb up to 15% of the reflected light and infrared radiation (Winkler 1994). As stated above, the effect of urban heat sources may be less relevant to many market crosses that are located in small settlements.

Precipitation

Moisture was noted earlier as being a major agent of stone decay. The action of rainwater itself landing upon a stone surface does not tend to cause direct mechanical damage. However, precipitation is a major factor in chemical weathering and decay due to salt crystallisation. Rainwater naturally absorbs carbon dioxide from the atmosphere, resulting in precipitation slightly enriched by carbonic acid. This can dissolve calcite cement in sandstone resulting in the gradual release of sand grains from the stone surface. Rainwater can also introduce damaging atmospheric pollutants into stonework, eg sulphur dioxide pollution in the atmosphere dissolves in rain to form dilute sulphuric acid. The permeability of sandstone allows deep penetration of moisture into the masonry. Often rain may be too brief to allow much moisture infiltration (Winkler 1994). However, facades exposed to driving rain can experience greater moisture penetration. Base courses of masonry can experience increased moisture due to rain rebounding off the ground, and also through the capillary uptake of ground moisture. Other forms of atmospheric precipitation also pose a significant risk of damage. Mist and fog are of greater acidity than rainfall. They can introduce impurities to the masonry and supply moisture for the crystallisation of salts and ice. See Sections 2.3.3.2 and 2.3.3.3 for details on the damage caused by chemical weathering and salt crystallisation. On granite, the low porosity means that less rainwater is absorbed and thus run-off tends to get channelled into the mortar joints, which are very permeable in comparison. Joints therefore represent a major source of water ingress into a granite structure.

2.3.3.2 Chemical weathering

Atmospheric pollutants that result in acid deposition on stone surfaces include sulphur dioxide and nitrogen oxides. They become dissolved in water to produce acid damaging to sandstone cement. These pollutants are produced by fuel combustion from industrial, transport and domestic use. Although a little sulphate and nitrate are produced naturally, automotive and industrial emissions represent the most prolific sources (Winkler 1994). The processes by which these pollutants are transferred onto stone surfaces are dry, wet and occult deposition (discussed earlier in Section 2.3.2.2). The dry deposition of atmospheric pollutants occurs close to emission sources. Due to the location of market crosses in Scotland, it is therefore predicted that in most cases industrial emissions should not represent a major agent in the decay of market crosses. However there may be a significant risk of decay posed by the location of market crosses in relation to busy roads.

Sulphur dioxide and nitrogen oxides form a dilute acid solution when dissolved in rainwater. The concentration of the acid is greater when they are deposited on stonework by mist or dew. Acid deposition can consist of a cocktail of acids from various sources, which can act in synergy to cause decay (Smith et al 1988). The relationship between pollution levels and decay rates is still not fully understood. The effects of atmospheric pollutants upon stone decay patterns may be delayed, since there appears to be no direct correlation between current pollution levels and current stone condition (Butlin 1989).

Sulphur-based acids

Sulphate is introduced into the atmosphere as sulphur dioxide by the combustion of fossil fuels, coal and gas. Coal is the greatest offender, containing as much as 8% total sulphur. Large quantities of sulphur dioxide are released through tall smokestacks by caloric powerplants and smelters roasting sulphate ores (Winkler 1994). Other sources for atmospheric sulphur are ocean spray, and in rural areas in the summer some sulphate may also be produced by the oxidation of a small amount of hydrogen sulphide rising from the soil. In addition, there are seasonal fluctuations in sulphate output due to use of heating systems in the home and workplace (Winkler 1994). Sulphur dioxide emissions have decreased by about 40% since peak levels in the 1960's, and power stations now contribute to around 70% of the emissions (DoE 1990).

Sulphate is introduced to the stone by the dry deposition of dust or soot, and to a lesser extent by wet deposition. There is a general presumption that sulphur-based acids are the most damaging pollutants to stonework, particularly to sandstone of a calcite cement (Winkler 1994). Sulphur dioxide and sulphur trioxide form sulphurous and sulphuric acids when combined with water, which can severely attack calcium carbonate stone (Dukes 1972). This can result in the loss of sand grains from stone surfaces washed by rainwater. On unwashed surfaces the acid converts some of the calcium to gypsum, deposited on the surface as a crust. Quartz-based sandstones are very resistant to sulphur-based acids, although they can nonetheless become quite soiled (Honeyborne 1990). A direct correlation has been found between the weathering rate of marble tombstones and the one hundred year mean sulphur dioxide concentration in the USA (Meierding 1993).

Nitrogen oxides

Nitrogen oxides are produced mainly by motor vehicles and, to a lesser extent, by power stations. Motor vehicle exhausts are a major and increasing source of nitrogen oxide levels in urban areas (Butlin 1989; Smith et al 1988). The higher incidence of idling engines in urban areas also leads to less efficient fuel burning. Although cars are now generally more efficient than they have been in the past, the number of cars on the road increases annually. There is a lack of evidence to prove that nitrogen oxides can directly attack masonry surfaces. However, synergistic processes involving nitrogen oxides and sulphur dioxide have been shown to result in accelerated stone decay (Vassilakos & Salta 1993).

2.3.3.3 Physical Weathering

External Attrition

Attrition refers to loss of grains due to the mechanical forces of natural sand-blasting. Opinion varies over the significance of the role of attrition in temperate Europe, and its effect here may be minimal (Honeyborne 1990). Accumulations of gritty dust in the angles of masonry can have a sand-blasting effect when swirled around by wind action. The effect may also occur in coastal areas where wind-blown sand can erode soft stone (Dukes 1972). Furrowed sandstone in coastal regions has often assumed to be so-shaped by attrition, alternatively this effect could be caused by the deposition of sea salts in the stone.

Thermal stresses

Direct solar incidence causes a stone surface to become more heated than the inside and to expand more. At night, these conditions are reversed. Thermal stress is thus created between the surface and mass of the stone on a daily basis. If these movements are restricted then stress is created which can cause fractures. The fluctuations in size are proportional to the dimensions of the stone. Masonry joints can also be opened in this process, allowing particles to settle which can prevent them from closing again properly (Torraca 1988). The stone structure affects its resistance to thermal stress; however, structure can vary throughout the stone and the structure can even change on exposure to weathering (Dukes 1972). Thus the resistance of a stone to thermal stresses can vary over time. As with attrition, the effects of thermal stresses may be less relevant in the climate of Scotland than in more extreme climates.

Frost damage

In transforming to ice, water expands by about 10%. Moisture becomes trapped inside the pores of a stone when surrounding water freezes, and the frozen droplets exert pressure against the pore walls. This can lead to internal stresses and subsequent fracturing of the stone. The frequency of freeze-thaw cycles is more important in frost damage than the duration of exposure to freezing conditions. Pore size is also a key factor. Stones with a fine-pored structure are more vulnerable to frost damage (Honeyborne 1990). Stones with high microporosity are particularly vulnerable as they can hold more moisture due to their greater capillarity powers (Dukes 1972). Stones in the UK may be little affected by frost, and the risk may only apply to projecting features that could become saturated with water on cold nights (Leary 1986; Honeyborne 1990). The exposed elements most at risk could include protrusions such as cornices, and also the bases of buildings where an ingress of ground moisture can be experienced (Hill & David 1995). Frost damage is more commonly observed in limestones than in sandstones.

The signs of frost damage are distinctive. The damage usually takes the form of a wafer-like layer or lens-like piece of stone breaking away from the most exposed surface of the piece of masonry, in the direction of most heat loss (Honeyborne 1990). A less common type of frost damage occurs when the block shatters seemingly in a single action into several pieces, with cracks radiating in many directions, perhaps resulting from multi-directional cooling in the stone. Frost action can also cause the extension of small existing fractures.

Vibrations from traffic

Irregularities in the road surface are thought to be the most significant cause of vibrations from traffic (Torraca 1988). The effect of vibration is more significant upon smaller structures, and cracked masonry may also be susceptible to increased damage due to traffic vibrations. Research has suggested that vibrations from traffic and other frequent types of vibration are not sufficient alone to pose a threat to buildings, and rather should be considered as a factor interplaying with other agents of damage (Torraca 1988).

Salt weathering

Pressure created in stone pores during salt crystallisation can lead to physical weathering. Soluble salts common in stone include carbonates, chlorides, sulphates and nitrates (Winkler 1994). The most common sources of damaging salts relevant to the present research, are from cement mortar, sea-salt, and atmospheric sulphur. Salts can also be lifted into stone from the soil through capillary uptake (Dukes 1972). Sea salt is most abundant in coastal locations; however, sea spray carries chlorides up to a distance of 200 or 300 miles from the coast (Winkler 1994). De-icing salts can be introduced to the stone through splashing and they can cause flaking near ground level. Salts can react with sulphur-based acid pollutants from the atmosphere (Honeyborne 1990). Sometimes salt-contaminated sand has been used for mortars, causing the salt to travel from the sand into the masonry when moisture evaporates near the surface of the stone.

Salt crystallisation is potentially the most damaging agent of stone decay (Smith et al 1988; Honeyborne 1990; Winkler 1994). There are many instance of salt damage to sandstones. The conditions required for salt weathering are more prevalent than damaging episodes of rainfall or freeze-thaw (Smith et al 1988). Salts cause damage to porous stones regardless of their chemical composition and can heighten the effect of other forms of decay. Salts are a prevalent threat in areas even virtually free of atmospheric pollution and frost (Honeyborne 1990). Their effect, perhaps introduced by atmospheric pollution, can continue in stone for many years after the source of the damage has been removed. In granite, salt crystallisation can initiate micro-fractures or cause them to be extended (Urquhart et al 1996b; Rainey & Whalley 1994).

Cryptoflorescence

Cryptoflorescence refers to salt crystallisation within the pores of stone, as opposed to efflorescence, which describes salt crystallisation on a stone surface. The process of cryptoflorescence is not yet fully understood (Honeyborne 1990). It is known that salts can damage stone in three ways (Smith, Whalley and Fassina 1988):

1. Crystallisation pressure - this occurs either as temperatures rise and water is evaporated, or as temperatures drop and solubility decreases. The crystals tend to grow along certain alignments within stone, forcing mineral grains apart and causing disintegration. Spalling may result when salts are concentrated at a particular depth. If crystallisation continues this can result in two other decay mechanisms:
2. Differential thermal expansion - with temperature fluctuations many salts expand and contract at different rates than the surrounding stone.

3. Hydration pressure - some salts hydrate and dehydrate in response to changes in the temperature and atmospheric relative humidity. Pressure can thus be exerted against the pore walls (Winkler 1994).

It can be difficult to tell whether damage has come about by the pure pressure of crystallisation, by hydration pressure, or by thermal expansion of crystals (Winkler 1994). The repeated wetting and drying cycles experienced by surface layers, known as 'fatigue loading', causes crystallisation pressure which can lead to mechanical damage. Decay will be manifested particularly upon the surfaces most exposed to drying, in the form of granulation, crumbling, blistering, scaling or spalling (Winkler 1994; Honeyborne 1990). Salts in combination may synergise to behave more aggressively than in their pure forms (Honeyborne 1990). The amount of pressure exerted against the pore walls depends to some extent upon the salt type, and on the pore size and structure. As with frost damage, fine-pored stones are more vulnerable to crystallisation damage. The rate of decay depends upon the frequency of crystallisation cycles. More rapid evaporation is experienced in high temperatures and on surfaces of greater exposure, and in such situations damage from cryptoflorescence can occur (Dukes 1972). Crystallisation damage can occur in the absence of rain. The humidity in the atmosphere is often sufficient to dissolve the salts, eg in coastal areas where relative humidity is higher, (Honeyborne 1990). The salts will recrystallise when the humidity falls. Cryptoflorescence can occur along with efflorescence.

Efflorescence

Efflorescence describes surface deposits of salt crystals, evident as a whitish substance, which can be revealed vividly against the background of strongly coloured stones (Winkler 1994). The salts are transferred to the stone surface from the inside of the stone during conditions of slower evaporation, ie where moisture feed is large, or where the wind speed is low (Torraca 1988). The slower evaporation allows the salts to be carried in solution to the masonry surface where they recrystallise. Efflorescing salts have the same source as those described above, initially derived through processes of dry, wet or occult deposition, or drawn from the ground by capillary uptake. They can be concentrated in particular sandstone layers. Although unsightly, efflorescence is relatively unharmful since the deposit is on the surface outside of the pore system (Torraca 1988). However it can cause corrosion of the stone surface if it is allowed to remain upon the facade (Dukes 1972). The salts can be removed easily from the surface, washed away by the rain or even washed back into the stone, but they can accumulate quickly again, transferred to the surface from the inside of the stone.

A cocktail of salts might be operating within the pore system of a stone. Thus the distribution of efflorescing salt can exhibit vertical zoning near the base of buildings. Salts can rise up through the stone from ground level by capillary uptake and become deposited according to their solubility. Salts of lower solubility crystallise readily near ground level, while those of greater solubility, like most sulphates, can rise higher within the pore system of a building. The height reached by moisture through capillary rise can be quite substantial, and is evidenced by a white rim of efflorescing salts with a wet outer rim. The wet zones can be formed when salts remain in solution (Winkler 1994). Salts obtained through capillary uptake can recycle back into the ground if they are soluble (Winkler 1994).

2.3.3.4 Biological weathering

Microorganisms can cause biodeterioration, attacking stone both mechanically and chemically. Both sandstone and granite structures can support various algae, lichens, fungi, bacteria, moss and higher plants. Damage caused by some microorganisms includes the production of surface deposits, discolouration, surface pitting, a weakening of the crystal structure, and accelerated weathering. There is evidence that algae, fungi, lichens and mosses extract ions by the production of carbonic, nitric, sulphuric, and other weaker organic acids (Winkler 1994). Due to their entrapment of water they can also contribute to physical weathering through the stress of wetting and drying cycles and by enhancing freeze-thaw cycles. Biological growths can bring about colour changes to a stone surface. As well as being potentially damaging, they can obscure detail, aid the establishment of higher plants, and trap dirt and pollutants leading to greater soiling. The way in which a stone reacts to biological growths depends upon its physical and chemical properties. Lichens and cyanobacteria can easily penetrate sandstones and other porous rocks, which can become colonised several centimetres below the surface. The effects are also determined by the mineral and cement composition of the stone. On granite, little data is available regarding the rate of biodeterioration processes (Bell et al 1994). However, biological soiling in itself does not generally constitute a major threat to stone condition (Urquhart et al 1996a). The main effect produced is the aesthetic alteration caused to facades by colonisation, particularly by algae.

Bacteria

Decay due to bacteria is complex and not yet fully understood (Winkler 1994). No evidence has yet been presented to indicate that bacteria can cause significant stone decay in the way exhibited by such processes as salt crystallisation, frost and air pollution. However, it is possible that they could contribute towards producing chemicals damaging to stone or mortar (Honeyborne 1990). Acids are produced by some autotrophic bacteria, which may attack the stone chemically. Heterotrophic bacteria are less harmful, having only a limited effect upon stone surfaces (Winkler 1994).

Fungi

The hyphae of fungi penetrate the stone surface and can cause some physical disruption of the surface grains. Fungi also produce organic acids for the uptake of mineral elements, from both sandstone and granite. This activity can cause stone decay through dissolution of the minerals. They can also cause colour changes on stone.

Algae

Algae do not produce damaging compounds, but they can encourage the growth of other organisms such as fungi and bacteria which can cause chemical weathering (Urquhart et al 1996a). Additionally algal cells and filaments within the pores can lead to physical stress when combined with wetting-drying and freeze-thaw cycles. Algae can appear more unsightly in areas of high atmospheric pollution due to their tendency to entrap dirt (Urquhart et al 1996a).

Lichens

The basal hyphae layer of lichens attaches itself very closely to surface rock grains. While other species are less penetrative, 'crustaceous' lichens extend their growth several millimetres into the stone and secrete damaging acid. The waste products of lichen undergo a chemical process, which can cause the stone surface to become loose and friable (Urquhart et al 1996a). Crystals can be lost from the stone surface as the growths dies and falls away naturally, or as it is removed (Fry 1985). This damage happens only very gradually, but can be disfiguring on ornamented parts (Torraca 1988). There is no evidence to prove that acids secreted by lichens represent a major damaging factor in stone decay; however, they can change the surface texture and can sometimes be considered unsightly (Dukes 1972). They can also produce a bleaching effect by extracting iron from the stone. Additionally, lichens retain water that could contribute towards other decay mechanisms (Urquhart et al 1996a). The corresponding increased time of wetness can cause mineral alteration in granite. As with sandstone, lichens can also cause the physical disruption of granite minerals. Lichen hyphae, as on sandstone, can penetrate crystals along the line of cleavage, particularly mica. The resulting mineral detachments are aided by the lichen's production of oxalic and other organic acids.

Mosses

Mosses are often relatively harmless but they can disrupt sandstone up to a depth of 1cm or more, and secrete acids which can dissolve the mortar binder. Their presence indicates abnormally wet conditions on stone (Dukes 1972). The moisture retained by mosses could contribute towards other decay mechanisms.

Higher plants

Higher plants can cause mechanical damage to stone structures. Plants with woody stems exert growth pressure, which can widen crevices and mortar joints (Winkler 1994). Their occurrence on a monument also indicates pockets of soil which harbour moisture that may aggravate other decay mechanisms.

2.3.3.5 Bird excrement

It is difficult to assess the extent to which birds contribute to stone decay mechanisms (Winkler 1994). The accumulation of bird droppings and nesting material can result in a compost which is broken down by bacterial action, and releases acids that can be harmful to limestone or calcareous sandstone. Phosphoric and nitric acids released due to large quantities of excrement can etch the stone. The nutrients from bird excrement can encourage algal growth. Some damage can also occasionally be caused by birds pecking at soft stone, perhaps to extract grit or salt (Honeyborne 1990).

2.3.4 Stone decay effects

This section describes the observable stone decay effects that result from the processes discussed above, including their appearance and likely causes. An ability to identify these decay types is necessary to the data collection and analysis of market crosses. Some confusion can potentially be caused by the proliferation of various terms applied in the field of stone decay to describe each decay type. Additionally, differences prevail in the definitions given for decay types by various authors. There is a need for an internationally accepted system of terminology and multilingual glossary (Searls et al 1997). Classification systems are sometimes found to be rather schematic in application. In practice decay can sometimes be seen at a transitional stage between the defined decay types (eg scaling to spalling, or granulation to crumbling). A weathering agent may give rise to a sequence of different decay types on a stone, corresponding to different stages within a decay cycle. For example, granulation can follow after spalling due to chemical changes having produced a weakened sub-surface layer. Fitzner et al (1992) experienced some difficulty in mapping and classifying stone condition, due to the frequency of different weathering forms being exhibited side by side and even on top of one another on individual stones. Apart from the problems of classification, the diagnosis of the damage can also be difficult, as some decay forms could arise due to a number of possible agencies, which can also interplay.

In broad terms, the loss of stone due to decay can occur through granular disaggregation, in which grains or crumbs of stone are shed from the surface, or through planar disaggregation, in which planes of stone become detached from the surface. Sometimes planes of stone detach to reveal a granulating surface beneath them. Another effect of weathering is the formation of crusts on the stone surface. Granite shows many of the same decay types as sandstone. The decay of granite can cause an increase in porosity, primarily through micro-cracking but also through the dissolution of some of the mineral grains (Urquhart et al 1997). A significant decay feature of granite is granulation around the mortar joints (Urquhart et al 1996b). In compiling the classifications shown below, an attempt was made to amass all the terminology used in the literature that describes decay types, and to assimilate some of the terms that duplicate others. A visual description of each decay type is presented below, along with possible reasons for its occurrence.

2.3.4.1 Planar disaggregation

Blistering

Blistering is visible as the swelling and rupturing of a thin surface layer, caused due to salt action beneath the stone surface. The source of the salts can be either atmospheric or derived from the mortar. Blistering occurs particularly at the junction of two different stone types and around joint areas generally. It can be caused due to the migration of salts from the mortar into the adjoining stone. It can also occur when the use of a hard mortar causes moisture to become trapped in the stone around the masonry joints, causing increased salt weathering in these zones. Sometimes granular disaggregation occurs underneath the detached fragments. Blistering can also be caused by the formation of a hardened, expanded, thin crust by deposition of minerals in the surface layer derived from deeper in the stone. This process is known as 'case hardening' and is most common upon calcareous sandstones, although the phenomenon is less seen on Scottish sandstones.

Delamination

Delamination is the shedding of surface scales due to the separation of bedding layers (Winkler 1994). It often occurs upon the surface of face-bedded sandstone and can be aided by the capillary uptake of moisture in the stone.

Flaking

Flakes are small planes of stone which become detached from the surface. Flaking has been distinguished from scaling on the basis of the size of the detaching fragments, whereby flakes are the smaller planes, <5mm (Smith et al 1992). A classification scheme by Fitzner (1992) subdivided flaking into two categories of 'single flakes' and 'multiple flakes'.

Scaling

Scaling can be considered as a larger scale form of flaking. Smith et al (1992) defined scales as >5mm in size.

Spalling

Spalling is otherwise termed as contour scaling or exfoliation. It is the detachment of a surface layer of stone in scales or sheets, following the profile of the surface. The detached layer is of a regular depth and can be up to several mm in thickness. In the initial stages of spalling development the stone surface will sound hollow when tapped. In some cases multiple layers of spalling can be seen on a surface (Fitzner et al 1992). Atmospheric pollution is a factor in spalling (Ashurst & Ashurst 1988;

Honeyborne 1990; Hill & David 1995). The mineralogical changes caused to sandstone by pollution can lead to spalling.

2.3.4.2 Granular disaggregation

Granulation

Granulation refers to the detachment of individual sand grains from the stone surface. In severe cases the grains actively detach to the touch. Granulation can cause the loss of stone to a considerable depth (eg up to a few centimetres). It is linked to the presence of crystallising salts and can occur around the area of masonry joints when water becomes trapped due to the use of a hard cement mortar. Granulation is also described in various sources as sanding, powdering and pulverisation.

Crumbling

Crumbling refers to the detachment of surface grains as larger, compact elements (Fitzner 1995). The crumbs consist of grains still cemented together, and can be up to a few millimetres in diameter. They can detach to the touch and cause a considerable depth of stone loss up to several centimetres. Crumbling is another form of decay linked to salt weathering.

Differential weathering

Differential weathering is the selective erosion of sandstone layers in masonry. The tendency for sandstone layers to vary in composition can create more inwardly weathered furrows, where the softer beds have eroded more quickly than the harder layers. The loss of stone inward from the surrounding surface can proceed to a significant depth, eg up to several centimetres or more.

Pitting

Pitting occurs when small pockets of a different material are eroded more readily than the harder surroundings. This can be caused by the selective solution of softer pockets of mineral matter, particularly carbonates, or due to the selective erosion of inclusions of clay clasts or pebbles (Fitzner 1992). The pits vary in size from stone to stone, from a few millimetres to two or three centimetres in diameter. They sometimes exhibit a dense distribution, producing a pock-marked appearance on the surface. Pitting is common, for example, on sandstones from the Elgin area in Moray.

Honeycomb weathering

This weathering form exhibits a distinctive 'honeycomb' appearance on the surface of stonework, where individual cavities can be up to several centimetres deep and wide. In the mature stages, smaller cavities can merge to form larger ones. It was formerly believed that honeycomb weathering was the result of mechanical erosion, caused by natural sand-blasting. This explanation is now regarded as being too simplistic. Subsequently, the cause was thought to be chemical weathering, and the role of salt crystallisation was postulated (Torraca 1988). Honeycomb weathering is associated with the presence of soluble salts and is most common in coastal locations. The salt responsible for this decay could be sodium chloride, which is found in coastal and arid environments. In siliceous sandstones the decay could be due to increased quartz dissolution rather than the result of pressure exerted by salt crystallisation (Young 1987). Increased exposure to wind and direct solar incidence are also factors linked to honeycomb weathering. As such, honeycombs could develop due to the uneven deposition of layers of silica beneath the stone surface, attracted by the sun and drying winds, and forming a hard layer. These accumulations could result in a differentially weathered surface, developing into honeycombs. Considerable amounts of salts become concentrated underneath these gradually eroding cavities, protected from washing rain (Winkler 1994). Alternative terms for honeycomb weathering are alveolar weathering and cavernous weathering. 'Caverns' is used as a descriptive term for larger forms of honeycombs. Some writers distinguish between honeycombing and cavernous weathering, suggesting that different mechanisms are involved (Smith et al 1992).

Dissolution

Dissolution is manifested as a porous, spongy-textured masonry surface. This effect can occur when the sandstone cementing material becomes dissolved.

2.3.4.3 Encrustation

Gypsum crust formed on the stone surface has a framboid texture and absorbs particulate soiling to produce a blackened appearance. Atmospheric smoke particles of soot and dust, as well as organic particles (plant remains, pollen, fungi, bacteria) contribute to producing the black pigmentation. The crust commonly occurs on the surface of calcareous sandstone, since it is formed from calcite in the presence of atmospheric sulphate (Winkler 1994). However, gypsum crust can also form when sulphate reacts with the calcium in lime or cement mortar, therefore crusts can also be found on buildings constructed from various stone types. The gypsum crystallises on the surface as water evaporates, and particles are incorporated from the air. The distribution of gypsum crust on a building is dictated by the architectural morphology, since it develops upon parts of the masonry sheltered from rainwash. Gypsum can be washed away by run-off on more exposed masonry parts. Airflow around architectural detail may also determine the distribution of such crusts upon a building, thus crusts upon sculptured parts can be quite thick (Whalley et al 1992).

Black crusts are disfiguring and may also cause damage to the stone when they break away from the surface, removing layers of stone material (Honeyborne 1990). The gypsum layer expands and contracts with temperature fluctuations, creating stresses that cause it to break away. It was formerly believed that such crusts were impermeable and could even protect the underlying stone from further decay, but recent research refutes this and it is now known that moisture can indeed penetrate the crust with damaging results (Smith et al 1988). Salt crystallisation can cause volume expansion behind the crust, visible as blistering. Granulation, flaking and scaling often occur on sandstone in association with crusts. The crust itself may not be the cause of such decay, rather salt weathering may be to blame. On granite, the extent to which crusts might be damaging is currently unknown (Urquhart et al 1996b).

2.3.4.4 Fractures

Fissures

Fissures are cracks visible in the stone, which can be either parallel to the bedding layers or independent of them. They can be the result of separation of the bedding layers if seen in section, or could be caused by freeze-thaw cycles, or due to settling where they run through several stones (Hill & David 1995). Alternatively, fissuring can occur due to the oxidation and expansion of an iron attachment bedded in the stone. Fissures can harbour moisture, which could contribute to other decay types.

Mechanical damage

Mechanical damage refers to the breakage of stone or the loss of compact stone fragments from the stone edges, usually due to an episode of impact. Freeze-thaw cycles are another mechanism that could cause the loss of stone fragments due to shattering. Other forms of mechanical damage could include inscribed graffiti or other wear due to human use.

2.3.5 The effect of factors of construction and design

2.3.5.1 Dowels

Dowels are straight fastenings, used internally to thread narrow pieces of masonry together to strengthen the mortared joint. In market crosses they are used to join sections of the shafts, and to affix the capital and finial to the top of the shaft. Historically, wood and iron have been used for this. Wood is unsatisfactory, while iron can cause damage to the stone if it becomes exposed to air and expands through oxidation. Currently stainless steel or manganese bronze are used as material for dowels, since they are thought to be virtually incorrodible. However, some market crosses still have iron dowels in their interior. These were usually coated with lead to curb their corrosion. The corrosion of internal iron elements takes a long time because access of water and oxygen to the metal surface is very slow. The destruction accelerates once cracks form during the expansion process as more moisture and oxygen reach the iron (Torraca 1988). Large spalls on the stone face or fissures may be due to such an expansion of iron dowels. There is also a potential problem of discolouring from the rust. The adverse effects of iron parts upon stonework have been known for many hundreds of years, although they have often been ignored in construction. The ancient Greeks coated iron pieces with lead during the construction of the Acropolis in the fifth century BC. Fifteenth century writers realised that iron cramps should be placed beyond the reaches of rainwater, and internal iron parts were run with lead in the eighteenth century (Mulvin and Lewis 1994). The technique of wrapping the iron piece in lead sheet or painting it with bitumen, and trying to ensure that the iron is not exposed, are measures that have been adopted to lessen the problem. Lead seems to stand the test of time and allows for thermal movement of the enclosed ferrous metalwork (Hill & David 1995). However, bitumen has been found to reduce the effectiveness of the bond of the metal to the stone (Honeyborne 1990). Mortar is an acceptable material for fixing dowels, but it can be tricky to fill in the void completely. Ideally dowels should be placed in the centre of the stone. Theoretically, iron and steel cramps or dowels set in a thick layer of mortar should not rust if the mortar can maintain its alkalinity, and is free from sodium chloride. However, mortars loose this alkalinity due to contact with atmospheric carbon dioxide. Mortars can even be made acidic if they are contacted by atmospheric sulphur-based acids, which can in turn increase the rate of the metal corrosion.

2.3.5.2 Mortar

From at least Roman times, sand and lime were used together as mortar. In the mid 1800's Portland cement was invented and its use overtook that of lime mortar. However, since the 1970's there has been a renewed increase in the use of lime mortar due to increasing recognition of the suitability of its use in the conservation of historical buildings and monuments. Historic Scotland now promotes the use of lime mortar for repointing historic buildings. The use of pure Portland cement mortar can cause damage to historic buildings. Solution can migrate from Portland cement into neighbouring porous materials and can cause dark spots on some sandstones due to alkali action. Portland cement is also hard and impermeable and this can cause water to accumulate in porous sandstone above the joints, leading to accelerated decay in the zones of waterlogged sandstone. Soluble salts are also prevented from evaporating through the joints, and can accumulate similarly in the stone enhancing decay. From the late 1800's, some market crosses may have been built or repointed using Portland cement. Mortar joints can affect the routes of moisture travel through masonry. Mortar must be permeable enough to encourage evaporation of water in the wall through the joints rather than through the face of the stone. Porous mortar can allow the transfer of water from one masonry block to the next, functioning rather like a pump (Winkler 1994). It is the sand in lime mortar that increases the permeability; however, the sand must be washed prior to their use in mortar to remove harmful salts. A balance should be sought between a hard, dense mortar which inhibits evaporation and movement, and a soft one which could be readily washed out and could introduce unequal stresses on the stonework (Hill & David 1995).

2.3.5.3 Juxtaposition of different stone types

Some stone types can be incompatible with each other when juxtaposed. For example, rainwash from limestone down onto sandstone can cause decay to the sandstone (Hill & David 1995). However, it is not predicted that limestone has been used in such a way in the construction of Scottish market crosses. A more likely scenario is where a calcareous sandstone has been inserted as a replacement part in structures made of siliceous sandstone. In such a case the siliceous sandstone could experience contamination by soluble salts, contributing towards its decay (Leary 1986). On granite increased decay can occur when it is situated beneath another stone type in a facade, particularly if the above stone is more porous or calcareous, eg limestone (Urquhart et al 1997).

2.3.5.4 Carved features

The greater the surface-to-volume ratio, the more exposed a stone will be to decay. As such, stonework with more intricate ornamentation or with high relief forms, or simply at corners of structures could experience greater erosion in comparison to flat, plain facades. Sculptured elements, such as finials, are particularly at risk in this sense. However, allowances are sometimes made for this by the selection of a suitably durable stone type for more highly carved pieces.

Due to the significant role played by water in the decay of stonework, a structure needs to have adequate provision for water drainage. Certain parts of a monument or building are more exposed to water, in their exposure to direct rainfall, to run-off and to groundwater. An understanding of the way in which water can move across the surfaces of monuments will be important in gaining an insight into the cause of the weathering patterns observed on the market crosses. Each cross has a different design; however, many examples have drip courses which aid the drainage of rainwater away from the lower stonework. Certain of the more architecturally complex market crosses have other features to prevent the accumulation of water behind their parapet (eg Turriff cross has drainage holes running through parts of the stonework and the tower-based crosses all have sculpted waterspouts). It is important to maintain the functioning of rainwater goods and to repoint masonry joints when required in order to prevent increased water ingress to the stonework.

2.3.5.5 Stone selection and working

Ideally masonry materials should be suited to their function. For example, more durable stone should be used for key structural parts, functional mouldings (which have to deal with more water), and for exposed masonry parts that have to incur harsher micro-climates. Stone selected for use in coastal locations needs to have greater weathering resistant properties than that used inland (Honeyborne 1990). Another set of factors relevant to the weathering resistance of a structure relates to quality of workmanship. Defects in the material selection or the 'bruising' of a stone during dressing or carving, can have damaging consequences (Honeyborne 1990).

2.3.5.6 Alignment of bedded sandstone masonry

The alignment of sandstone masonry relative to the ground is governed by some time-honoured fundamentals in construction. Sandstone should be laid down along the lines of its bedding planes or, in certain circumstances, it can be laid edge bedded (ie like the leaves of a book standing on a shelf, with the beds oriented on end and running back into the wall). Edge bedding can be used for coping, cornices, sills, string courses and stone ridges. Face bedding, where the bedding is aligned with the facade, can lead to delamination. These fundamentals are rarely breached; however, there may be some such damage resulting in cross shafts and slabs due to the vertical alignment of the bedding for these parts.

2.3.6 Summary of stone weathering

Most market crosses are built from sandstone, which is a stone type relatively vulnerable to weathering. Stone properties affect the resistance to decay. The pore size and structure affect moisture transfer and the decay that can occur due to salt crystallisation and frost damage. Sandstone contains a natural cementing agent that varies in composition. Calcareous cements are more vulnerable to chemical weathering, while argillaceous sandstones with their clay-based cement can be vulnerable to decay through mere wetting and drying. Stone can be soiled by biological growths and by particulates deposited on the surface due to atmospheric pollution. Soiling is not a major factor in stone decay, although it could be considered to be aesthetically damaging. However atmospheric pollutants deposited on stone can generate chemical weathering, particularly sulphur-based acids and nitrogen oxides. Moisture and salts are widely considered to be the prime agents of stone decay. Climate and micro-climate are thus important in determining the amount of moisture that is dealt to a stone surface, and the degree of its evaporation. Such wetting and drying cycles enable salt crystallisation, which creates damaging pressure in the stone pores. A number of terms exist with which to classify stone decay type. Broadly, decay can be divided into the categories of granular disaggregation, planar disaggregation and fractures. Factors of the monument design and construction can also influence damage patterns. These include architectural characteristics, mortar composition, dowel material, juxtaposition of different stone types and factors of workmanship.

2.4 Stone Conservation

Developments in stone conservation methods and materials are known from historical records. Reference was made in the fifteenth and eighteenth centuries to the use of cramps, and nineteenth century references indicate an awareness of stone decay due to rainwater and its solvent action (Mulvin & Lewis 1994). There are recorded examples of nineteenth century attempts to hinder erosive action through use of protective coatings for buildings, eg linseed oil. Interest in urban stone decay and conservation treatment has increased globally since the 1970's, partly because of accelerating erosion in spite of the introduction of 'clean air' acts, and also due to popular debate about 'acid rain' (Smith et al 1988). A broad scientific base is now being utilised along with the traditional geosciences, including chemical, biological and material sciences. However, recent use of accelerated, laboratory-based modelling of weathering mechanisms to test the effect of conservation materials may not adequately reflect the long-term processes (Smith et al 1988). Other research has aimed to evaluate the societal and economic considerations in stone conservation, to explore whether these could have a valid role along with technological options in policy decisions. However, these economic evaluation methods may be less appropriate when applied to the built heritage. Further research is required into methods for describing stone deterioration and prediction of the future rate of deterioration, and on methods to quantify the effects of environmental pollution and the extent of damage due to this (Baer & Snethlage 1997). The present research aims to address these issues in relation to market crosses. Additionally, more informed conservation treatment programmes and a reduction in environmental pollution would help monument preservation. However an improved framework for the management and planning of conservation treatment is also needed (Baer & Snethlage 1997). Greater quality control of conservation treatments and regularity of monument maintenance are a further requirement (Ashurst & Ashurst 1988).

2.4.1 Conservation charters

Many national, international and thematic charters have been produced since the 1930's, which aim to set out broad principles and clarify definitions in the field of built heritage conservation. They tackle questions of why and how we should conserve our heritage. The question of exactly *what* we should select to conserve tends to be left largely up to individual nations, although the age of a historic structure is a universal characteristic underlying the selection. Evaluating the art-historical, cultural, social and economic contributions that can be made by individual buildings and monuments is an area that is less easily defined internationally. During the course of the twentieth century there has been a shift in the perceived value and definition of heritage. The perceived benefits of protection and conservation are now broader, more fundamental, and more populist (Bell 1997). UNESCO, ICOMOS and the Council of Europe have been the foremost producers of built heritage conservation Charters. Bell (1997) offered a comprehensive survey and synthesis of conservation charters. The general historical development of the Charters can be summarised as follows. The first was the *Athens Charter* (International Office of Museums 1931) which discussed international issues of conservation, and particularly the ethics of work on protected sites and structures. In the 1950's UNESCO passed a series of conventions with the aim of improving protection to the built heritage as well as other types of other cultural property, particularly those of worldwide significance. The *Venice Charter* (ICOMOS) followed in 1964 and is the best known conservation Charter with regard to the built heritage. It provided a strong framework of guidance for historic building conservation. Its production led to the founding of ICOMOS in 1965, an international body concerned with aspects of conserving, protecting and promoting the built heritage. ICOMOS have since sought to develop the set of principles first laid out in The *Venice Charter.* The Council of Europe Charter for Architectural Heritage (1975) asserted the emotional and social values of the built environment. It explored the value and relevance of the past to contemporary life and the positive social effects that can be generated by maintaining historic buildings and monuments. As a reaction to the increasing value placed upon environmental diversity and cultural traditions, a number of national Charters were then produced around the 1980's, beginning with the Australian *Burra Charter* (ICOMOS Australia 1979). Further Charters produced during the 1980's tended to focus upon specific types of sites, monuments and landscapes. They sought to assert the value of these particular types, and to produce principles that were more tailored to them.

With regard to the particular concerns of the present research, all of the charters agreed that conservation should be minimal, non-destructive as far as possible and reversible. They also recommended that conservation work should stand out as representing work of a later date than that of the original fabric, at least to the trained eye (Bell 1997). Additionally, many of the charters advocated that protection should incorporate a continuing programme of maintenance, and that all stages of the work of intervention should be accurately documented in the form of reports, illustrated with drawings and photographs (eg *Venice Charter* 1964, *Burra Charter* 1979). Furthermore, they advised that these records should be placed in public archives accessible to researchers. The *Venice Charter* recommended preservation of the traditional setting of historic structures. Regarding pollution, UNESCO recommended banning polluting industries in proximity to protected sites, and taking measures to reduce the damaging effects of noise, shocks and vibrations created by vehicles and machines (UNESCO 1962 and 1976). It was recommended that research into the effects of pollution and the means to reduce or eradicate it should be supported (eg *Athens Charter* 1931), and that anti-pollution policies should take account of conservation needs (*Council of Europe* 1985). The problems created by increasing automotive transport have been considered by UNESCO (1962 and 1976) and ICOMOS (1987). They recommended that significant buildings and monuments should be protected by controlling traffic in historic town centres, and that parking areas should be designed which do not disturb the built heritage or degrade the environment.

A conservation charter pertaining to the built heritage of Scotland has also recently been published (Historic Scotland 2000a). This draws upon existing international charters, but has been designed with the needs of Scotland's heritage in mind. It contains a number of broad principles representative of the Government's policy towards conservation of the built heritage, intended to inform those responsible for its care. Of relevance to work upon monuments such as market crosses, it recommends that:

- Efforts should be made to promote the built heritage for the enjoyment and education of the public (Article 4);
- Conservation ought to be undertaken within the framework of a conservation plan which could guide the proposed action (Article 5.3);
- Records should be made of the conserved monument before, during and after the work and the records should be stored in an accessible archive (Article 5.3);
- Conservation should seek to retain or enhance the setting of the monument (Article 5.8);
- Conservation programmes should include arrangements for the regular monitoring and maintenance of the monument (Article 5.10). This Article is particularly important considering that the long-terms effectiveness of some modern conservation treatments is not yet fully understood.

2.4.2 Conservation bodies

Historic Scotland has a statutory role in advising and undertaking conservation of the built heritage, and promoting historical monuments as a resource to the public. Most market crosses are Listed Buildings, and it is a statutory requirement that any proposal for work to a Listed Building by a Local Authority or other owner must first be submitted to Historic Scotland for approval. It is often the case that Historic Scotland is also further involved in undertaking the actual conservation treatments. Sometimes monuments can be treated in situ; however, in some cases it is necessary to remove part of a monument to the Conservation Laboratory to undertake the work. It is a policy of Historic Scotland that intervention work to historic structures should aim to conserve, rather than to restore. Replacement parts are made only as a last resort, if an original part is so degraded as to be beyond conservation (Gordon, Historic Scotland 1996, pers comm). Some of the methods and philosophy for masonry repair by Historic Scotland are described below in Section 2.4.5, where they pertain to specific types of conservation work. Historic Scotland has also recently launched a programme to record Scotland's carved stone monuments, described later in Section 2.5.3.1.

Other non-statutory organisations have recently been established to provide advice and a forum for discussion on Scotland's built heritage. Of potential significance to the conservation of market crosses, the Historic Burghs Association of Scotland (HBAS) was established in 1995 to foster partnership between those involved in the planning and management of historic urban centres. They aim to encourage a multi-disciplinary approach in promoting and preserving the built heritage of Scottish burghs and to encourage high quality conservation. Another organisation of potential relevance to market crosses is The National Committee on Carved Stones in Scotland (NCCSS), founded in the mid-1990's. They are an advisory forum with the aim of co-ordinating local and national bodies, promoting the need to record and preserve carved stone monuments and raising awareness about unsuitable conservation measures.

2.4.3 Protective designations

Listed Buildings

The practice of selecting buildings for Listing began in the late 1930's, and the designation was first made statutory between 1969-71. A resurvey of Scottish buildings commenced in 1978 and is ongoing. The lists are intended to inform the work of owners, planners, conservators, local historians and academics. They can also act in guiding grant-awarding bodies and can help preservation societies to prioritise. Any work planned to a Listed Building must be referred to Historic Scotland for approval. Three main categories are used in Listing, defined as follows:

- Category A: *"Buildings of national or international importance, either architectural or historic, or fine little-altered examples of some particular period, style or building type"*. 22% of Scottish market crosses are Category A Listed Buildings.
- Category B: *"Buildings of regional or more than local importance, or major examples of some period, style or building type which may have been somewhat altered"*. 37% of Scottish market crosses are Category B Listed Buildings.
- Category C(S): *"Buildings of local importance, lesser examples of any period, style or building type, whether as originally constructed or as the result of subsequent alteration..."*. This group also now includes the best of the monuments and buildings that were formerly Listed as in the non-statutory Category C. 6% of Scottish market crosses are Category C or C(S) Listed Buildings.

A further 35% of the crosses are not designated as Listed Buildings. A group category may additionally be assigned where the value of a building or monument is perceived to be enhanced by its functional relation to other adjacent historic structures, eg as part of a townscape or other original planned layout. Four of the market crosses have been assigned a group category. The 'A for Group' category will continue to play a role; however, the 'B for Group' and 'C for Group' categories are being phased out and the affected monuments are being re-categorised. Currently there are over 43,000 Listed Buildings in Scotland (information from Historic Scotland Web site, 2000).

Scheduled Ancient Monuments

A lower proportion of Scottish market crosses are Scheduled Ancient Monuments (34%). Scheduling provides another, more restrictive, statutory, protective designation. Indeed, some market crosses are both Listed Buildings *and* Scheduled Ancient Monuments; however, in these cases the Scheduled Ancient Monument legislation takes precedence. Ancient monuments are Scheduled when they are considered to be of national importance, and the designation usually applies to monuments which have become redundant in terms of their original use. The site of a monument is also important to the criteria in Scheduling. Therefore if a market cross has been moved from its original site then this impairs its significance with regard to Scheduling. The unique character of a monument and the existence of associated historical documentary evidence are other factors that add value to the case for its Scheduling. Around 6,300 monuments are Scheduled in Scotland. Any work planned to such monuments must receive scheduled monument consent through Historic Scotland.

2.4.4 Methods for monitoring and evaluation

2.4.4.1 Monitoring stone condition and treatments

It is widely thought that historical masonry should be subject to regular and systematic examination, such that the practice of intervention is timely and not merely a remedial response to an event of damage (eg Searls et al 1997). Although conservation resources are sometimes limited, regular maintenance should aim to ensure that all rainwater goods are kept functional, joints are adequately pointed, vegetation is rooted out and ferrous metal painted or replaced with non-corrosive materials. Conservation charters generally advocate minimal conservation; however, this should be balanced against the need for 'maximum prevention' (Searls et al 1997). The ability to differentiate between slow decay, which could continue without visible effects for several more years, and rapid decay needing immediate attention is important (Bristow 1990). Often slow decay could be allowed to continue for several more years before repair is actually necessary. Misjudgement by inexperienced persons has sometimes resulted in rushed and unsuitable conservation measures (Bristow 1990). Intervention could also seek to deal with relevant environmental factors that pose a risk, eg through legislation on pollution or traffic schemes. There is additionally a need to consider the effect of successive treatments upon monuments, since conservation measures have a lifespan.

Searls et al (1997) suggested a systematic approach to recording and monitoring the condition of historic masonry. Preventative measures should begin with the research of archived records for details on the monument, including its condition and intervention. Field survey should then be undertaken to collect data of the monument condition and its environment. Techniques used should preferably be non-destructive, although it may be possible to take a small sample (eg of soiling, crust or flaked stone) for laboratory analysis. Larger samples can be obtained and examined where parts of the monument have to be replaced or removed for repair. The use of photography, photogrammetry, CAD drawings, video, sketches and written notes could all provide useful supporting evidence. Quantitative and consistent classification systems are important, since different individuals will be involved in the recording in future periods. Expert systems could be useful, which pose questions appropriate to the observed conditions. Accurate three-dimensional measurements of monuments ought to be taken. Based upon the gathered data, an attempt should then be made to diagnose the cause of damage, to propose intervention objectives and treatments, and to plan the future analysis and measurements required. Treatment options should be thoroughly examined in relation to the archived and field data, the historical importance of the structure, its future use and the prevailing conservation philosophy. A monitoring programme should also be designed at this stage. Intervention may then proceed if necessary. Any new data that comes to light during intervention work should force a reconsideration of the suitability of the treatment. The treatment should be overseen by a quality control mechanism. Monitoring of the effectiveness of the treatment and continued routine evaluation of the monument should follow. If results are unsatisfactory, a new diagnosis should be undertaken. Experienced personnel are best suited to carry out annual inspection (Searls et al 1997). This is an ideal system of management; however, resources may dictate that it is only possible to implement such a programme for certain monuments of high-profile or high-risk status.

2.4.4.2 Conservation databases

A number of databases have been developed with the aim of enabling more consistent interpretation and diagnosis of stone decay, and providing a framework to guide stone conservation practice. The development of hand-held computers for use in the field has now opened up possibilities for even more efficient logging and downloading of data. Expert systems can be useful for non-specialists attempting to classify and diagnose stone decay, and seeking conservation solutions. Such systems can also include photographs to help in the identification of decay types. For example, the *Masonry Damage Diagnostic System* is an electronic system developed for the diagnosis of damage to historical brick structures (Van Hees et al 1996; Van Balen 1997). This resource was designed to interpret decay with regard to environmental factors, by way of a reasoned, interactive approach, tailoring the questions to the user's responses. The database was aimed at end-users including local and national authorities involved in the care of the built heritage, as well as universities and restoration architects. Other databases that have been set-up contain records pertaining to stone condition and conservation treatments at specific monuments. For example, the *MONUFAKT* database was established to disseminate information on conservation methods and effects, and aimed to bridge the gap between research and practice (Stephan 1996). The records include information about each monument's history, architecture, care, stone properties, condition and environment, along with details of conservation methods and materials. The need for detailed data regarding the long-term effects of treatments was recognised, and the importance of monitoring the effects of conservation and of recording the failures was emphasised. A further resource for those involved in the care and conservation of monuments is the *Conservation Information Network* database (Canadian Heritage Information Network). This recent initiative is the result of an international collaboration, designed to enable greater dissemination of conservation information, including that for historic stone monuments. This provides access to information about available conservation materials, their application and their suppliers, and facilitates information exchange between individuals in the profession.

2.4.4.3 Economic valuation

Methods to evaluate elements of the built heritage could help in allocating scarce conservation resources. The societal and economic considerations in stone conservation have been evaluated by some researchers, in order to explore their potential contribution to policy decisions. Economic valuation is non-elitist and aims to establish what society prefers to invest in (Mohr & Schmidt 1997). Cost-benefit analyses and contingent valuation are such methods that have been applied to the field of monument conservation with varied success.

Cost-benefit analyses consider the social and economic factors involved in conservation, and seek to measure the overall benefit and costs that an environmental change will cause or accrue. These valuations previously made use of the avoided maintenance cost to indicate the benefits to monuments of reduced atmospheric pollution. However, in some cases maintenance and repair work cannot fully protect against degradation, and intervention can sometimes even generate other types of degradation in monuments. In addition, the value of a monument may often be perceived to arise from its degree of originality, therefore full replacement or replication would not restore the full benefit to the public (Morey et al 1997). Historical monuments and their maintenance cannot easily be valued in absolute monetary terms. Additionally, the value to tourism can be difficult to quantify, particularly when a monument forms part of a critical mass of heritage and cultural assets in an area. The evaluation of a monument to the public must consider both use and non-use values. Cost-benefit analysis was found to be unsuitable in investigating the potential role of monument protection interests within atmospheric pollution legislation (Livingston 1997b). It was recommended that monuments could instead be treated as a natural resource or an endangered species, since they are similar in having nonmarket values.

Contingent valuation sprang from cost-benefit analysis in the early 1970's. This method attempts to place a value upon an environmental good where no market currently exists. Many historic monuments are unmarketable. Attempts have been made to quantify non-use values, such as appreciation of a famous monument that the survey respondent might never visit, or the desire to preserve something for the benefit of future generations (Mohr & Schmidt 1997). Morey et al (1997) identified the different levels of use from which the 'value' of a cultural or historic object might be derived:

- Direct use, eg visiting monuments
- Indirect use, eg viewing pictures of sculpture
- Passive use, eg appreciating that cultural objects could be effective in conveying history to current and future generations. Passive use is potentially more important than direct use (Morey et al 1997).

The contingent valuation approach can be applied to measuring non-use values, if surveys are carefully designed (Mohr & Schmidt 1997). One method of contingent valuation is 'willingness to pay', in which attempts are made to quantify the value placed upon monuments by the surveyed public. To carry out such a study, a critical threshold needs to be defined beyond which continuing degradation would not be acceptable. Contingent valuation can make this a subjective decision-making process based upon aesthetics, and virtual computer graphics can be applied in this area. However, 'willingness to pay' surveys can be flawed, in that respondents could over-value a monument if the question is hypothetical with no real pay transaction. Additionally, such questions often raise ethical objections, because it can be perceived as inappropriate to value such objects in financial terms (Morey et al 1997).

2.4.5 Stone conservation materials and methods

The following sub-sections describe some of the main types of conservation treatments developed to remove or counter masonry soiling and decay. The circumstances of their application, their effects and the prevailing philosophy with regard to their use are also outlined. The effect of such treatments on the sampled market crosses is discussed in detail later in the thesis (Section 4.5.2).

2.4.5.1 Stone cleaning

A certain degree of soiling upon a monument can be considered acceptable and can even help to convey its historical character (Morey et al 1997). Therefore soiling need not necessarily be seen by conservators as a disfiguring feature. Indeed, stone cleaning methods which use either chemical or physical methods are damaging to masonry, and in some cases the damage has been exacerbated by unskilled operatives (Andrew et al 1994). Additionally, the long-terms effects of stone cleaning have not yet been fully investigated. Therefore, stone cleaning of historical buildings and monuments is currently not recommended. An exception could perhaps be made in rare cases where the soiling is predicted to cause severe stone decay (eg the substantial detachment of gypsum crust along with underlying layers). Gentle water washing can reduce algal growth and superficial loose particles; however, this will have only a limited effect upon particulate soiling. Among market crosses there is one recorded instance of stone cleaning. Edinburgh High Street cross has been cleaned using chemical methods with damaging results (see later Section 4.5.2.5).

2.4.5.2 Removal of weeds

As with particulate soiling, a little biological growth could be considered to visually enhance the historical character of a monument, and might thus be perceived as aesthetically pleasing. However, it is generally accepted that any 'woody' plants are physically damaging to structures, and pockets of soil which support higher plants can also retain moisture which could aggravate other decay types. The policy exercised by Historic Scotland is that growths need only be removed if they are causing damage. Generally, more reticence is now being exercised by Historic Scotland and English Heritage with regard to removing 'weeds' from historical monuments. Some of the species that colonise monuments are under threat (eg certain lichens and higher plants). While some common species can grow within a few years, certain other species on vertical surfaces take up to 80 years to grow due to their soil requirements. These may not be removed unless they are seen to be causing actual harm (Ross, Historic Scotland 1999, pers comm).

2.4.5.3 Biocides

Biocides are applied as washes or incorporated into other coatings such as paints, and can be used to remove lichen, algae and other microorganisms from stone surfaces. The long-term effects of using biocides are not yet fully understood. Their effectiveness and lifespan vary, depending upon the biocide composition and the stone characteristics (Urquhart et al 1995). Alkaline treatments have the disadvantage that they can form soluble salts or cause colour changes on the surface (Torraca 1988). Biocides tend to act only as a temporary measure to slow biological colonisation, and microorganisms unaffected by the treatment can quickly recolonise the stone. The short life of many biocides results in the need for regular application (Urquhart et al 1996a). They can be effective against algae for up to about two years; however, they are effective for longer against lichen due to its slower growth rate. Lichen on historic masonry should only be treated with biocide if, during removal from a test patch, the lichen is pulling away surface grains. However, lichen only rarely causes pitting and decay (eg at Culzean Castle), and lichens and mosses are sometimes protected in individual building conservation strategy. Biocides are not used much in conservation by Historic Scotland (Ross 1999, pers comm). They should be applied to historical monuments only as a last resort, in response to a hazard rather than for cosmetic reasons, eg when algal growth is considered to be a safety hazard upon steps. Attempts could be made in the first instance to remove algae with a brush and water. Some limited success has also been achieved through the use of UV radiation to expel some types of algae and associated bacteria from stone surfaces (Fry 1985; Winkler 1994). However, there are no recorded instances of the use of these or of biocides on Scottish market crosses.

2.4.5.4 Repointing

Repointing may be necessary in order to treat masonry joints from which mortar has eroded, or if pointing in the past has been badly applied, or in certain cases where later repointing is not in keeping with the original building. Masonry joints can also become weakened when plants take root in the joints, drawing out lime from the mortar. Routine repointing work tends to be the responsibility of the Local Authorities unless a monument or building is in the care of Historic Scotland. Hard, Portland cement is not suitable as a mortar or as a repair material applied to historic monuments. Its impermeable properties can cause water to become trapped in the adjoining stone, which can aggravate other decay mechanisms. Additionally, in the setting process soluble salts can migrate from Portland cement into the adjacent stone, which could result in subsequent decay due to salt crystallisation processes in the stone pores (Leslie & Gibbons 1999). In contrast, lime-based mortars are permeable and do not produce soluble salts during setting, therefore their use for repair is now favoured. Indeed, they are the traditional material for pointing and they allow the free drainage of moisture through their porous system, a factor important in combating masonry decay. A recent resurgence of lime production in Scotland has therefore been encouraged by Historic Scotland for use in repointing historical stonework.

Mortar material ought to be of equal hardness to, or slightly softer than, the surrounding stone such that they weather at roughly the same rate. Through time, mortar breaks down and becomes loose and sandy. The degraded material needs to be raked out, to a depth of at least 5cm, in order that the new mortar can grip the stones. Portland cement is normally used in small quantities in the 'tamping' mortar, which is packed in to the deeper part of the joints in order to enhance the strength of the repair. Lime mortar with a sand aggregate should be used for the external repointing. The pointing must be finished such that it is slightly recessed, allowing water to run off the edge of each stone. Techniques during the setting process, such as stippling, brushing or washing of the mortar can be used to produce a more mellow, traditional-looking effect. The same tamping and pointing method can also be applied in filling stone fractures. In the past, hollows in the stone due to former attachments on both horizontal and vertical masonry surfaces have also been filled for cosmetic reasons; however, this action is not strictly necessary. Vacant joints in the steps of market crosses may not necessarily represent a problem provided that water can still drain away freely from them. However, there is the possibility that they could affect the overall stability or could leave the monument vulnerable to mechanical damage, eg through being knocked by a passing vehicle. Additionally vacant joints could be vulnerable to frost damage. They should therefore be repointed when the opportunity arises (Ross, Historic Scotland 1999, pers comm). Joints at higher elevations should also be repointed due to the risk of instability and since more stone is affected during the drainage of water down through the joints.

2.4.5.5 Sealers and water repellents

The idea behind sealers is to provide an impervious skin, preventing moisture access to the stone interior. However, pressure can develop behind such a sealed surface by moisture trying to escape, pulled towards the surface by temperature differentials, and flaking can occur. In past centuries linseed oil and paraffin were used as sealents. These tended to generate more problems than they solved, producing effects such as embrittlement, peeling, yellowing and blotchiness, due to attack by ultraviolet radiation. (Winkler 1994). Records indicate that it was a custom before 1900 to smear animal fat on the stone surface of the market cross at Fowlis Wester stone once every year (Jackson 1989). In this case, the extent to which the sealant has aided or hindered the decay of the stone is unclear, since the stone is centuries old and has experienced severe delamination. Winkler (1994) advised against the use of sealers on sandstone, due to the risk of scaling and bursting.

Water repellents allow some water vapour ingress into the stone, since they coat each grain with a thin layer. There are many variables in the stone properties and in the variety of chemicals that can be used. However, the use of water repellents is contentious since the long-term effects are not known and they tend to be recommended only as a last resort. They can hinder the outlet of moisture derived from capillaries and masonry joints, and can cause a darkening of the surface colour. There are no recorded instances of the application of water repellents on market crosses in Scotland.

2.4.5.6 Consolidants

The application of consolidants introduces a bonding agent into the pore structure. Consolidants are applied as a substitute for the natural grain cement lost from the stone surface inward as a result of weathering. Like water repellents they can also reduce the ingress of water; however, they do not greatly alter the stone porosity. Most modern consolidants are organic chemicals, but some others are inorganic. Some types merely fill the open stone pores, while others are filler-strengtheners. In the case of granite, the penetration depth and subsequent effectiveness of consolidants may be limited by the comparatively low porosity of the stone. The application of epoxy resins as special solvent formulations for consolidation from the 1960's was observed to yield problems and this type of consolidant has generally not been used with much success in the UK. Problems are exhibited by most organic compounds in their reaction with ultraviolet light. Additionally, most organic sealers and consolidants can lead to crumbling after only a few years of exposure (Winkler 1994). Silicic acid ester is non-organic and is the consolidant type most commonly used on sandstone.

The use of a consolidant should be a last resort when decay is rapid, quantifiable, and its mechanisms are adequately known, and also when the composition and technique of consolidation are understood (Ashurst & Ashurst 1988). Currently the long-term effects of consolidants have not been fully studied. They can be effective at stalling the detachment of stone particles for around ten years. However, considering the lack of knowledge about their effects, they should only be used where it is certain that the affected, carved stonework will otherwise definitely detach or crumble away within the near future. As with other modern conservation treatments, full records of the masonry should been made prior to its use and the consolidant should be applied by experienced conservators. There is very little record of the use of any consolidants upon Scottish market crosses; however, its use was advised in the case of Edinburgh High Street cross (1990 report, Historic Scotland Restoration Records).

2.4.5.7 Epoxy resin

Epoxy resin has been used as a conservation material since the 1950's. On market crosses it has been used commonly to strengthen key joints and to treat planar disaggregation on the stone surface. It has been much favoured as a fixing material, particularly for securing dowels and cramps, due to its ease of use and great strength. It has excellent adhesive properties and is more effective than mortar when used as a 'glue' to stick broken stone fragments back onto monuments or to hold detaching parts in place. However, its strength is a liability in the same sense as cement mortar. Epoxy resin is impermeable, therefore using it heavily over a large surface area could cause problems in which moisture becomes trapped in the stone. It also weathers at a different rate to the stone, and can form pockets for water to gather if it stands proud of the surface to form a lip. Additionally, epoxy resin can cause mechanical damage due to the difference between its thermal expansion coefficient and that of the stonework. Thus, stresses and cracks can result in the stone around the resin. Epoxy resin can take on a yellow appearance due to external exposure to UV light (Winkler 1994), and when humidity fluctuates the resin maintains a constant colour, unlike the surrounding stone. Other initial observations suggest that it could deteriorate and become brittle (Hill & David 1995). The extent to which epoxy resin can stand the test of time as a fixing agent is not yet known. Its use on stone surfaces should therefore be sparing, and as a last resort measure in countering rapid and substantial planar disaggregation of the stone.

2.4.5.8 Plastic repairs

Plastic repairs are made with a soft material, usually a mortar, which resembles the stone once set. They are used as a small-scale alternative to stone replacement, or to remodel a former profile. Plastic repairs have been applied to a number of market crosses (eg heavy re-modelling of Beauly cross shaft in 1987). Crushed stone can be used as an aggregate in the mixture to achieve an appropriate colour match to the surrounding stone. The mortar mixture needs to be of comparable strength or weaker than that of the stone context. The mortar may weather faster than the stone; however, this is less damaging than using a dense, impervious mortar which could break away from the masonry and cause further damage (Torraca 1988). Often plastic repair has been carried out in an amateur fashion, on too large an area. Such work can potentially be a visual and mechanical failure. In making a plastic repair to a masonry surface, the decayed stone should be cut away to give a sound surface. The surface of the new repair needs to be flush with the surrounding stone. The mortar may need to be covered with damp sacking at first to avoid shrinkage cracks from too rapid drying, and several visits may be required during its setting to monitor the drying process. Historic Scotland have a policy of using materials for plastic repair that can be removed with solvent later if desired.

2.4.5.9 Cement rendering

A common intervention method in the past was to coat stone surfaces with cement render. It was thought that the application of a porous, hydrophilic layer would form a substitute surface which could undergo all of the decay effects normally experienced by a masonry surface. It was intended that damage normally caused by processes such as thermal shock, salt crystallisation, frost and attack by acid gases would be limited and the masonry core thus largely protected (Torraca 1988). Some market crosses have a coating of cement render upon the surface of the shafts and finials (eg at Cromarty, Inverbervie and Tain). In these cases the render was applied at a later date, to provide protection and to restore the profile of the weathered masonry surface. The render coating on these crosses has since become cracked, although it is difficult to establish the condition of the underlying stone. Removal of the render could improve evaporation rates and reduce moisture content (Torraca 1988). However, it could also generate further problems if the underlying stone is already in a fragile state.

2.4.5.10 Stone replacement parts

In certain cases, degradation may be so advanced as to necessitate the replacement of the affected masonry parts. The piece of masonry can be replaced entirely or the surface layer can merely be cut out. Where a stone has lost so many layers that it poses a risk of weakening within the structure, the entire stone may be replaced. A suitable match needs to be found; however, it may not be possible to identify the provenance of the original stone. Additionally, in the case of older monuments the original quarry is likely to be disused. Stone properties can vary across even short distances in a quarry, thus the results of the laboratory testing of one sample cannot always be accurately applied to other samples of that stone type. For the selection of a replacement part, a representative sample of existing stone parts should ideally be examined (Dimes 1990). At the very least, the replacement part should have a similar porosity and cementing component to the stone context. Although a good geological match might be found, the colour may not be a great match, nevertheless this changes with time and weathering. Sometimes the replacement of a defective block in an ashlar facade can be helpful in preventing decay of the stone below (Bristow 1990). Decaying stones which have an obvious structural or functional role within a monument should have priority for replacement, eg drip courses, quoinstones and voussoirs (Ashurst & Ashurst 1988). However, assessment of eighteenth and nineteenth century restoration suggests that the least possible stone replacement, the fewer problems that are generated (Bristow 1990). Market crosses have commonly experienced the replacement of stone parts in previous restoration work. However, it is currently the policy of Historic Scotland to introduce replacement parts only as a last resort, if the original part is so damaged as to be beyond conservation.

2.4.5.11 Replacement of ferrous parts

Iron dowels were previously used to join narrow pieces of masonry, eg in joining the shaft, capital and finial of many market crosses. The mechanical damage that can be caused to stone by their oxidation and expansion was described in Section 2.3.5.1. Iron fittings embedded in monuments including market crosses now tend to be removed during conservation work and replaced with non-ferrous metal parts. Metal detectors can even be used to seek out the ferrous pieces in the stone.

2.4.5.12 Desalination treatment

Soluble salts can be removed from masonry to some extent by the use of a clay-based poultice, which draws salts from the stone by capillary forces. The treatment can potentially reduce the damage caused by salt crystallisation. The technique can be applied to large, plain areas of masonry and stone with simple architectural detail. There are no recorded instances of its use on Scottish market crosses.

2.4.5.13 Graffiti removal

The graffiti pigment composition, the depth of its penetration, the stone properties and the condition of the stone surface are important factors when considering a suitable graffiti removal method. The applied pigments can penetrate the pores of stone causing difficulties for removal. The problem is compounded in cases where different pigment types overlap upon a surface (Urquhart 1999). Its removal can cause more damage to the stone than the graffiti pigments themselves, therefore a balanced decision is required. Some graffiti pigments are transient and will eventually fade or fall away from the stone surface naturally through exposure. Otherwise, both chemical and physical methods for removal are available, as well as laser cleaning. Solvents or other chemical agents are used to remove some pigments; however, a 'ghost' image of the graffiti is sometimes retained on the stone. Chemical methods are nonetheless often preferred to abrasive methods as they are less damaging to the stone. Laser cleaning also tends to be non-damaging although it is comparatively costly. Anti-graffiti coatings are available to prevent the penetration of applied pigments into the stone. However these can reduce the water-vapour permeability of the stone and can change the appearance of stone surfaces. Permanent anti-graffiti coats are generally not suitable for historical masonry surfaces; however, temporary coating types may be considered in some cases (Urquhart 1999). Applied graffiti does not seem to feature greatly on the market crosses visited during the present research.

2.4.6 Stone conservation summary

Increasing concerns to conserve built heritage can be traced historically, particularly with the development of charters over the last 70 years. A currently prevailing, general philosophy is that conservation of historical buildings and monuments should seek to preserve, rather than to restore or reconstruct. Previously records of conservation work have been lacking; however, increasing attempts are being made to document episodes of conservation to monuments. Existing protective designations for monuments cannot guarantee good conservation methods and do not provide for the regular monitoring of monument condition. There is, indeed, no general system in place to regularly monitor monument condition and resources for this activity are scarce. Economic valuation techniques have been applied to quantify the social and economic benefits of monument conservation with limited success. Some conservation materials used previously on stone are now known to be damaging, and the long-term effects of some other modern conservation materials are currently not known (eg biocides, water repellents, consolidants and epoxy resins). Research into these is ongoing, and includes the use of stone in field exposure and artificial ageing tests. Therefore the use of some modern conservation materials is currently recommended only as a last resort in response to rapid deterioration.

2.5 Techniques of recording and mapping stone decay

Until recently, the mapping and recording of masonry has not generally been concerned with the close-range examination of decay on individual stones. Rather, survey work has traditionally been more concerned with recording architectural form. However, there is an increasing recognition that this information is incomplete, and that an understanding of what is happening in the decay process is required. A body of literature dating from the 1980's dealt with developing recording methods for stonework (eg NORMAL 1988; Fitzner & Kownatzki 1989; Fitzner et al 1992 &1995; Heinrichs & Fitzner 2000). These systems drew influence from two sources of practice: engineering geology (the geomorphological mapping of areas for large civil engineering construction projects) and archaeology (recently the domains of archaeology have broadened from planning site and aerial details to include standing buildings), (Houston, BRE 1997, pers comm). A recent development is the application of digital mapping to record stone condition (eg Wilson 1995). Stone condition has also been recorded during recent sample testing in the laboratory and in the field. Other methods of measurement have been investigated in order to research stone decay rates upon buildings and monuments. Knowledge of stone weathering rates and mechanisms is still incomplete, but could be enhanced in the future through greater recording in the present and in subsequent monitoring.

2.5.1 The need for recording

The condition of stonework ought to be recorded before and after instances of intervention, including repair work and remedial work that will require future monitoring (ICOMOS 1990; Bristow 1990). Drawings have a vital role to play in planning repair work, particularly if they can indicate parts that have undergone previous restoration or conservation work. For example, the position of stone replacement parts and the location of new ties and cramps inserted can be indicated on drawings. These can allow the conservator a fuller understanding of modifications and intervention previously made to a historical monument, highlighting vulnerable elements. Drawing records made after repair work will be valued by those charged with the future maintenance and restoration of a building. Such drawings could be produced routinely during the contract and no great time and expense need be spent (Bristow 1990). For the benefit of future work projects, records should be deposited in a local or national archive. Detailed mapped and recorded data of masonry condition could comprise an integral part of systematic programmes to monitor the effectiveness of conservation materials and techniques, and the condition of stonework generally. Photography, photogrammetric drawings, CAD drawings, video, sketches and written notes are other record types that also provide useful documentation. The involvement of different individuals in the recording programme over time ideally requires a quantitative and consistent classification system, perhaps incorporating pro-formas (Searls et al 1997). Attempts have been made to develop classification schemes for stone decay to enable such consistency

(NORMAL 1988; Fitzner & Kownatzki 1989; Fitzner et al 1992 &1995; Heinrichs & Fitzner 2000, see Section 2.5.3.2 below).

A monument survey should begin by researching any pre-existing, archived records of the building or monument condition. This could reduce any duplication of recording effort and allow an improved interpretation of the monument's intervention history. During survey there are various means and degrees of recording visual information. Basic hand measurement can be used to produce simple dimensional sketches with notes on site. More accurate scale drawings could be compiled later from this, and could be informed by photographs taken during the survey. Sophisticated photogrammetric techniques are also available to aid the scaled mapping of facades. The use of classification and quantification systems for identifying and measuring stone decay and soiling allows greater consistency in the records. Various recording and mapping techniques in use are described below.

2.5.2 Photographic techniques

Photography is a very useful addition to the record as it can convey ornamental details, colours, setting, and perspective more easily and effectively than drawings (Sanpaolesi 1972). Buchanan (1983) and Gray & Ferguson (1997) described some practical techniques for use in conventional photography of buildings and carved stones. More complex photogrammetric techniques such as rectified photography and stereoscopic photography can be applied to produce an accurate scaled mapping of facades. Photogrammetry refers to the science of measurement and analysis from photography; however, it is not a method which is accessible to everyone. The equipment is rather expensive and some skill is required for the operation and extraction of results.

Rectified photography requires a special or modified camera, which has the effect of largely eliminating scale distortions normally produced by converging verticals. It is reasonably quick and easy to prepare, although the film plane of the camera must be exactly parallel to the horizontal and vertical lines of the facade. However, its accuracy is limited to only flat facades. Depth in the masonry subject introduces distortion in scale, eg recesses or projections on a facade (Dallas 1980a; Dallas 1980b; Burns 1985). For this reason it would be unsuitable for use in mapping market crosses which are mostly circular, hexagonal or octagonal in plan, and which feature narrowing upper components. Rectified photography is not as accurate as stereoscopic photogrammetry, although it is relatively cheaper on the whole. Current computer software can allow some rectification of ordinary scanned digital images, so that a facade could be rectified upon the computer screen if desired. However, the accuracy of this is limited as the operator must assume that the outline of the facade exhibits perfect geometry, which may not be the case in reality.

The use of close-range, stereoscopic photogrammetry for architectural survey began to be developed in the 1960's, adapted from its use in long-range, aerial, landscape survey. It requires specialist equipment both on- and off-site. A metric camera is required which is designed and calibrated for photogrammetry, with known, stable interior orientation, a film flattening device, fiducial marks and usually a fixed focus. The equipment consists of two cameras mounted upon a base bar, which provides a fixed relative orientation between the two. Some skill is needed in positioning the equipment prior to photography. Stereoplotting apparatus, now available digitally, is also needed off-site. Stereopairs of photographs can be viewed with a stereoscope to convey a three-dimensional image of the subject. Unlike rectified photography the depth of field, such as masonry projections and recesses, does not pose a problem because three-dimensional scale is accurately recorded by this system. It also requires less time on-site than if a facade were to be accurately surveyed by hand. There is a considerable outlay involved however, and trained operators are required. The system is therefore too costly to use except in cases of large facades that exhibit complex architecture or sculpture, or for masonry elevations not easily accessed (eg bridges). Some conservation bodies hire skilled contractors to undertake photogrammetric surveys in certain circumstances. There has been a general increase in the requirement of such elevation mappings, driven by increasing concern for the conservation and restoration of the built heritage. Photogrammetry has been used for detailed studies of particular building facades where very accurate mapped information has been sought. For example, experiments were undertaken on a marble building in Philadelphia to gauge the weathering rate through stereoscopic photogrammetry (Coe et al 1992). A system of control rods and paper 'targets' had to be set up on the building facade to allow the measurement of erosion to the stonework. Stereo photographs were taken of the facade four years apart in 1987 and 1991. However, it was concluded that this time-span was insufficient to produce any meaningful differences in the measurements, particularly as an error value must be taken into account. The development and use of close-range stereo photogrammetry for architectural survey has also been discussed by Foramitti 1972, Karara 1979 and 1985, Atkinson 1980, Dallas 1980a, Dallas 1980c, Torlegård 1980, Dowman & Scott 1980, Fetterman 1985 and Mikhail 1985.

2.5.3 Mapping techniques

A number of methods are used to record the condition of monuments to a greater or less degree; however, attempts to map stone decay and soiling are much less frequent. Institutions charged with the care of monuments tend not to make use of techniques to map in detail the features of decay and conservation, and rely instead upon photographic recording and note-making for this. However, decay-mapping techniques have been pioneered in the NORMAL system (1988) and particularly by Fitzner & Kownatzki (1989), Fitzner et al (1992; 1995) and Heinrichs & Fitzner (2000). Digitised mapping is another method recently applied to the recording of masonry facades. The digitisation can even be undertaken directly on-site (eg Wilson 1995).

2.5.3.1 Current institutional recording methods

Historic Scotland generally record masonry condition before and after conservation episodes, both for monuments in their own care and for monuments which are Scheduled or Listed. While the data recorded for stonework condition in past decades has been relatively scant, it has been much more comprehensive in recent years (Gordon, Historic Scotland 1997, pers comm). These include details of monument condition in the form of letters, memos, sketches, photocopied published extracts, abundant photography, conservators' reports and final conservation reports. Conservators' reports are produced immediately prior to conservation and have a standard structure incorporating monument characteristics, condition, and recommendations. During intervention, data is logged regarding the overall programme, method, materials and costing. Photographs are taken showing the monument and monument parts before, during and after conservation. However there are generally no mappings to illustrate the forms and distribution of decay interpreted across the stone surface.

Historic Scotland have recently launched a mapping and recording project for carved stones in Scotland. The methodology was designed by the Buildings Research Establishment (Yates et al 1999). The general aim of this research is to aid the formulation of measures for conserving carved stone in Scotland in the future. It is intended that all relevant carved stone monument types in the care of Historic Scotland will be assessed. As there are no examples of Scottish market crosses in State care, this monument type is not represented in the research by Historic Scotland. Note that this is a major factor in the selection of this monument type as the subject for the present research. The designed pro-forma and practitioners guide produced by the BRE will be used in the field for gathering data of individual monuments. Similar to the market cross research, the aim of the field assessment is to describe the stone condition and its environment, and to identify decay causes. There is a concern to identify locations at which stones appear to be particularly at risk from their environment. The field assessment was designed with non-specialist end-users in mind. The pro-forma consists of a series of questions and prompts relating to the monument and its environment. There are five areas of data to be gathered for each monument: background research; visual inspection and measurement of the monument and its location; assessment and recording of the environment; detailed description of the monument; assessing condition and causes of decay. The written information is to be supplemented by a full photographic record. No special equipment is to be used for assessing the stone condition, rather visual observation will be the means of measurement. A key to lithology is included to guide the non-experienced recorder in identifying the stone type, based upon a simple flow-chart system. The assessment is designed generally to be iterative in nature with many guidelines, so that an interpretation might be arrived at which agrees with all of the observations made. The recorders are required to suggest the decay causes and attempt to estimate the relative importance of these. There is no specified requirement to quantify the observed decay in terms of its distribution and severity across the masonry. However a rating is to be selected to describe the overall condition and risk for the monument from a five-point scale. The variables recorded by Historic Scotland in their research programme are similar to those gathered during the market cross surveys in the present research. However, the market cross data will additionally include consideration of the differing ages of stone components due to stone replacements, and will also seek to classify the decay severities and soiling densities.

The RCAHMS record data on stone condition during specific temporary projects. There is no formal, systematic, regular programme of inspection for the sites and monuments contained in their inventory. All survey data is archived within the NMRS, and selected parts are published. The Threatened Buildings Survey records those at risk from demolition, renovation, neglect and decay. When a planning application regarding a Listed Building poses such a risk, it is the statutory duty of the RCAHMS to record details of the stonework in advance of the alteration. In most of these cases only photography is used, although a drawing may be required in certain cases. The RCAHMS also undertake thematic recording for certain under-recorded and potentially threatened types of building, eg tolbooths (RCAHMS 1996). There are further archaeological survey programmes, which relate to selected geographical areas (e.g SE Perth), which do not include market crosses, although they do include some stone monuments (eg Pictish stones) and ruins. It is only very rarely that the RCAHMS would produce a measured drawing for a piece of sculpture such as a market cross. There is generally no attempt to classify or quantify stone condition during a survey. The investigator will produce site notes that will be archived, but there is no set pro-forma. Decay is generally not indicated on elevation drawings of masonry. It is considered to be the duty of the architect to inspect a building for decay with a view to replacing stonework. Photogrammetry is not generally used by the RCAHMS, as they do not usually see a need for this. However, they do make use of rectified cameras. Other methods used to produce scaled drawings are hand measurement or, for certain types of stones, rubbings can be taken. The RCAHMS policy on rubbings is that only one will be executed, and a photostat of this will be stored in the NMRS. Rubbings are not taken of fragile surfaces. Buildings are usually drawn at a scale of 1:10, and reproduced at 1:15. To survey the higher parts of a building or monument a stepladder or a 'high-spy' camera mounted upon a telescopic pole arrangement will be used (Boreland, RCAHMS 1997, pers comm).

Other institutions in the UK charged with the care of buildings and monuments similarly do not use a systematic method during intervention to map surface decay or conservation (eg National Trust for Scotland; CADW Welsh Historic Monuments; Northern Ireland Environment and Heritage Service). The policy of the National Trust for Scotland is that recorded information should include survey drawings, photographs showing details and wider setting, a short written description and an historical/archaeological analysis. The CADW policy on stone repair in Wales is to call in a specialist consultant for advice (Kelly, CADW 1997, pers comm). The National Trust for England (NT) similarly rely upon the advice of a network of specialist advisers for recording and conserving the great range of materials found on its properties. Most of the specialists are consultants, including contract conservation architects, surveyors and conservators. Given the great number of conservator contractors retained on a project-by-project basis, pro-forma recording is not considered feasible by the NT. However, basic standards of documentation are issued to NT regional offices for transmission to the contractor. Techniques and equipment for recording are commensurate with the requirements of the project. Use of the latest relevant new technologies (eg non-destructive surveying with pulse radar, or infra-red thermography, etc), is promoted to the regional staff. A computer-based inventory system is currently being developed by the NT, in which all survey and conservation records will be stored and accessed (Stewart, NT 1997, pers comm).

2.5.3.2 Other recording and mapping methods

Techniques for the detailed mapping and classification of stone decay and soiling were pioneered by Fitzner & Kownatzki (1989), Fitzner et al (1992; 1995), Heinrichs & Fitzner (2000) and the NORMAL system (1988). The weathering classification systems were applied for mapping stone condition onto base elevation drawings of monuments. In particular, the system by Fitzner et al provided a key influence for the data recording methods used during market cross surveys in the present research and is therefore described in detail below.

The NORMAL system was developed by the *CNR Centres of Milan and Rome for Studies into the Causes of Deterioration and Methods of Conservation of Works of Art* in the 1980's. It is a technique for classifying and mapping the macroscopic decay of stone monuments, with the aim of establishing standardised methods during decay analysis and conservation work. The NORMAL *Recommendations* series (1988, published only in Italian), arose from a multi-disciplinary research programme and were designed to allow updating through regular surveys. The NORMAL system of stone decay classifications defined weathering phenomena that could be discerned by the eye. The classification scheme was intended for use in mapping stone condition onto base elevation drawings of facades.

This method was further developed by Fitzner & Kownatzki (1989), Fitzner et al (1992; 1995) and Heinrichs & Fitzner (2000). A structured, logical system of classification for weathering forms was designed for use during detailed studies of masonry facades. The methodology was applied in a systematic way to both buildings and monuments. Some of the numerous classifications proposed by Fitzner et al are identical to or can be assimilated with the decay types described in Section 2.3.4. Fitzner et al recognised that detailed knowledge of stone condition, derived from the systematic examination and mapping of masonry, is important for stonework conservation. The classification developed was designed to be objective, systematic and duplicable. The mapping of decay types, including their surface distribution and severity rating, was intended to enable comparative analysis with regard to variables such as the orientation of the facades. A five-point damage severity scale was used, representing a range from *'very slight'* to *'very severe'* (Fitzner et al 1993). It was acknowledged that the rating system for damage severity was not objective but rather involved estimation. Thus, a further development was the designation of absolute values for judging severity of decay forms, eg the severity rating for spalling could be derived by considering the depth of the stone loss (Fitzner et al 1995). Value judgements were made during surveys regarding the cultural importance of masonry parts, in which greater value was placed upon the ornamented stonework. For these masonry parts the weathering classes were correlated to higher damage categories (Fitzner et al 1993). Facades were further zoned and rated on a scale of 0-5, according to the severity of damage exhibited on the stonework (Heinrichs & Fitzner 2000). These damage ratings were intended to convey the priority for intervention on various parts of the monuments and the scheme was aimed to offer benefits to risk estimation. Comparison of the monuments regarding their overall 'damage index' was intended to allow a ranking, in which more degraded monuments could be targeted as needing urgent intervention.

To produce the mapping, the decay classes were identified through visual observation and recorded upon an existing large photograph or elevation drawing of the facade. Most stones exhibited more than one decay type adjacent or superimposed, and it was therefore regarded as insufficient to record only one main decay type per stone (1993). Where the size of the base map allowed, it was recommended that different weathering forms occurring side-by-side upon the same stone were mapped. Where combined weathering forms could not be delineated, the existence of dominant and subordinate weathering forms were indicated. Certain combined decay forms were assigned a double negative value in the rating, ie where one decay type was observed on top of another the overall damage severity was more highly rated. For inaccessible masonry elements, the use of binoculars or a telescope was suggested, with a corresponding reduction in the level of subdivision of classifications due to the larger error present (Fitzner et al 1993; 1995). It was recommended that the designed mapping system should consist of two phases: an initial survey to define only the main weathering forms, and a secondary more detailed survey to map the weathering upon each stone in detail. The initial recording exercise would include a lithological mapping, the laboratory examination of stone samples and a photographic survey of the variety of weathering forms that exist upon the facade. This documentation would allow comparison of the weathering forms with those recorded upon other buildings or monuments. The classification recorded for each stone was represented upon a digitised elevation drawing of the facade by use of a symbol and colour-coded key. In one study, the percentage surface area covered by the different weathering classes was calculated (Fitzner & Kownatzki 1989), while a later application calculated percentages of surface area according to the degree of decay severity (Fitzner & Kownatzki 1989; Heinrichs & Fitzner 2000).

Attempts were additionally made to relate the mapped decay patterns to stone properties (Heinrichs & Fitzner 2000) and local environmental factors, ie the general climatic patterns and the microclimate incurred by the orientation of stonework (Fitzner et al 1995). However there was no indication of a thorough and systematic recording of environmental data at the mapped monuments. It was recommended that the mapped data should form the basis for long-term monitoring, and that the records should be updated regularly to allow this (Fitzner 1993).

The method developed by Fitzner et al is potentially a very powerful recording tool, is highly engineered and provides a detailed, point-in-time interpretation of the stonework condition. However, one potential problem in classification arises where a severe weathering manifestation has been transformed into a different weathering category of less intensity during a subsequent phase in the decay process. Additionally, users of the classification system have found it to be time-consuming (Houston, BRE 1997, pers comm; Ball & Young 2000). It requires specialist geological knowledge, and there is a general feeling within the British conservation bodies that the scheme is too complicated and that a simplified version could be developed (Houston, BRE 1997, pers comm). There are numerous elements to the classification system and corresponding key which are difficult in practice for the surveyor to recall, requiring reference to the defined classifications on a site practitioners sheet (Houston, BRE 1997, pers comm). Fitzner has been progressively refining this system and applying it to a variety of cultural objects in various environments. Nevertheless, a smaller data set might be more user-friendly, and attempts could also be made to record further environmental details.

A modified version of this system was subsequently used to examine the effects of stone cleaning on masonry facades (Ball & Young 2000). Weathering data for cleaned and uncleaned building facades was examined in relation to environmental variables, with the aim of investigating whether stone cleaning of buildings led to accelerated decay. In mapping facades an assessment was made for each stone, similar to Fitzner et al, to allow the quantification of decay forms across a facade. It was found to be more efficient to make use of a lower number of categories within the classification system, eg a 3-point scale was used for rating the soiling severity, as opposed to Fitzner et al's 6-point scale. A pro-forma supplementary to the mapping exercise was also designed for the data collection. Similar to the present market cross research, variables relating to the building morphology, the nature and condition of the stonework, soiling, orientation, exposure, the morphology of the built environment, proximity to roads and stone-cleaning data were recorded in the pro-forma.

Another example of the application of such a mapping exercise was to investigate the soiling of a roadside wall in Oxford (Viles & Antill 1999). Current photographs were scanned and corrected to create a base for the mapping. The distribution of each decay and soiling type was mapped and the percentage of area covered by these on the stone blocks was measured. From this a zonation in the distribution of decay classes was noted. A supplementary programme of chemical sampling was also undertaken where fragments of crust from different levels on the wall were analysed.

Such mapping exercises can provide a high level of detail, of great potential use in analysing features of decay, soiling and conservation. They go beyond photography in providing a clearly delineated interpretation of these features and will be useful in informing subsequent research and conservation.

2.5.3.3 Digitised mapping

Computer Aided Design (CAD) can be effectively used to display digitally mapped data of masonry façades. (Wilson 1995; Fitzner & Kownatzki 1989). There has been a recent growth in popularity of using various CAD systems to download survey data and digitise site plans and sections. Analysis and interpretation have thus been made easier due to the flexibility of this format. Scanned photographic images and text can also be linked to this system. Indeed, a full photographic record should accompany surveyed features. Although digitising existing drawings can be time-consuming, time can be saved if the data is created digitally on-site, with the use of a variety of data loggers, and photogrammetry or rectified photography. However, traditional hand-survey methods are still recognised as essential to supplement the digital survey, particularly in such cases where part of the stonework is obscured by features such as vegetation. Mappings such as these, produced in conjunction with conservation work, are now finding their way into the archives (eg English Heritage and the National Monuments Record). Digital presentation of mapped data is effective at summarising and exploring relationships in complex data sets (Wilson 1995). The levels of data visualised at any one time can be controlled and further layers can be added, for example relating to subsequent conservation measures. Wilson (1995) applied an on-site digital mapping technique to a masonry façade at Fountains Abbey, in which use was made of hatching and colour coding to indicate decay. Digital mapping, supplemented by photography, has the potential to become a more widespread recording method in the future.

2.5.4 Methods for measuring stone condition

2.5.4.1 Field equipment

Some simple items of field equipment can be used to gauge certain stone properties, while other more sophisticated gadgets can help to identify certain decay effects concealed beneath a stone surface. A hand lens of x10 magnification can be used to identify whether the stone is granular, compact, crystalline, coarse- or fine-grained, and sedimentary or otherwise (Dimes 1990). If necessary, a pocketknife could be used cautiously to scrape off any surface grime or coating to reveal the underlying stone. Another modest and inexpensive piece of equipment known as the Karsten tube can be used to measure the permeability of stone. Ideally this test should be performed in dry conditions when the moisture content of the stone is minimal. In this simple test, the open end of the tube is temporarily sealed onto the stone surface, and the absorption by the stone of small units of water against time is measured.

Various high-tech, non-destructive testing methods are available for use on stone monuments in the field. The equipment is expensive and generally requires specialist operation. As the present research aims to design a recording method that is affordable and accessible to non-specialists, only a brief note of these will be made here. Techniques include ground-probing radar, pulse velocity, monofrequency waves, radiography and geoelectric techniques, infrared thermography, the moiré method, and acoustic emission. The former two techniques of radar and sonic tests are applied quite commonly to masonry and can be used to detect discontinuities, voids and flaws, and even the effectiveness of consolidant injections. Commercial ultrasound instruments have been in use for decades to test the soundness of concrete walls and pillars for cracks. The complexity and heterogeneity of stone fabric however was found to confuse the results of this method in the past, creating many problems of interpretation. However, it is a non-destructive and rapid technique, and has been used with some success upon testing rock soundness of marble statues. Porosity of sandstone has also been tested by ultrasound (Winkler 1994). Of the less common techniques, radiography can be used to detect voids and inclusions, and geoelectric techniques can provide an indication of density, voids, and water content. The infrared thermography technique is sensitive to heat flow across a surface, and can thus be used to detect moisture near a stone surface or to locate metal ties. The moiré method involves generating an interference pattern, which can be used to investigate growth of surface cracks over time and general changes in form, while acoustic emission also allows the study of fissure development. The suitability of certain techniques to the study of historical monuments is still being tested, eg monofrequency waves with their potential to be used for investigating concealed areas and water. Non-destructive techniques cannot currently provide adequate information about the distribution of moisture within stonework, one of the most significant agents of stone decay. However, a partial indication of this could perhaps be gained by combining different testing methods (Nappi & Côte 1997).

2.5.4.2 Stone testing

Many stone testing programmes have been undertaken with the aim of investigating stone decay mechanisms and parameters and, ultimately, conservation solutions. Traditional investigation methods of the weathering of certain scattered monument types, as in the present research, could have the disadvantage of being of limited general application due to the specific nature of each architectural construction and each locality. However, laboratory tests allow the opportunity for various stone sample types to be analysed subject to a constant set of environmental variables.

A number of national and international conservation bodies have published guidelines of standards to be applied to stone materials testing and weathering simulation (eg CEN, RILEM and ASTM in the USA; DIN, VDI or WTA in Germany; NORMAL in Italy; BRS in the UK; and UNE in Sweden). Laboratory and field exposure experiments continue internationally, particularly with regard to the effects of atmospheric pollution upon stone. In the laboratory for example, UMIST have researched the effects on stone of dry deposition and acid rain in the UK, and experiments in Spain by the ETS Ingenieros Industriales (1986) have indicated that pollutants act synergistically upon stonework. The penetration and depositional activity of pollutants is now generally appreciated. Laboratory equipment can allow the means to artificially age stone in order to study the effects of decay, including salt action and physical weathering. Environmental variables can be replicated and accelerated, including temperature and humidity variations, allowing investigation into the effects of cycles of freeze-thaw and salt crystallisation. However, the accelerated, laboratory testing of weathering rates and effects are inadequate alone, when a 5cm^3 cube of stone is taken to exhibit the same effects as a full-scale wall or elevated piece of sculpture (Livingston & Baer 1984). Additionally, in observing the effects of a single parameter in the laboratory, the action of other variables is excluded which may otherwise play a significant and synergistic role in 'real' weathering (Mirwald & Brüggerhoff 1997).

Field-exposure tests of stone provide another source of weathering and soiling data. The results are biased in cases where the environmental variables are localised; however, some research programmes have made use of scattered exposure sites, and incorporate tests upon conservation materials, biological soiling, weathering and the effects of atmospheric pollutants. Field exposure tests have been undertaken in the UK by the Building Research Establishment (1992) and the Robert Gordon University (1997). Numerous other exposure studies have been carried out within various other European countries upon different stone types. International exposure programmes have been undertaken by the UN/ECE (1991) and EUROCARE (1992). However, there is generally a need for more research involving multiple variables, incorporating a variety of stone types and environmental factors (Mirwald & Brüggerhoff 1997). Specific areas that require further exploration include:

- Methods for extrapolating damage processes with regard to intensity and time;
- Identification of internal agents or clusters of agents which are decisive for the fatal breakdown of stone;
- The role of detailed mapping in revealing areas of specific risks on an object (due to a specific kind or intensity of weathering process);
- The possibility of deriving a general strategy of mapping environmental influences on objects, particularly for those of complicated geometry or of a very diverse material composition.

(Mirwald & Brüggerhoff 1997). These needs will be addressed in the present research into the weathering of market crosses.

2.5.5 Methods for measuring decay rates

It is generally accepted that weathering rates have increased. The cause is presumed to be atmospheric pollution. From Medieval times local industries, eg iron smelting, caused some localised pollution. In more recent times, especially in the twentieth century, there has been a general global increase in atmospheric pollution (described earlier in Section 2.3.3.2). To enable the prediction of future decay rates and trends, it would clearly be useful if 'base-line' data existed from the past with which the current condition of market crosses could be compared, and the data then used in an extrapolation process. For the most part, detailed, scaled elevation drawings of market crosses do not exist from the past. Where they do exist (eg Stuart 1856-67), they do not illustrate weathering or soiling types except for some mechanical damage, eg an altered cross shaft profile due to detached chips. One means of gauging recent decay rates could be to compare the present condition of certain stone monuments with previously cast replicas. Many plaster casts were made of important pieces of sculpture in the nineteenth and early twentieth centuries, although these mainly relate to classical subjects and decorative Celtic crosses. Historical photographic evidence could provide another means of measuring decay rates. However, this type of evidence must be used with care as constants are required to be maintained during the photography if a scientific comparison is sought. The exact appearance of objects in a photograph, including any stone decay features, is dependant upon the prevailing light and atmospheric conditions, distance, angle and photographic equipment. It would be virtually impossible to replicate photographic conditions at a monument in the present to match these unknown variables in the past. Therefore, where old photographs of market crosses were consulted in the current research they could be used only as a guide (see later Section 3.9.2). However, the regular application of photogrammetry to a masonry facade offers some potential (see previous description of Coe et al 1992, Section 2.5.2).

In the field it can take many years of weathering to produce a detectable rate of degradation. Typical rates of stone surface recession are around 1mm per century (Livingston & Baer 1984). However, there are difficulties involved in considering an average damage rate. Damage mechanisms vary greatly in their rate throughout the cycle, thus the average damage rate should not be interpreted as the instantaneous rate. Damage rate is therefore often expressed in time units of a century or even a thousand years. Measuring the change in physical dimensions is seen as a theoretically reliable indicator of the effects of weathering. Livingston & Baer (1984) distinguished between two types of surface loss. Surface recession across a relatively plain façade involves erosion on a plane fairly parallel to the original surface. However, for ornamented stonework, or even masonry corners, the effect involves a rounding of features, or widening of incised grooves, thus the degree of angles and radii are modified. This might be better described as 'loss of detail', and presents increased difficulties for quantification. Surface roughness can be used as an indicator of weathering rate over a relatively short time-span, if it can be assumed that the degree of roughness originated as a constant amongst a group of samples. However, this decay process represents the loss of intergranular material, which is generally more reactive, and therefore should not be extrapolated to represent the rate of weathering as a whole. Surface recession could alternatively be gauged by reference to some indicator of the original surface level, which might be provided by a quartz vein or other hard inclusions visible in the stonework. Similarly, lead plugs or lead infill used for lettering could be used as control markers. The so-called 'lead lettering index' has been used as a method in the past for measuring erosion of graveslabs, particularly marble, based upon the height of lead outstanding (Inkpen 1999). Alternatively, original surface levels could be sought underneath plaques or flashings. Another possible technique for gauging weathering rate is to measure the mass and composition of rainwater run-off from a building or monument (Livingston & Baer 1984). In theory, if the distribution of rainwater flow across a stone surface could be determined, one might be able to calculate the annual total mass lost from the stonework. This assumes that erosion occurs, ie material is lost, in direct proportion to the amount of rainfall. In reality, material loss arises from a range of interplaying factors and could be active between spells of rainfall. In addition, while analysis of run-off from limestone or marble might allow quantifiable results, surface material lost from sandstone via run-off would be minute, perhaps even negligible, when measured over a period of years.

The development of computer models in recent years has encouraged research into stone damage diagnosis and extrapolation. Equations have been postulated which take account of environmental conditions and stone properties. An attempt was made to apply mathematical techniques to link damage quantitatively with atmospheric pollution, and to establish 'dose-response' functions (Livingston 1997a). The damage function was quantified in terms of rates of material loss or of surface recession by the application of an equation. Variables such as relative humidity, stone moisture content, surface roughness and surface coverage by anti-weathering chemicals were included in the study (Livingston 1997a). Ideally this could allow the lifespan of monuments to be predicted given a fixed rate of air pollution, and the timing of intervention could be based upon this data. However, fixed rates of atmospheric pollution are an unlikely scenario, and there is currently no full understanding of the role of 'memory effect' in stonework (ie the potential for decay effects to continue after the weathering agent has disappeared or has been reduced).

Further research into decay rates is required so that stone durability and thus the effectiveness of conservation treatments can be predicted (Baer & Snethlage 1997). It is thought that no single type of experiment can provide a reliable 'damage function' for stone, either generally or at the level of a single stone type. However, in the meantime the measurement of relative damage rates for groups of mostly constant stone samples could theoretically produce fairly valid results (Livingston & Baer 1984).

2.5.6 Summary of recording and mapping techniques

Detailed recording of decay, soiling and conservation is important for monitoring stone condition, particularly with regard to weathering rates and the effects of conservation. The value of such information is increasingly being recognised. Photography is an important recording medium, and many institutions involved in conservation rely heavily upon this. However methods for mapping decay and soiling have recently been developed by researchers. Mapped details convey a greater level of information than photography, as they provide interpreted and clearly delineated details of decay and soiling. Mapping techniques facilitate a qualitative and quantitative assessment of decay, and provide base-line data that could be used to inform future studies. They could allow rates of decay and soiling to be monitored, and the effects of previous conservation to be assessed. In future, this could enable more effective and timely intervention. Digital mapping techniques have also been applied to recording decay on masonry facades, and offer a flexible means of presentation through use of multiple layers of visual data. A number of sophisticated gadgets (eg remote sensing equipment) have a limited application in recording certain subsurface details of stone condition, although they are generally expensive. Stone condition has otherwise been recorded in field exposure and laboratory testing of stone samples. These experiments have added to our knowledge of the mechanisms and rates of stone weathering and soiling. Other methods of recording stone decay on monuments have been developed for investigating and modelling decay rates, with the aim of allowing the future prediction of stone condition on historical structures. Further research into decay and soiling rates and mechanisms, and greater efforts in detailed recording and mapping, are generally required.

2.6 Risk Assessment

2.6.1 Review of risk modelling

2.6.1.1 Definition of risk and associated terms

The term *'risk'* is sometimes used in a rather vague sense and has attracted a range of definitions. While the traditional definition of risk implies positive and negative outcomes equally, ie exposure to a possibility of loss or gain (Cooper & Chapman 1987), in common usage it often carries negative connotations. The difference between hazard and risk should be recognised. *Hazard* is the innate property of a process, activity or substance to cause harm. It is thought that our perception of hazards is continually subject to increase, due to past events and new technologies (Ansell 1992). Advances in technology have certainly required the development of more sophisticated means of evaluating risk than our own bodily senses can traditionally predict (Phillips 1992). *Risk* refers to the probability and magnitude of damage due to a hazard. It is the *'chancing of a negative outcome'* (Rescher 1983, in Wharton 1992). Often 'risk' is used as a term for probability or dangerous consequences, but risk is a function encompassing both of these (eg Wharton 1992; Ballard 1992; Spjotvall 1987). On the basis of pre-existing data, risk is usually calculated in industry as:

Risk = frequency x consequence of hazard

(Ballard 1992; Spjotvall 1987). Thus, occasional events of low impact, or rarer episodes with more serious consequences might both be considered as representing an acceptable risk (Ballard 1992). *Risk analysis* is a general term used to describe approaches dealing with the identification, evaluation, control and management of risk (Cooper & Chapman 1987). A *risk assessment* specifically involves estimating the probabilities and size of the outcomes (Wharton 1992). In the present research into market crosses, risk and its associated terms are used in the following sense:

Risk: A rating based upon the scale, severity and likelihood of damage to the stones of market crosses.

Risk assessment: The process of rating the extent to which monuments, both individually and collectively, are at risk.

Risk assessment model: Describes and rates the vulnerability of the monuments to various risks of stone decay from factors of the environment, intervention, climate and monument characteristics.

Risk management: The practical application of this foresight with the aim of risk reduction, anticipating all the potential trajectories of monument condition. Effective, comprehensive risk management should include the planning and implementation of preventative action, a monitoring system, contingency planning and even the advance prescription of remedial reaction to unintended eventualities. The intervention criteria and recommended conservation presented in the final section of the thesis (5.4) are intended to contribute to such a management framework, along with the recommendation that treated monuments are subject to regular monitoring.

Hovden & Larsson (1987, 53-4) listed a variety of risk perception types according to seven different viewpoints: *individualistic, system critique, legal, ideal, fatalistic, economic-moral and technological-rationalistic*. For example, the *technological-rationalistic* interpretation of risk depends upon a quantified level of safety, in which science defines the risk criteria. An *individualistic* interpretation of risk, on the other hand, involves a voluntary process in which benefits to be gained are mentally weighed up against the risk. The former approach is, of course, relevant for the present research. In classifying hazard causes, a distinction has traditionally been made between anthropogenic and natural hazard types. This reflects the recognition that man can to some extent more readily predict and reduce the chance of hazards generated by human error, while hazards of a natural origin are less easily controlled. However, this distinction would be a grey area with regard to market crosses, since the effects of anthropogenic factors (eg atmospheric pollution) and natural weathering processes are constantly active (rather than episodic). The two also act in combination in producing stone decay.

2.6.1.2 Current areas of application

Many risk assessment models have been developed in relation to finance, industrial design, and engineering. Additionally they have been used for planning in the event of natural disasters, fire, chemical spillage, technological failure, and the general health and safety of employees and/or the public. These models are generally not very well suited to the area of stone weathering as they deal mostly with episodes and accidents, rather than with the effects of long-term environmental variables. In addition, risk assessments are often undertaken in the project design phase, with a view to incorporating the benefits of such foresight into the system design. We cannot re-design our historical monuments, rather we must design our intervention for optimum preservation of these assets.

2.6.1.3 Methods of modelling risk

There is no generally applicable risk analysis method or assessment model. Some models are simple, while others are complex and incorporate factors of uncertainty about events and activities, responses to these, and even the consequences of these responses (Cooper & Chapman 1987). However, a common approach for risk analyses involves:

- *Comprehensive identification of potential problems;*
- *Clear analysis of why the problem would occur;*
- *Quantitative statements concerning likelihood and consequences;*
- *Prioritisation of areas for improvement.*

(Ballard 1992). The risk assessment should seek to provide data which demonstrates a relative ranking of both the hazards and the systems/equipment which contribute to these, and the benefits to be gained from modifying them accordingly (Ballard 1992). While these objectives are obviously geared towards reducing the risk of failure in industrial technological systems, we could substitute 'systems/equipment' with the various factors which cause stone decay, eg environmental conditions or inappropriate types of intervention.

Sometimes a risk analysis involves the use of a few different risk assessment methods, reflecting differences in the contributing factors. For example, use could be made of mathematical field models, zone models and simulation models within any one fire risk assessment, dealing respectively with flow of air and smoke, geometry of space, and an overall view of the fire protection system (Phillips 1992). The interaction between such models during a damaging incident must be adequately considered. The production of related sub-models can address questions of scale, since risk assessment can be either specific and localised or more general.

Flow diagrams

Flow diagrams can be used in risk analysis to illustrate possible courses of action and effects. Fault trees, pioneered by Fussell in 1976, can be prepared and used subsequently to 'trouble-shoot' or diagnose problems, as they illustrate the possible event sequence leading to the damage (Ballard 1992; Ansell 1992). However, one problem with this network analysis is the question of how to reduce the models to a manageable size, without excluding possible sequences of events or failures that might contribute to the hazard. Risk analysis approaches can be 'top-down' or 'bottom-up'. 'Top-down' approaches consider the hazards open to the system holistically, and seek to explore how these faults or dangers might arise. 'Bottom-up' approaches begin by examining the performance of the 'components', and examining how they might cause a systemic failure (Ansell 1992). In terms of the decay of historical monuments, the 'top-down' approach could apply to assessing the effects of an environmental factor (eg high atmospheric pollution), while the 'bottom-up' method could consider the vulnerabilities of the stones.

Non-numerical risk assessments

A common and basic form of risk assessment used, eg regarding health and safety within a company, might take the form of a simple table (eg see Table 2.1 below). Such a system need not involve numerical calculations, but at least provides a framework within which risks can be systematically identified and evaluated, and appropriate pre-emptive measures can be put in place to reduce the risk.

Table 2.1 Example of a hypothetical fire risk assessment, without the use of formulae or calculations

Cause/factors	Likelihood	Severity of consequences	Estimated risk	Solution	Pre-emptive action
Employees smoking	Low	High	Moderate	Avoid	Enforce a 'no smoking' policy in all areas of the building
Storage of inflammable materials	Low	Very high	High	Mitigate	Store the materials with appropriate space between bays; increase fire detection and fire-fighting equipment in storage areas
Kitchen fire	Moderate	High	Very high	Mitigate	Kitchen not to be left unattended during cooking; increase fire-fighting equipment in kitchen

The estimated level of risk could be colour-coded within such a table in order to emphasise the perceived 'danger' represented by the identified factors. Solutions depend upon the circumstances as well as the level of estimated risk. The company or organisation could decide to accept, mitigate, transfer (ie insure against), or avoid the risk. With regard to stone weathering it is not feasible to insure against the loss of stonework, since historical monuments are assets which cannot be replaced by money.

Formulae

Formulae are sometimes used in quantifying the probability and magnitude of damage in risk assessment. Such a formula has been designed in the current research on market crosses for use by practitioners (developed later in Chapter 5). In calculating probability one needs to investigate the likely frequency of hazards and their consequences, based upon past records. Some equations make use of scoring systems, for example, in financial risk management (Thomas 1992). Such systems can also take into account the level to which a community, individual or body - or market cross - is 'equipped' to deal with the hazard. Thus the level of vulnerability depends to some extent upon the scale of '*preparedness*' (Hedge 1987). With regard to market crosses, the level of inherent vulnerability depends upon their architectural and stone properties, their condition and the degree of maintenance to which they are subject. Their condition and maintenance are subject to gradual but continual change. However, risk assessment need not make use of probabilities, as they may be irrelevant in some cases (Cooper & Chapman 1987).

The severity of the consequences may be quantifiable (eg in financial terms), or in other cases a rating could be assigned. In theory, it should be possible to quantify consequence in the case of market crosses if we regard this as being the resulting volume of stone lost due to decay. However, there are other factors involved, eg the degree of important or historical carved detail which could be lost, as opposed to the loss of stone from a plain ashlar surface. Any mathematical technique applied to risk assessment thus needs to be appropriate to the specific system under analysis. The extent to which the results are meaningful and useful depends upon how well the mathematical concept fits with the 'real world', and how much the practical situation has been tailored to fit the model (Spjotvoll 1987).

Psychological element

Traditionally risk assessment has focused largely upon quantifying probability. However, this approach does little to articulate the social/behavioural influences upon risk. Recently, phenomenological studies of risk assessment and response have been undertaken, eg to assess perceptions of personal risk, and to interpret and model the action of individuals judging risk in emergency situations (eg Brehmer 1987; Hale 1987; Glendon 1987; Rasmussen 1987; Hedge 1987). These studies are less relevant to market crosses, because acts of intervention are likely to arise from a structured process of rational decision-making, based upon existing scientific knowledge. In addition, there is little personal risk involved in monument care.

2.6.1.4 Assessing the calculated risk levels

Once risk levels have been calculated or estimated for various hazards, judgements should be made about what constitutes an acceptable risk. This will indicate the need for any preventative action and can involve weighing up several factors. Some general factors affecting risk acceptability and which could be applicable to monument decay could include:

- The severity of the consequences
- Whether the exposure to risk is continuous or occasional
- Whether the effect is immediate or delayed
- Whether measures can reasonably be taken to avoid or reduce the risk

- Whether the origin of the risk is natural or anthropogenic, and thus whether or not the risk could be controlled

(Litea, Lanning & Rasmussen 1983, in Hedge 1987). These issues are addressed in greater detail in Chapter 5.

2.6.1.5 Limitations and benefits of risk modelling

Limitations

Difficulties can arise in risk assessments when no frequency data for hazardous events is available. This problem is pertinent to the current research, since most stone decay and weathering processes are ongoing. Additionally, there is little data on which to base predictions of decay rates. A lack of data may mean that some hazards and consequences are not anticipated, and the magnitude or probability of other consequences could be under- or over-estimated. Therefore, the perceived potential outcome may not match the actuality. Risk models can never be validated for the whole range of their behaviour (Phillips 1992). They also need to be updated in accordance with any new data and any changes to the system or circumstances.

Different types of risk need different treatment and analysis. The problem of numerous small accidents cannot be analysed with the same tools needed for examining eventual long-term health effects, and the risk assessment literature often overlooks these diverse needs (Bjordal 1987). This example of the effects on human health provides a good analogy for stone weathering because it is similarly a long-term type of hazard producing delayed effects.

Risk assessment involves a degree of subjectivity, in which value judgements are made about the significance of some factors and about when it might be necessary to intervene. There are issues of how low a probability should be to justify its treatment as a negligible factor, and how to judge what constitutes undesirable or unacceptable consequences. The solutions to these questions depend upon the nature of the hazards being investigated and the availability of suitable means to counter them. Furthermore, decisions about courses of action are often not made on the basis of risk alone. Moral, political and financial issues are just some of the other factors which influence decisions about intervention.

Benefits

Risk management in general allows greater perception of risks, their interaction and their effects upon a project. It therefore enables better contingency planning and the introduction of measures to reduce risk exposure. Future costs and other undesirable consequences can thus be reduced or avoided. Risk analysis can also help in establishing accountability, and deciding who should be responsible for particular risks. The analysis shows that the risks have been fully considered and that the measures taken to control it have been appropriately calculated and are justified (Cooper & Chapman 1987).

2.6.2 Application of risk modelling to market crosses

2.6.2.1 Methodology

Risk assessment models developed in other fields are mostly inappropriate to the present research into market crosses, as they incorporate personal risk and financial risk as the significant elements. In addition, the events of stone degradation contrast with the subjects of existing industrial models in that the decay is chronic, the impact is delayed, and the agents interact. In building the risk assessment model, the field data collected for market crosses will be used to gain an insight into the parameters for decay, by undertaking the following:

- Listing all hazards (potential agents of decay)
- Identifying the chain of events or correlations linking these hazards with consequent decay types
- Quantifying the occurrence rate of the hazards
- Quantifying the consequent stone decay
- Identifying any interaction between hazards
- Ranking hazards relatively, on the basis of severity of consequence and probability (eg motor traffic emissions are expected to represent a major hazard)
- Identifying criteria for intervention and appropriate courses of action

2.6.2.2 Risks types relevant to market crosses

Unlike most other situations for which risk models have been developed, in the area of stone weathering and conservation there is little element of risk to human health and the losses are not primarily financial (although remedial conservation work could be costly). While there might be an emotional and political reaction within the human population if a monument was destroyed or left to decay, the risk examined by this research refers to the quantified loss of historical stonework. The hazards that cause this are the interactive processes of weathering phenomena, architectural characteristics, stone properties, environmental agents, and anthropogenic agents, including inappropriate intervention.

2.6.2.3 Benefits of a risk assessment for market crosses

A quantification of the risks in relation to stone weathering of market crosses would demonstrate a systematic and logical process of reasoning, which could be presented in support of recommendations and strategies for the management of such monuments. Demonstration via a model could help to justify decision-making, whereby risk decision criteria and processes could be clarified. Intervention timing and methods could thus be improved, and plans could be made for the direction of resources. Management could refer to such a prepared risk analysis or assessment in direct response to a problem. These models would be of most use where the insight gained from their construction has informed the design of a system or a management plan including monitoring, in which risk is minimised. An investment of resources and skills is required in this practice; however, timely intervention may save some conservation costs and unnecessary stone degradation in the long-run.

2.7 Summary of key issues from the literature review

The market cross played a central role within the social and economic history of towns. Today they are a symbol of burgh heritage, their location often still marking the historic heart of burgh activity. Research into the architectural and historical characteristics and the origins of Scottish market crosses proceeded from the mid-1800's and continued until 1928. There has since been a lack of synthesised research into Scottish market crosses. Market crosses have undergone a high rate of intervention due to their central, urban location, particularly with regard to their removal and the piecemeal replacement of their stone components. Some previous intervention attempts may have been inappropriate and damaging. Their location at town centres, often at road junctions, may place them at particular risk from damaging emissions in the atmosphere.

Most Scottish market crosses are built from sandstone and have been vulnerable to decay and soiling. Stone properties have a significant influence upon weathering. Pore characteristics and composition of cementing material are particularly important factors in the resistance to decay. Generally, biological and particulate soiling are not thought to constitute a major source of damage to stone, although they could be considered aesthetically damaging. Decay, encrustation and particulate soiling are increased due to atmospheric pollution, particularly emissions from combustible fuels containing sulphur-based acids and nitrogen oxides. Moisture and salts are considered to be the prime agents of stone decay, resulting in a variety of decay effects. High frequencies of wetting-drying and freeze-thaw cycles are known to cause particular damage to stone. The amount of moisture ingress to stone is influenced by climate and microclimate, as well as by characteristics of the monument itself. Some monuments incorporate remnants of previous intervention, which can be damaging where inappropriate materials have been used.

Awareness of the benefits of conserving historical buildings and monuments has increased, and is illustrated particularly by the development of conservation Charters since the 1930's. A large number of monuments are protected by statutory designations. Most market crosses are classified as Listed Buildings and, to a lesser extent, as Scheduled Ancient Monuments. However, there is no system to allow regular monitoring of the condition of market crosses and, indeed, of most monuments. A number of modern conservation materials are available to treat stone decay and soiling. However, since stone weathering is a very gradual phenomenon, the long-term effectiveness and effects of these materials upon stone is not yet fully understood. Substances such as stone consolidants, water repellents and biocides are therefore recommended for use only as a last resort measure to combat decay, on small areas of stonework. In extreme cases it may be considered appropriate to remove a monument indoors in order to prevent significant losses of stonework.

The benefits of recording detailed data on stone condition and conservation are also increasingly being understood. Information about conservation applied to monuments has not been highly documented in the past, although a greater level of detail is now being recorded. The mapping of stone condition on masonry facades provides a high level of visual information, in which decay and soiling can be assessed qualitatively and quantitatively. Classification schemes for mapping stone condition have recently been developed, and such data could provide a base-line that has great potential to inform future research and conservation. However, stone condition is not mapped by the statutory bodies charged with the care of buildings and monuments. Instead these bodies rely heavily upon photographic surveys and note-making. Mapped data subject to updates through subsequent monitoring could ultimately facilitate an improved understanding of weathering rates, and thus more appropriate and timely intervention. Digital mapping can be used effectively to convey multiple layers of data, and can even be directly produced on-site. Its use has the potential to increase in the future. Stone condition has additionally been measured and tested through field exposure and laboratory testing of stone samples. Experiments replicating accelerated temperature and moisture variations have been used to investigate the effects of weathering upon stone, and field exposure tests have been undertaken to research rates of soiling. Other investigation techniques for gauging decay and soiling rates upon monuments are limited due to the lengthy time-spans involved. Knowledge of stone weathering rates and mechanisms is still incomplete and requires continued research.

Risk assessment has been applied in the fields of finance, health and safety, technological failure and natural disasters. Since these risks are episodic they are not analogous to stone weathering. However, the general concepts and methods of such risk assessments could be adapted to predict the consequences of weathering upon market crosses, including consideration of relevant hazardous agents. Risk is a function of probability and magnitude of consequences. These are quantified or rated in various ways and their evaluation is improved through the use of previous data of damage. In the case of market crosses and most other historical monuments and buildings, little or no previous data is available to link the occurrence and development through time of damage to the various hazardous agents. Risk modelling generally offers benefits to contingency planning for damaging instances, and the foresight obtained can be used to make improvements in existing systems or designs. For market crosses, the predictions could allow more timely and improved intervention. In the long-term this could reduce remedial conservation costs and decrease the damage to the monuments. Regular monitoring and updated assessments could also allow an improved understanding of the rate and processes of decay.

In conclusion, the literature review indicated gaps in knowledge, which will be addressed by the research objectives. In particular, methods for mapping stone decay and soiling are lacking and are not widely used. The research will draw upon recent mapping methods to develop a design tailored to market crosses and will demonstrate the benefits that this detailed recording method can offer. The general condition of market crosses in Scotland is previously unresearched and largely undocumented. The present research will create a detailed information resource, particularly through fieldwork, which will be valuable for future studies. The causes and effects of some decay and soiling types are currently unclear. The collection and analyses made during the research will add to the current state of knowledge in this area. They will also elucidate the particular sets of circumstances that are contributing to the decay of market crosses, which have incurred unusually high levels of previous intervention compared with other monument types. The development of predictive models of weathering for monuments is a problematic area, due to limitations in knowledge about the mechanisms and rates of decay. The present research will address these problems by gathering and analysing field data, and showing how this data can be used to predict stone condition, with a view to encouraging improved intervention and conservation strategies. Risk assessment methods offer a systematic and quantitative means of achieving this, and have not previously been applied in the area of monument degradation.

3. DATA COLLECTION AND RECORDING METHODOLOGY

3.1 Sample selection method

Consultation of archives and published material indicates that there are presently 151 surviving examples of market crosses in Scotland. This includes a few examples of which only a fragment survives, as well as four examples that have been moved indoors into churches or museums, and two fibreglass replicas. However, the vast majority are substantial monuments standing in town centres. It would not be possible to select a truly representative sample from this population due to the unique nature of each monument in terms of its architecture, stone type, individual history of intervention, geographical location and climate. A totally random sampling strategy would introduce the potential for bias from individual crosses with outstanding characteristics, and would also include market crosses of unknown or debatable date, decreasing the confidence level. The heterogeneous nature of the data was therefore unsuited to random sampling. An additional limiting factor upon the size of the sample group was the time available for fieldwork. The aim was therefore to select a *'convenience sample'* to provide as wide a picture as possible. It was important that the principal factors were well represented within the selected sample. Based upon material consulted during the literature review, certain factors were hypothesised as having a significant effect upon the monument condition, and these are listed below in descending order of expected risk to the market crosses:

- Monument age
- Stone type and properties
- Geographical location (ie due to climatic factors, altitude, coastal proximity and Local Authority)
- Land-use type and environment (especially exposure to motor exhaust emissions)
- Architectural morphology
- History of inappropriate intervention methods or materials

Although stone properties are a highly significant factor in erosion, it was not possible to measure these during the research. Investigation of sandstone properties including mineralogy, cement type, porosity and alteration can only be undertaken in a laboratory. It would not be feasible to remove samples of historical stonework from the monuments in order to apply laboratory tests. Publications and existing archives such as the National Monuments Record, Regional Sites and Monuments Records and Listed Building data do not record such information for the market crosses, or indeed for any monuments. In most cases the quarries from which the stones were originally hewn are now disused or even of unknown provenance. Visual observation allowed some estimation of certain stone characteristics during fieldwork, such as the sandstone cement type, grain size and degree of sorting. However, in the absence of the later field visits this data could not be included in the sample selection criteria.

The sampling rationale was therefore to select a factor type common to all of the monuments - ie their age - and to consider for selection only market crosses for which an indisputable date of pre-1600 could be established. Due to the complicated individual history of intervention at each cross, the pre-1600 criteria was applied to the earliest part of each monument. Nineteen crosses satisfy these criteria, a number that could be easily accommodated by the fieldwork programme. The sampling strategy adopted meant that a 100% confidence level underpins assertions made for pre-1600 market crosses, since all of these were sampled. Furthermore, an examination of the recorded characteristics of these crosses showed that they exhibited a suitably wide range in terms of geographical location, climate, land-use, architectural type and level of intervention. The aim was to extrapolate the results from this pre-1600 sample to the broader market cross population of later construction dates. Although the confidence level of trends extrapolated to the broader population is lower, it can be borne in mind that the selected sample also includes market cross components which post-date 1600. The general frequency with which market cross components have been replaced means that most of the sampled market crosses include components that span a broad date range.

The decay rate of the crosses may not have been constant over the last few centuries and may have accelerated in the nineteenth and twentieth centuries due to the effects of atmospheric pollution. Thus, all other things being equal, a market cross dating from the nineteenth century may have suffered almost as much decay as a sixteenth century example and may require an equivalent level of intervention. To test this and to help formulate the management strategy, it was therefore decided that a selection of more recently constructed crosses should also be included in the sample. A further eight crosses were selected based upon this and the additional criteria that they should be representative in terms of their geographic distribution while fairly close to the examples already selected, and that the surviving cross remains should be substantial rather than fragmentary. It was decided that two crosses would be picked from each century post-dating the sixteenth (with the date again based upon the earliest surviving part of each cross).

3.2 Sample description

The crosses selected for the sample are listed in the Table 3.1 below along with a brief description of their date, design , designation, condition and environment. These characteristics comprise a range of values representing an appropriate cross-section of the broader population. For example, all of the land-use types and Listed Building Categories recorded for the population are represented in the sample.

Table 3.1 Summary of range of values for variables used in the sample selection criteria

Location of sampled market crosses	Region and OS national grid reference	Architectural type and theme of carved detail	Land-use type (immediate and general)	Listed Building Category	Date of earliest part	Originality of surviving parts	Frequency of re-siting	Degree of conservation undergone	Coastal proximity
Old Aberdeen	City of Aberdeen NJ 9391 0846	Shaft-upon-steps with heraldic capital and religious finial (now lost)	Pedestrian thoroughfare, city	B; A for group	1545	Poor	3	Low	Coastal
Ancrum	Borders NT 6282 2457	Shaft-upon-steps, former finial lost	Communal green, village	B	Late 1500's	Moderate	1	Moderate	Very inland
Banff	Aberdeenshire NJ 6896 6397	Shaft-upon-steps with crucifix finial	Pedestrian thoroughfare, town	A	1900	Poor	0	Low	Very coastal
Beauly	Highland NH 5268 4645	Shaft-upon-steps with undecorated capital	Pedestrian thoroughfare, town	None	1430	Poor	2	High	Inland
Bowden	Borders NT 5540 3051	War memorial with shaft and ancient cross finial	Grass verge, village	C	Late 1500's	Poor	0	Low	Very inland
Campbeltown	Argyll & Bute NR 7204 2044	Re-used Celtic cross with intricate religious carvings	Communal green, town	A	1380	Moderate	2	Low	Coastal
Cromarty	Highland NH 7898 6739	Shaft-upon-steps with cross finial	Museum garden, town	B	1578	Moderate	2	High	Very coastal
Culross	Fife NS 9868 8594	Shaft-upon-steps with heraldic finial	Traffic island, town	B	1588	Moderate	0	Low	Very coastal
Cupar	Fife NO 3752 1457	Pedestal base with shaft and heraldic finial	Traffic island, town	B	1683	Moderate	2	Low	Inland
Dallas	Moray NJ 1218 5183	Shaft-upon-steps with cross finial	Churchyard (in use), rural	A	Early 1500's	Good	0	Moderate	Inland
Duffus	Moray NJ 1750 6863	Shaft-upon-steps with cross finial	Churchyard (disused), rural	A	1300's	Good	0	Low	Coastal
Dunbar	E Lothian NT 6793 7895	Shaft-upon-steps and recently added capital with gargoyle protrusions	Pedestrian thoroughfare, town	B	1500's	Moderate	2	Moderate	Very coastal
Dundee	City of Dundee NO 4016 3008	Steps with pedestal, shaft and heraldic finial	Temporary indoor storage (normally pedestrian thoroughfare), city	B	1586	Poor	6	High	Very coastal

Table 3.1 Summary of range of values for variables used in the sample selection criteria *(continued)*

Location of sampled market crosses	Region	Architectural type and theme of carved detail	Land-use type (immediate and general)	Listed Building Category	Date of earliest part	Originality of surviving parts	Frequency of re-siting	Degree of conservation undergone	Coastal proximity
Edinburgh High Street	City of Edinburgh NT 2577 7359	Tower-base, shaft and heraldic finial	Pedestrian thoroughfare, city	A	1450	Moderate	4	High	Coastal
Edinburgh Canongate	City of Edinburgh NT 2647 7381	Steps, pedestal, shaft and heraldic finial	Churchyard (in use), city	B	1500's	Poor	4	Low	Coastal
Fowlis Wester	Perth & Kinross NN 9278 2404	Pictish cross-slab with intricate relief	Indoors (church), village	B	700's	Good	2	Moderate	Very inland
Houston	Renfrewshire NS 4053 6692	Shaft-upon-steps with sundial finial	Pedestrian thoroughfare, village	B	1300's	Poor	1	Low	Inland
Inveraray	Argyll & Bute NN 0966 0856	Re-used Celtic cross with intricate religious carvings	Pedestrian thoroughfare, town	A	1400's	Moderate	2	Moderate	Very coastal
Inverbervie	Aberdeenshire NO 8316 7268	Plinth with shaft-upon-steps and undecorated finial	Roads & carpark, town	B	1737	Good	0	Moderate	Very coastal
Inverkeithing	Fife NT 1301 8287	Shaft-upon-steps with heraldic finial	Pedestrian thoroughfare, town	A	1398-1500's	Moderate	2	High	Very coastal
Ochiltree	E Ayrshire NS 5081 2118	Shaft-upon-steps, finial lost	Traffic island, village	B	1836	Moderate	0	High	Inland
Ormiston	E Lothian NT 4142 6927	Monolith crucifix mounted on steps	Grass verge, village	B	1400's	Moderate	0	Low	Inland
Pencaitland	E Lothian NT 4409 6890	Pedestal with shaft and sundial finial	Grass verge, village	C(S)	1695	Moderate	0	Low	Inland
Rossie	Perth & Kinross NO 292 307	Shaft-upon-steps with heraldic finial	Arable field, rural	A	1746	Good	1	Low	Inland
Rutherglen	S Lanarkshire NS 614 616	Shaft-upon-steps with heraldic finial	Pedestrian thoroughfare, city	C(S)	1926	Good	0	Low	Very inland
Tain	Highland NH 7800 8212	Shaft-upon-steps with heraldic finial	Pedestrian thoroughfare, town	B	1500's	Poor	1	Low	Coastal
Turriff	Aberdeenshire NJ 7232 4979	Gothic Revival style pedestal with cross finial	Traffic island, town	B	1865	Moderate	1	Moderate	Inland

The sample characteristics are as follows:

3.2.1 Sample size

Twenty-seven market crosses were selected for the sample, representing approximately 18% of the total surviving examples in Scotland. This provided a sufficiently large proportion for analysis and for the development of a predictive model. Budget restrictions inhibited a larger sample. As the research objective is to develop and test a methodology, the sample could be extended in a future project.

3.2.2 Monument age

Each cross within the initially selected group of nineteen had at least one component pre-dating 1600. Thus, the earliest date of each market cross in this group ranges from the eighth century to 1588. However, other replaced components incorporated within these crosses date from as recently as 1996. Appendix B shows the date of construction of sampled crosses in relation to the date of carving of their components. The initial sample group consisted of:

Old Aberdeen	**Dallas**	**Houston**
Ancrum	**Duffus**	**Inveraray**
Beauly	**Dunbar**	**Inverkeithing**
Bowden	**Dundee**	**Ormiston**
Campbeltown	**Edinburgh High Street**	**Tain**
Cromarty	**Edinburgh Canongate**	
Culross	**Fowlis Wester**	

The eight crosses additionally selected include earliest parts which date from the following centuries:

Seventeenth century:	**Cupar**
	Pencaitland
Eighteenth century:	**Rossie**
	Inverbervie
Nineteenth century:	**Turriff**
	Ochiltree
Twentieth century:	**Banff**
	Rutherglen

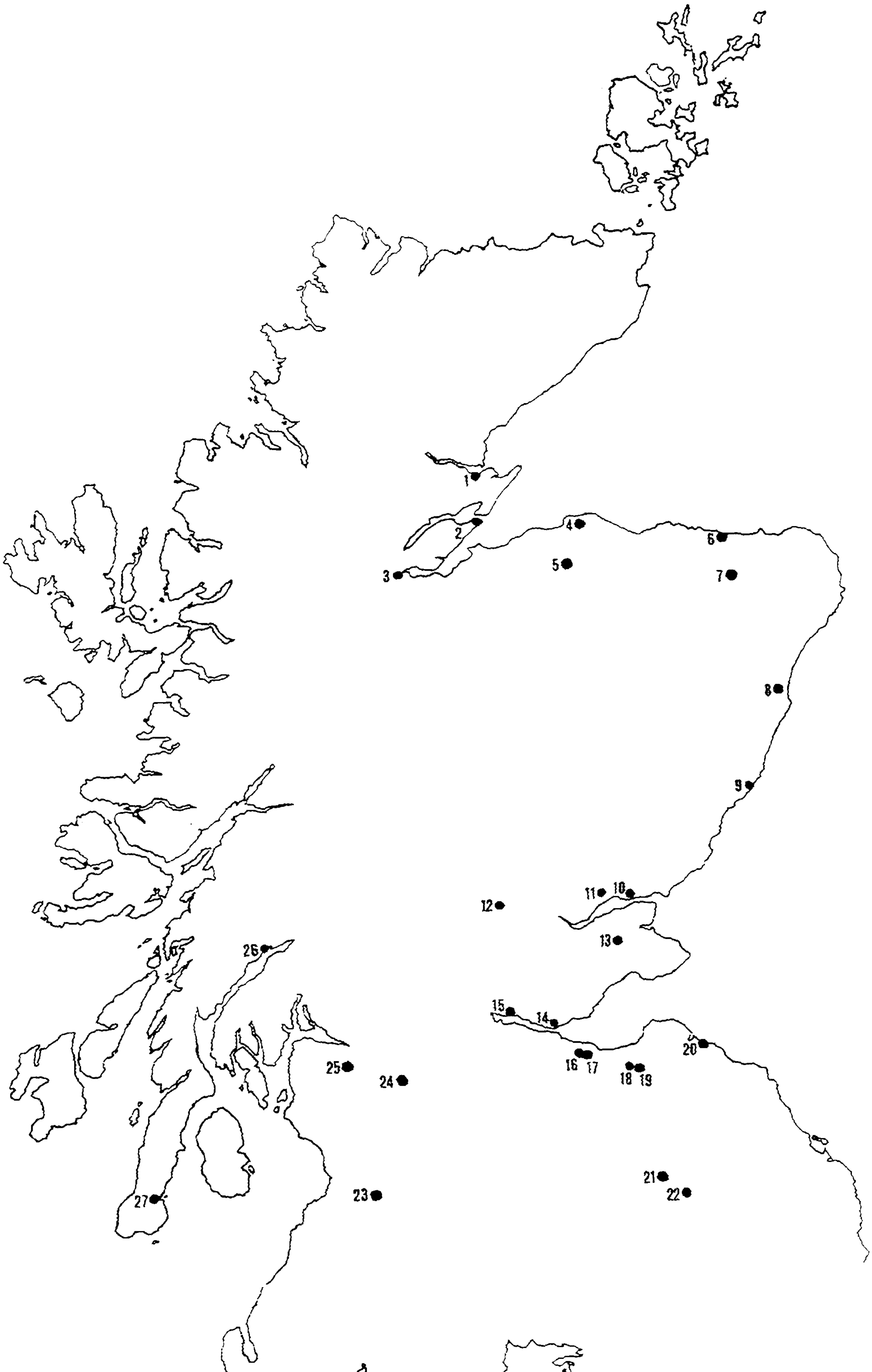
3.2.3 Geographical location

The sample has a scattered geographical distribution extending to Tain in the North, and with examples in the North-east, the Central Belt, Lothian, and the Borders, and West as far as Campbeltown. The distribution is shown in the map in Figure 3.1. The key to the numbering in the map is as follows:

1 Tain	10 Dundee	19 Pencaitland
2 Cromarty	11 Rossie	20 Dunbar
3 Beauly	12 Fowlis Wester	21 Bowden
4 Duffus	13 Cupar	22 Ancrum
5 Dallas	14 Inverkeithing	23 Ochiltree
6 Banff	15 Culross	24 Rutherglen
7 Turriff	16 Edinburgh High Street	25 Houston
8 Old Aberdeen	17 Edinburgh Canongate	26 Inveraray
9 Inverbervie	18 Ormiston	27 Campbeltown

Altitude varies from 5 to 180m OD (the range for the entire population is 5 to 265m OD). See also description of coastal proximity below (Section 3.2.10).

Figure 3.1 Map showing the distribution of sampled market crosses.



3.2.4 Architectural type and theme of carved detail

The architecture in the sample represents a reasonable cross-section of the whole It includes one tower-base type, a few with tall octagonal or square pedestals, two re-used Celtic crosses, a re-used Pictish cross-slab and many others approximating more or less to the common shaft-upon-steps morphology. Some have heraldic finials, others exhibit various types of Christian cross, sundials or unornamented finials. The degree of carving ranges from plain to intricate. The sample therefore exhibits satisfactory architectural diversity.

3.2.5 Land-use type

Crosses with both urban and rural settings are included in the sample. Five crosses have city locations, twelve are in towns, seven are in small villages, and three have a rural location. It is therefore expected that there will be varied exposure to pollution from urban sources. A range of land-use types is represented, with sampled market crosses located on pedestrian thoroughfares, on roads, communal green areas, grassy verges, on arable land, in churchyards, and even inside a church in one case (Fowlis Wester). The ground surfaces around the sampled crosses include tarmac, paving stones, cobble stones, grass and even a flowerbed. The data for land-use type is incomplete for the other, unsampled crosses as in some cases this cannot be established without site visits. Of the five market crosses now located indoors, two fall within the sample. The Fowlis Wester cross-slab was removed indoors in 1991. However, archived records had indicated that Dundee cross was located out-of-doors on a pedestrian thoroughfare, and it was not until the day of the field visit that it was discovered that this monument had been removed indoors two months previously. Out of the ten population examples located within private grounds, one falls into the sample group (Rossie).

3.2.6 Listed Building category

This is a statutory designation, corresponding to 3 levels of protection represented by (in descending order of importance) Category A, B and C(S). The range in the sample is representative of that in the broader cross population. On the other hand, Scheduled Ancient Monuments are rather over-represented in the sample. Sixteen (59%) of the sampled crosses are Scheduled Ancient Monuments, compared with 34% in the whole population. This is not expected to have any effect upon the levels of observed decay and soiling recorded during the survey, although ideally, monuments afforded greater statutory protection should exhibit a high standard of conservation.

3.2.7 Originality of surviving parts

In the above Table (3.1), the originality of surviving parts describes the degree to which the crosses still consist of their original parts or have had parts replaced (listed in further detail in Appendix B). Thus, 'good' survival indicates that all parts of the monument have remained in place since its construction, while 'poor' survival indicates that the monument has been massively modified, or has been mostly replaced with later parts. It is a measure of the extent to which parts within any one market cross are contemporary with one another. The addition of new stone parts to a monument could introduce a new set of problems if their properties are not sufficiently matched to those of the existing stones. Most of the crosses are complete in their overall composition, with the exception of Ancrum in which the upper area of the shaft is truncated and finial missing, and Old Aberdeen and Ochiltree which both have their finial missing. It was decided that all sampled market crosses ought to be largely complete, with adequate dimensions, in order to produce a suitable quantity of stone decay data. For example, several cases were excluded from the selection process because they survive as merely a small, single fragment, such as the socket stone at Castle Hill, Old Cullen, the stump of a shaft at Marykirk, and the fragment at Forfar.

3.2.8 Frequency of re-siting

The frequency of re-siting in the sample ranges from 0-6 instances per cross. As Dundee is the cross which has been subject to the most frequent re-siting out of all of the crosses in Scotland, the sample represents the entire range of re-siting frequencies. Market crosses have tended to remain within the same general area of their origin through time, with removals usually involving short distances of several metres. The site of each market cross is important in determining the micro-environment to which it is exposed and the act of removal itself poses risks of damage. Occasionally crosses have been re-erected such that the orientation of their facades has changed. Certain of the components from at least three crosses in the sample have an altered orientation due to this (Ancrum, Beauly and Inverkeithing). This fact was taken into account in the later data analysis.

3.2.9 Degree of conservation undergone

In Table 3.1 above, this classification represents the level of conservation undergone by each monument. Note that a 'low' rating does not necessarily indicate neglect and poor condition as it depends to an extent upon the age of the cross, its environment, and the condition and resilience of the stone. Indeed, some instances of repair have proved unsuitable and introduced further stone decay. The crosses exhibit various frequencies of conservation episodes, commonly including repointing, plastic repairs, clamping, rendering, replacement of parts and removal of some parts indoors. However, details of the types of intervention methods and materials used in the past have often not been well-documented, and in many cases the field surveys helped to clarify the nature of the intervention acts.

3.2.10 Coastal proximity

Moist, sea-salty atmospheres could be a factor in the decay observed on crosses with a coastal location. The influence of this can be tested since the sampled crosses are located at various distances from the coast. In order to ensure a more rounded representation of the amount of salt-loading in the atmosphere at cross sites, the coastal proximity was not simply derived by measuring the lowest distance to the coast from the cross. Some crosses are more open to marine influence if they are encircled by sea on more than one side (eg if on a peninsula). Additionally, the wind direction may affect the risk posed to monuments by sea-salt. As Scotland is part of the British Isles, no locations are very far from the sea if we compare them to sites in the middle of other larger continental masses. However, the categories used in the classification scheme are a four-point scale intended to provide an indication of the relative degree of coastal proximity *within* Scotland. During the data processing, distance to the sea in eight directions was measured from each cross (ie N, NE, E, SE, S, SW and W, NW). The subsequent classification scheme includes consideration of the number of directions from the cross in which the sea is located in close proximity. Coastal proximity, for the purposes of the data analysis, also includes large firths (the Tay and the Forth) and inlets (Loch Fyne). The sampled crosses are located at various distances from the coast. The criteria for the classification is as follows:

Very coastal: Lowest distance from the cross to the coast is <2km, in at least 3 directions (eg N/NE/E)
Coastal: Lowest distance from the cross to the coast is <5km, in at least 2 directions (eg N/NE)
Inland: Lowest distance from the cross to the coast is between 5-20km in any direction
Very inland: Lowest distance from the cross to the coast is >20km in *all* directions

In conclusion, the crosses selected for the sample exhibit a sufficiently good cross-range of data values for the key variables considered most important to stone decay and soiling.

3.3 Pro-forma and database design

A relational data-base was designed, containing the following seven sets of data about the market crosses:

- Cross location and designations
- Site history
- Environmental features
- Intervention
- Ownership
- Stone properties and architectural characteristics of individual cross components
- Decay/soiling patterns for individual cross components

Market crosses have frequently been moved around, therefore the database is designed to include this chronological data. That is, it incorporates data regarding re-siting episodes and changes in the environmental factors incurred by each cross since its erection. This is achieved by use of the '*Site history*' and '*Environment*' sets of data, in which information pertaining to successive locations can be recorded for each cross. Data relating to these former sites was obtained, where available, from documentary evidence or alternatively could be deduced in some cases.

Often market crosses have also had certain of their component parts replaced over the years. The resulting composition introduces further factors affecting decay into the equation. Therefore this information was also considered in the analysis and was incorporated in the *'Cross components'* data set. Here, data regarding the architectural characteristics, stone properties and condition was recorded per component, thus allowing for differences in their date.

3.3.1 Classification and recording of individual cross components

The classification and recording of individual cross components presented some difficulties and the method used therefore requires some explanation. The early examples of market crosses are relatively simple in construction, and frequently consist of a few basic component types: a stepped base, socket stone, shaft, capital and finial. However, later examples of market crosses sometimes have other built features such as pedestals, and are more varied and complex in their design. Subdividing the crosses into their constituent components in a consistent and meaningful way is therefore problematic. However, the following classifications were used to subdivide the crosses into units for analysis:

Steps
Socket stone
Plinth
Pedestal
Shaft
Finials
Friezes
Capitals
Built tower-base

The full range of these components is, of course, not represented in the design of every cross. However, the morphology of each cross can usually be described by selecting four or five of these component types. Note that in the subsequent data analysis, some component types which exhibited low frequencies in the sample were merged with other similar component types for the purposes of query, eg finial, friezes and capitals were considered together, as were steps and plinths. There were a few other miscellaneous architectural forms which were unique or had very low frequencies, eg inscribed boulder, well and fountain; however, none of these occurred within the sample group.

Market crosses have sometimes had very complicated intervention histories and many could potentially have an indefinite life-span, enabled by piecemeal replacement of the constituent parts. Over the centuries some examples have been modified and had component parts replaced, and other examples have been almost completely redesigned (eg Dundee and Aberdeen Castlegate crosses). Some are now left only with a core or a marginal piece of the original. Therefore, the issues of the age and the state of survival of individual crosses can become quite confused. However, the construction date and the survival category recorded in the database were each an overall assessment assigned per market cross and classified according to the oldest part of the monument. In a few cases, a repair has been made using a stone indent or a small part of a component has been replaced, eg only part of the shaft of Dundee cross is original. In such cases, the component was nonetheless dated in the database by the age of its oldest part. Market crosses are 'living' monuments in the sense that their history is ongoing. Restorations are still being made to them and will no doubt continue to made to them in the future, as they are still seen as having a role to play, albeit a changed one, in town centres. Accordingly, all component parts despite their date were examined and recorded in the same way. Recording the condition of the more recently carved monument parts will add to our understanding of decay mechanisms from the earliest stage of their development.

The data collection and analysis aimed to deal with current decay and soiling patterns observed on the crosses. However, the condition of the replaced, damaged components ought also to be taken into account for a more comprehensive analysis of the survival of market crosses over recent centuries. This information was recorded within the database where available, and these former cross components were denoted as such in the database by prefixing them with a minus sign.

3.3.2 Data fields for pro-forma and database

The variables collected and recorded in both the paper pro-forma and the database are listed below, grouped by general type. In the case of several of the variables, values were described by selecting an appropriate pre-defined classification. For example, the state of survival, level of carved detail and traffic density were all variables with classified values. This allowed standardisation in the data for more effective statistical analysis. Lists of the range of options and the criteria for their definition can be found in the Appendix C. All surviving crosses in Scotland were individually recorded in the database; however, an increased level of data was collected for the sampled crosses. The data types recorded for all of the population crosses are shown in normal font in the lists below. This data was collected by consulting the existing archives and publications (these sources were reviewed in Section 2.2). However, the data types collected during the fieldwork and pertaining only to the 27 sampled crosses are shown in italics.

Location and designation

These variables record details that are mostly already recorded in existing archives, and which refer to the current situation of each market cross. The data includes locational details, protective designations and climatic characteristics:

Market cross i.d. no.
Town
Street
District
Local Authority Region
National Grid Reference
Architectural type of cross
NMRS i.d. no.
SMR i.d. no.
Listed Building Category
Date of Listing Building designation
Scheduled Ancient Monument status
Scheduled Ancient Monument i.d. no.
Date of Scheduling designation
Date of cross construction
Date of NMRS consultation
Date of SMR consultation
Cross included in the sample?
Date of field survey
Light conditions during field survey
Moisture conditions during field survey
State of survival of monument
Conservation requirements
Altitude
Coastal proximity
Wind speed
Site aspect
Topographic features affecting environment
Humidity
Annual average daily mean temperature
Annual average precipitation
Annual average days of air frost
Average annual days of fog
Local climate station
Climate station altitude
Historical background of cross (free text field)

Site history details

The following variables record data pertaining to each site occupied by the cross since its construction. The data fields are as follows:

Market cross i.d. no.
Site sequence no.
Location within town
Date of erection upon site
Land-use type
Documentary evidence of damage (free text field)

Environmental features

The following set of variables describe environmental factors associated with each market cross, for every site they have occupied since their construction:

Site no.
Environmental feature
Proximity to environmental factor
Orientation of environmental factor in relation to cross
Date range for existence of environmental feature
Road class (for most prominent nearby road)
Traffic density (for most prominent nearby road)
Environmental comments (free text field)

Cross component data

The following set of variables were recorded for each individual component in the crosses (ie commonly for the shaft, steps, socket stone, capital and finial):

Component i.d. no.
Component type
Component age
Component material
Source of stone (quarry or locality)
Sandstone cement type
Sandstone grain size
Degree of sandstone sorting

Stone colour
Architectural features
Degree of carved detail
Sandstone inclusions
Details of damage (free text field)
Applied features and substances

Decay/soiling patterns

These variables record information about the decay and soiling observed on each sampled cross component during the fieldwork programme of the research in 1998. A separate entry was made for each decay and soiling type per component. Note that more specific information regarding the surface extent of the decay and soiling types is shown upon the drafted mappings.

Component i.d. no.
Component type
Decay/soiling class
Decay/soiling type
Severity or density of the decay/soiling
Surface extent of the decay/soiling
Orientation(s) of the cross facade upon which the decay or soiling is apparent

Intervention details

The following set of variables records details of intervention episodes that have occurred since the erection of each cross. The data includes all documented episodes of intervention derived from the existing archives. However, information about previous intervention is often not detailed in these archives, and in some cases intervention episodes are not even recorded. Therefore, deductions made from field observations and archived photographs were also used to derive this data during the research. A separate entry was made per intervention episode, per cross, to describe the following:

Cross i.d. no
Class of intervention
Type of intervention
Year of intervention
Body responsible for the intervention
Cross components affected
Details of intervention (free text field)
Source of intervention details

Ownership details

The following data were also recorded about the ownership of the each cross since its construction, since some crosses were occasionally purchased and removed by private owners:

Market cross i.d. no.
Owner
Date from which ownership commenced

3.4 Mapping method

A mapped illustration of decay and soiling on a monument conveys a different level of information in comparison to a photograph. A mapping provides an interpretation of the observed decay, soiling and conservation features, with delineated boundaries, whereas in photography these features may be less clearly visible and variously interpreted by subsequent workers. It is therefore not sufficient to record such features by photography alone. The mapping method used in the survey was developed from that pioneered by Fitzner et al (1989; 1992; 1995; 2000), in which decay and soiling and features were identified on-site by visual observation. The decay and soiling patterns were delineated in each mapping, and were named and assigned classifications to indicate their severity and surface extent. Applied conservation materials were also mapped. These recordings were drafted onto scaled elevation sketches of each facade of the crosses. Examples of two of the elevation mappings produced during the fieldwork are shown in Figure 3.2a and 3.2b, and the success of this technique was reviewed following the fieldwork (see Sections 3.8.1 and 3.8.2 below).

Figure 3.2a Example of a mapped facade: Ancrum market cross, Border region.

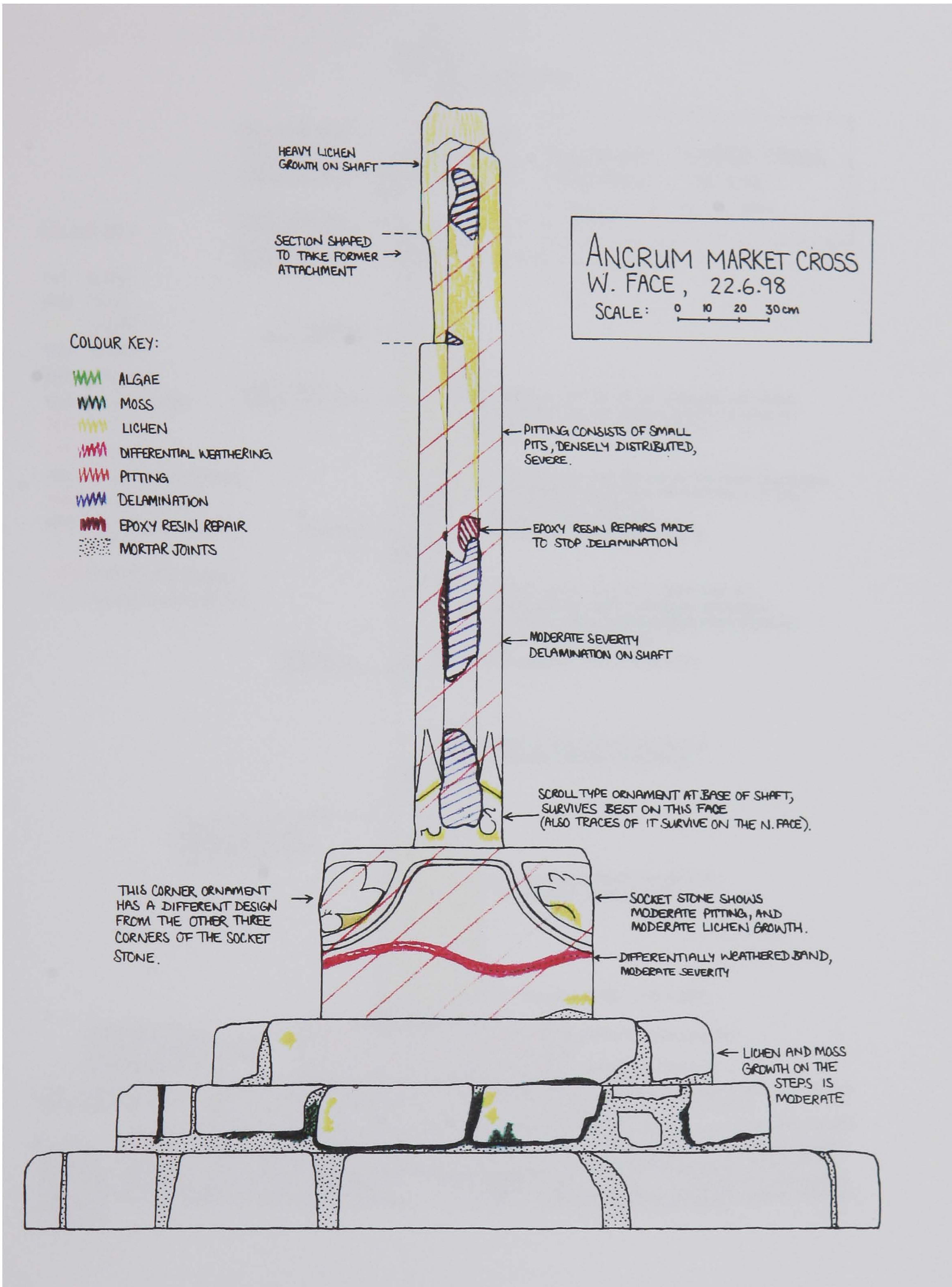
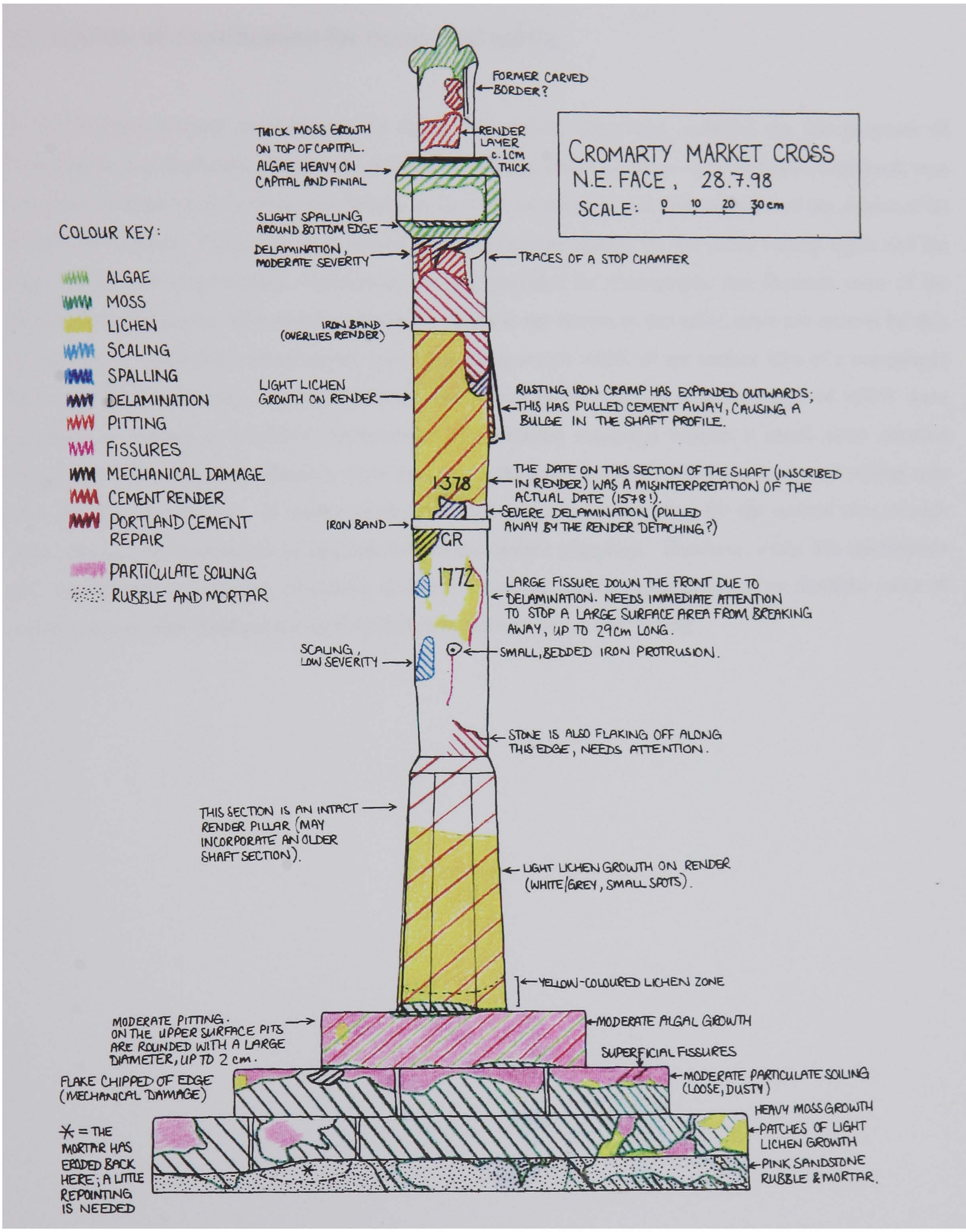


Figure 3.2b Example of a mapped facade: Cromarty market cross, Highland region.



3.5 Scheme of classification for decay and soiling

A classification scheme consisting of 24 decay and soiling types was compiled for the purposes of recording during fieldwork. Each case of decay or soiling observed upon each sampled component was classified in terms of its severity (or density in the case of soiling), and also in terms of the extent of its surface distribution. Table 3.2 below shows the classification criteria for the decay/soiling types and the degree of their severity/density. References are also provided for photographs that illustrate some of the decay and soiling types. The distribution classification is not shown in this table, since the criteria for this can be simply explained: decay/soiling types extending across >50% of the surface area of a component were classified as having a 'general' distribution, while those covering a surface area of <50% were described as having a 'localised' distribution. The drafted mappings contain a much more detailed indication of the surface distribution, since they depict the exact boundaries of each decay and soiling type observed upon the crosses. It was originally intended that an absolute value for the surface area of each decay and soiling type would be calculated from the drafted mappings. However, while this distribution data was drafted and roughly classified, time did not allow for the transference of an absolute value of surface area into the database for each recorded instance of decay and soiling.

Table 3.2 Scheme used during fieldwork for classification of decay and soiling

BIOLOGICAL SOILING TYPES				
Soiling type	**Identification criteria**	**Severity/density classification**		**Photo plate reference**
Algae	Green, sometimes streaky, slimy growth across the masonry surface.	Low	Thin, light green layer/patch through which the masonry is visible	-
		Moderate	Bright green layer	-
		High	Thick, continuous, dark green layer, obscuring the masonry surface.	Plate 3.1
Lichen	Growth evident as numerous small spots or large maculae across the masonry surface Colour, degree of foliage, growth rate and environmental preferences vary according to species.	Low	Scattered, small spots.	-
		Moderate	Large maculae.	Plate 3.2
		High	Continuous, thick layer.	Plate 3.3-3.4
Moss	Green, furry growth occurring in patches on the masonry surface or growing along the line of joints or crevices.	Low	Small spots	-
		Moderate	Continuous strip or larger patches	-
		High	Continuous, thick layer.	Plate 3.5
Higher plants	Grassy weeds and/or plants with 'woody' stems rooted in masonry joints or crevices.	Low	Small patch(es) of young, grassy weeds	-
		Moderate	Strip or multiple patches of weeds	-
		High	Mature and abundant growth of grassy and/or woody plants	Plate 3.6
Fungi	Small spots or patches of a furry growth on the masonry surface, grey-green, black or brown in colour.	Low	Small spots of fungal growth	Plate 3.7
		Moderate	Larger spots of fungal growth	-
		High	Continuous, thick layer of fungus	-

Plate 3.1 Heavy algal growth on Ormiston market cross finial.

Plate 3.2 Moderate lichen growth on Pencaitland market cross steps.

Plate 3.3 Dense lichen growth on Rossie market cross.

Plate 3.4 Dense lichen growth on Dallas market cross socket stone.

late 3.5 Dense moss growth on Cromarty market cross steps.

Plate 3.6 Dense growth of higher plants on Rossie market cross steps.

Plate 3.7 Small, white spots of fungal growth on Fowlis Wester cross-slab.

Table 3.2 Scheme used during fieldwork for classification of decay and soiling *(continued)*

NON-BIOLOGICAL SOILING TYPES				
Soiling type	**Identification criteria**	**Severity/density classification**		**Photo plate reference**
Bird excrement	Whitish droppings normally on upper parts of monument	Low	Solitary or scattered splatters	-
		Moderate	Dense splatters	-
		High	Thick and continuous layer	-
Black crust	Thick, crusty layer upon sheltered parts of the masonry surface, mainly composed of gypsum. The black colouration is caused by soiling.	Low	Isolated dark patch	-
		Moderate	Thick black patch of crust	-
		High	Thick, black continuous layer; parts of the crust may be detaching or blistering	Plate 3.8
Efflorescence	White deposit of salt crystals upon the masonry surface, particularly around the joints and base of the structure	Low	Scattered, thin deposit of salt grains	-
		Moderate	Moderate patches	-
		High	Thick, continuous strips or layer	Plate 3.9
Painted graffiti	Graffiti drawn or written on the masonry surface with pens or paint	Low	Isolated, small patch	-
		Moderate	Multiple small patches	-
		High	Large, visually intrusive patch(es) of graffiti applied with paint	-
Particulate soiling	Film of dirt particles (eg soot) adhering to the masonry surface. Sometimes the soiling is a thin, hard layer, in other cases the deposit consists of loose, dusty particles.	Low	Light grey, thin deposit	-
		Moderate	Grey-black layer	Plate 3.10
		High	Thick, black, sooty deposit or thick layer of loose, dusty particles	Plate 3.11
Staining	Localised stains upon the masonry surface, due to leaching from metal attachments	Low	Light, surface trace	-
		Moderate	Moderate stain	Plate 3.12
		High	Large, dark stain	-

Plate 3.8 Severe, black gypsum crust on Edinburgh High Street market cross.

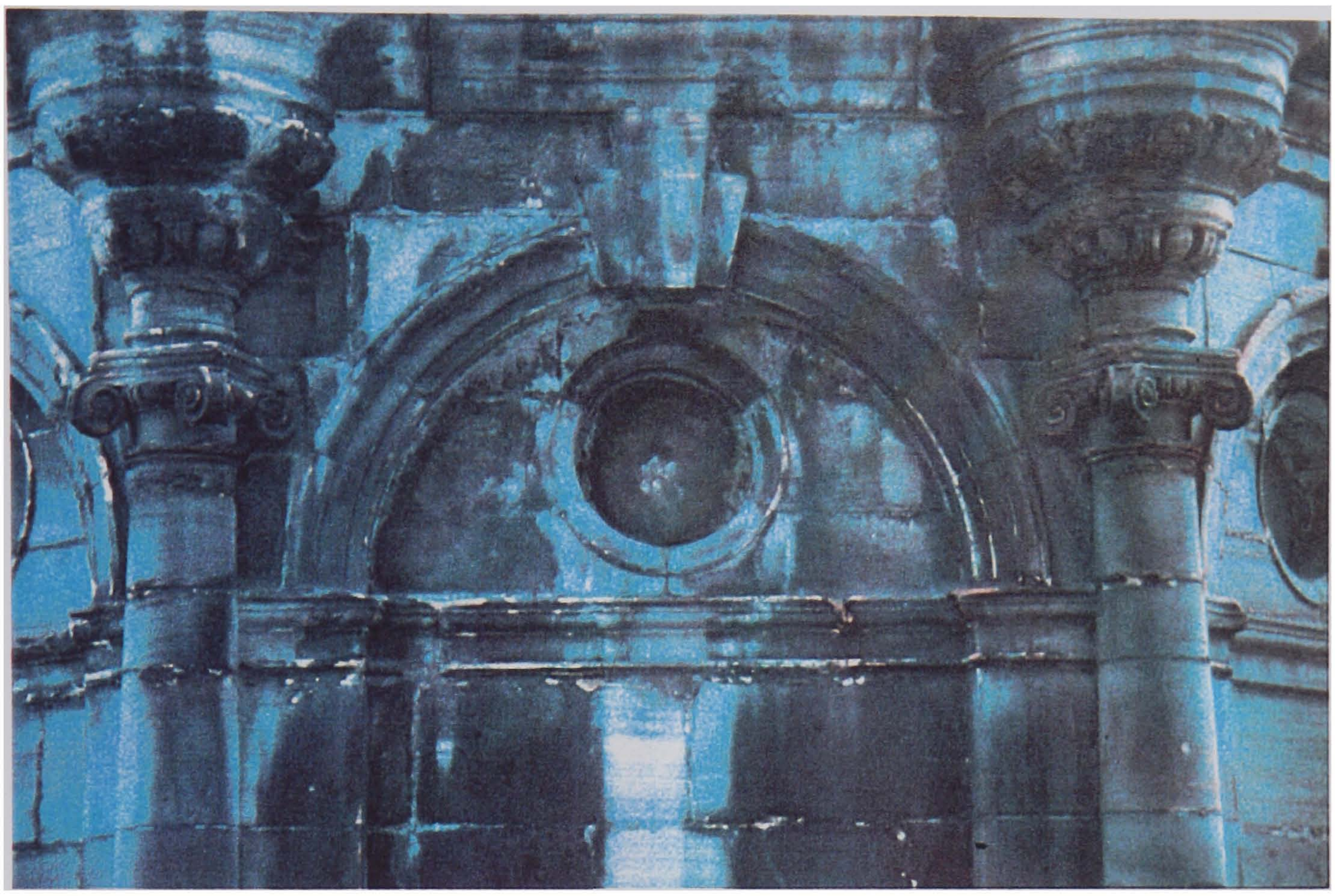


Plate 3.9 Dense efflorescence deposit on Edinburgh High Street market cross.

Plate 3.10 Moderately dense particulate soiling Ochiltree market cross.

Plate 3.11 Dense particulate soiling on Culross market cross.

Plate 3.12 Moderate staining left by iron attachment on Edinburgh Canongate market cross.

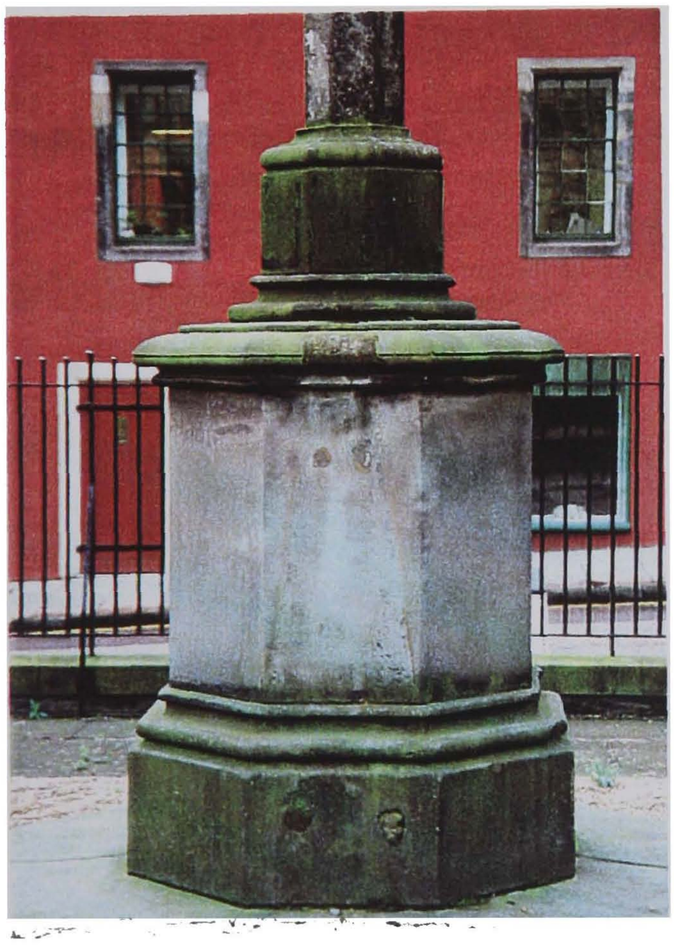


Table 3.2 Scheme used during fieldwork for classifying decay and soiling *(continued)*

GRANULAR DISAGGREGATION TYPES				
Decay type	**Identification criteria**	**Severity/density classification**		**Photo plate reference**
Crumbling	Large 'crumbs' of sandstone grains, up to a few mm in size detach from the surface when touched	Low	One or two small crumbs can be detached when rubbed	-
		Moderate	Some small crumbs detach to the touch	-
		High	A substantial amount of stone crumbles away from the surface to the touch	Plate 3.13
Differential weathering	The masonry surface has eroded inwards in places; more vulnerable layers have weathered deeper, producing a furrowed profile	Low	Very shallow (<2mm) continuous strips of grains lost from the surface	-
		Moderate	Some layers eroded inward to a depth of a few mm	Plate 3.14
		High	Numerous vulnerable layers eroded inwards to a depth of between one and a few cm.	Plate 3.15
Dissolution	The cementing material has been dissolved leaving a porous, spongy-textured masonry surface	Low	Affected stone has an increased porosity	-
		Moderate	Affected stone is weakened and has a visibly increased porosity	-
		High	Affected stone is weaker and has a very porous, spongy appearance	-
Granulation	Individual sandstone grains are detaching from the surface	Low	Grains have been shed from the surface, but the surface is stable when touched	Plate 3.16
		Moderate	A few grains detach when the surface is rubbed	-
		High	A substantial quantity of individual grains detach from the surface when touched	Plate 3.17
Honeycomb weathering	A dense network of cavities across the masonry surface. Individual cavities can have a diameter of between one and several cm, and can be up to a few cm deep.	Low	Dense network of small, deep pits	-
		Moderate	Cavities are dense with moderate diameter of 1-2cm	Plate 3.18
		High	Large, mature cavities, with some that have merged together	-
Pitting	The masonry surface is pock-marked with small, shallow pits	Low	Small, shallow pits (<5mm diameter), widely scattered	-
		Moderate	Small, densely distributed pits, or large, scattered pits	Plate 3.19
		High	Numerous, dense, large pits (5-20mm diameter)	-

Plate 3.13 Severe crumbling on Cromarty market cross shaft.

Plate 3.14 Moderate differential weathering on Tain market cross socket stone.

Plate 3.15 Severe differential weathering on Ormiston market cross socket stone.

Plate 3.16 Light granulation on Culross market cross shaft.

Plate 3.17 Severe granulation on Dunbar market cross shaft.

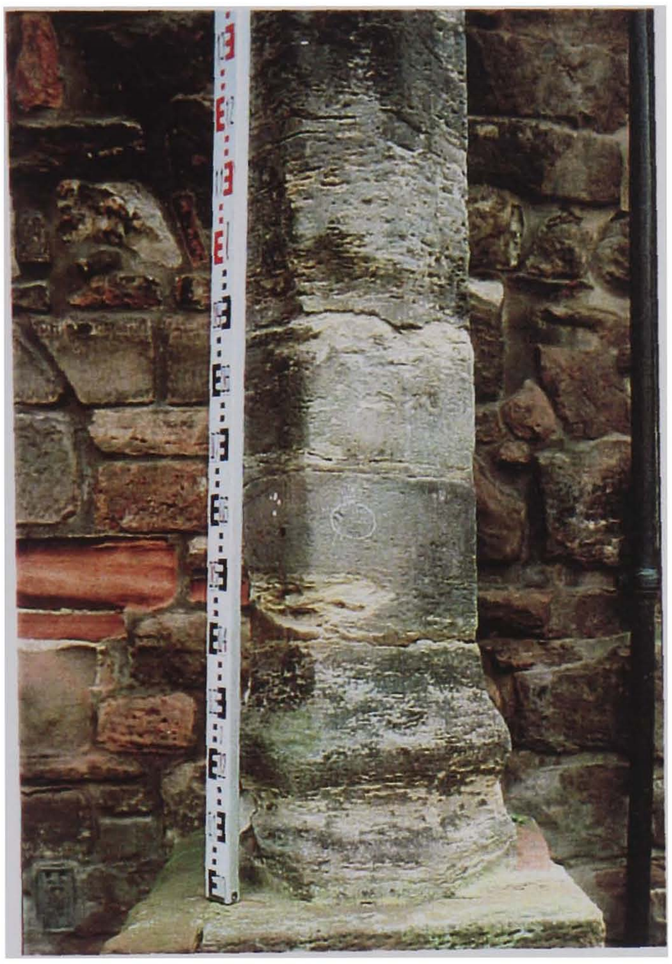


Plate 3.18 Moderate honeycomb weathering on Ormiston cross-shaft.

Plate 3.19 Moderate pitting on Turriff market cross pedestal base.

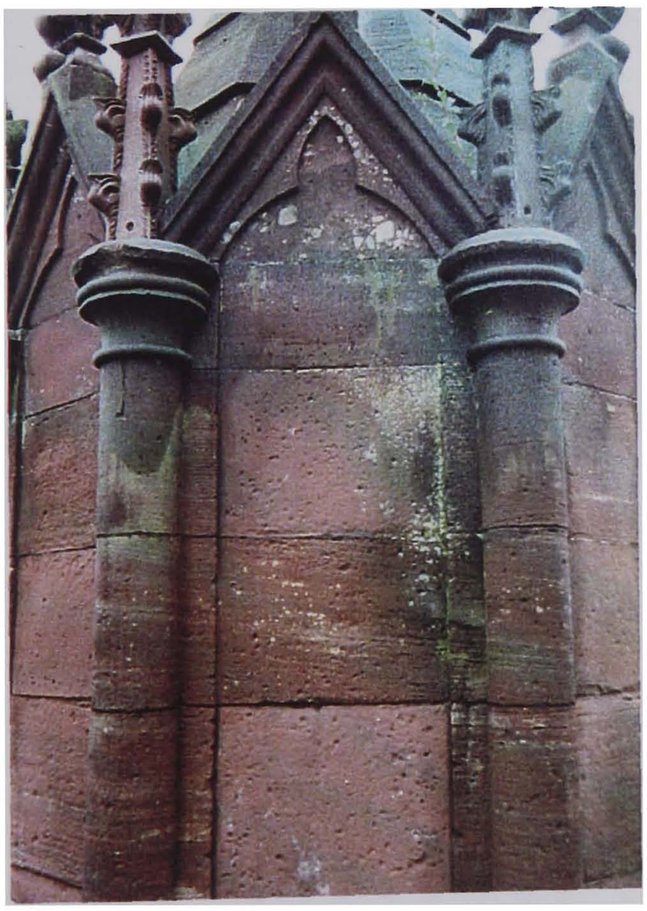


Table 3.2 Scheme used during fieldwork for classifying decay and soiling *(continued)*

PLANAR DISAGGREGATION TYPES

Decay type	Identification criteria	Severity/density classification		Photo plate reference
Blistering	Swelling and rupturing of a thin surface layer, evident as patches of small scales blistering outwards	Low	Scattered small blisters <1cm	-
		Moderate	Series of small blisters (<1cm diameter), flake and crumble from the surface when touched	-
		High	Large blisters (up to several cm diameter), flake and crumble from the surface when touched	Plate 3.20
Delamination	Separation of sandstone layers causing detachment of planes. Often occurs at the surface of face-bedded sandstone	Low	Some small scales have delaminated (<2mm depth)	-
		Moderate	Delamination has occurred to a moderate depth (2-5mm) and further scales are developing	-
		High	Large delaminating scales feel loose or detach to the touch, multiple layers may be exposed	Plate 3.21
Flaking	Small planes of stone (<5mm diameter) are detaching from the masonry surface	Low	One or two small, thin flakes have detached	-
		Moderate	Some flakes have detached, and further flakes are detaching	-
		High	Flakes are numerous and/or are relatively thick	Plate 3.22
Scaling	Larger planes of stone (>5mm diameter) are detaching from the masonry surface	Low	One or two small scales have detached	-
		Moderate	Some scales have detached, and further scales are detaching	-
		High	Large or thick scales detach to the touch	Plate 3.23
Spalling	Layer of stone of consistent depth is detaching from the surface, following the surface contours. Detaching pieces make a hollow sound when tapped	Low	Thin layer 1-2mm thick has spalled or is spalling	-
		Moderate	Layer 2-5mm deep is detaching, or two or more thin layers are detaching simultaneously	-
		High	Material spalled/spalling to depth of 5-10mm (one thick layer or multiple layers detaching)	Plate 3.24-26

FRACTURE TYPES

Fracture type	Identification criteria	Severity/density classification		Photo plate reference
Fissures	A crack (or cracks) of various widths penetrate the masonry, for a short distance or splitting the entire masonry part	Low	Single hairline fissure (<1mm wide) of limited extent and depth	-
		Moderate	Two or three fissures affecting the stone to up to half its depth	-
		High	Substantial depth of stone penetrated by a network of multiple fissures, or a wide crevice	-
Mechanical damage	An impact has caused breakage or chips have been accidentally or deliberately broken off the edges of the masonry	Low	A small chip has been lost off the edge of the masonry	-
		Moderate	A few small chips or one or two larger chips have been lost off the edges	Plate 3.27
		High	A substantial chip has been lost or a masonry part has been completely broken in half or fragmented	Plate 3.28

Plate 3.20 Severe blistering on Edinburgh High Street market cross.

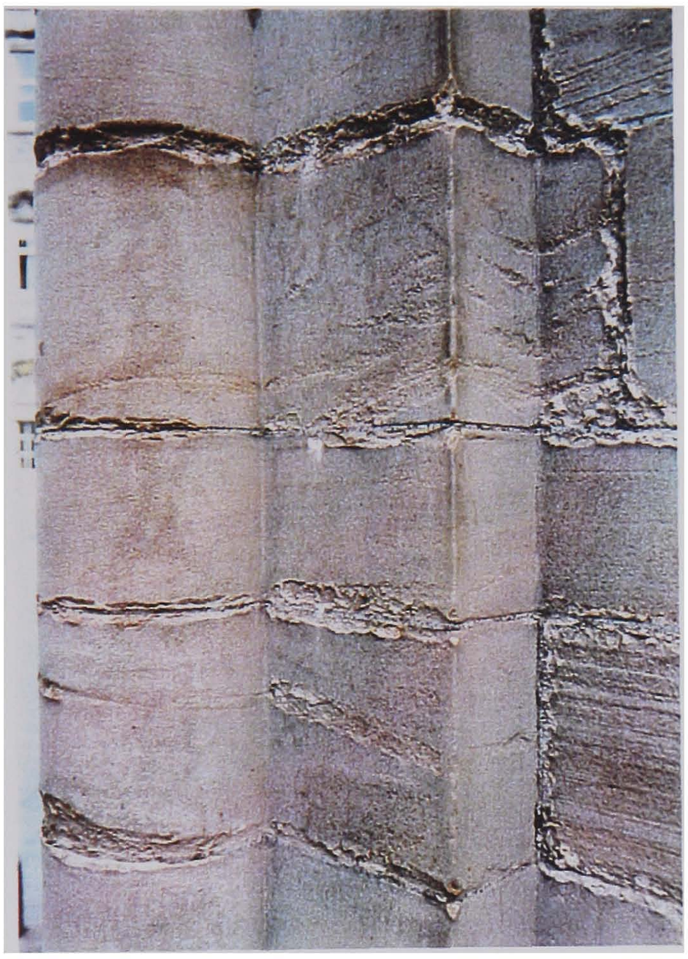


Plate 3.21 Severe delamination on Fowlis Wester cross-slab.

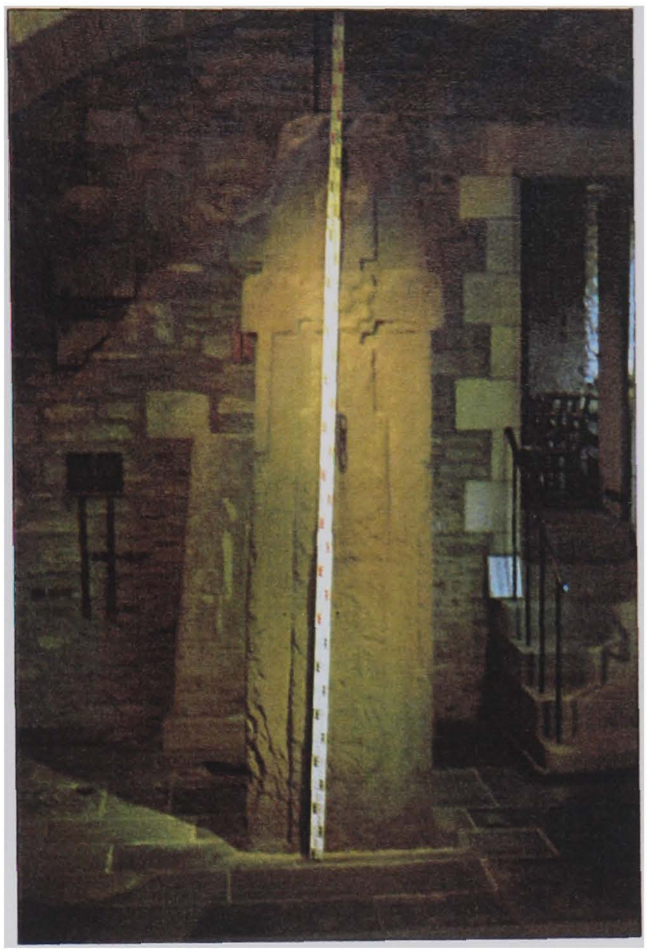


Plate 3.22 Severe flaking on Old Aberdeen market cross shaft.

Plate 3.23 Severe scaling on Turriff market cross pedestal base.

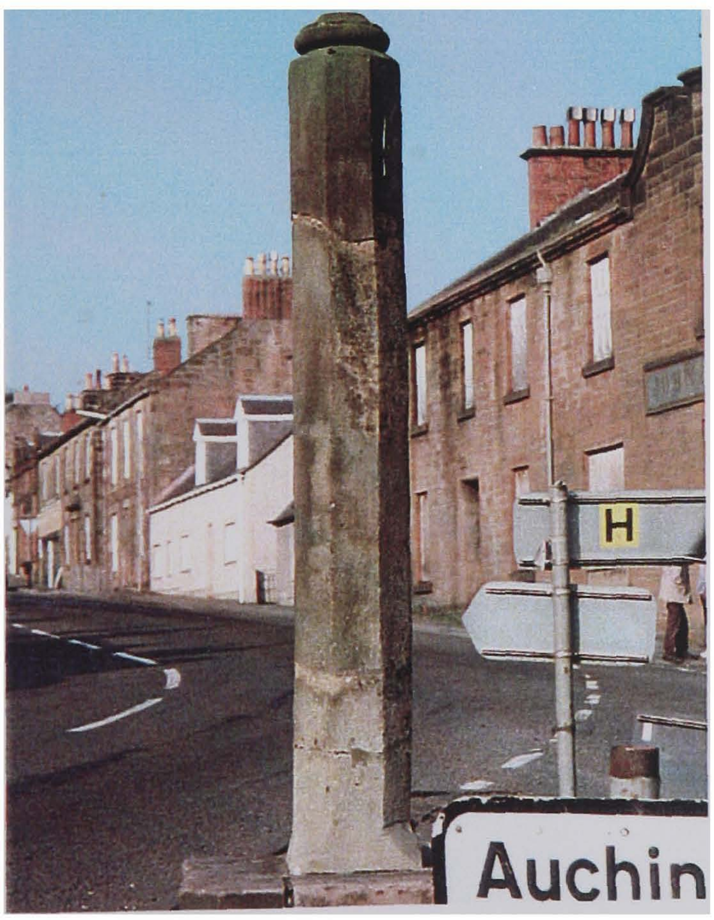
Plate 3.24 Severe spalling on Edinburgh Canongate market cross steps.

Plate 3.25 Severe spalling on Pencaitland market cross pedestal base.

Plate 3.26 Severe spalling on Rutherglen market cross steps and shaft base.

Plate 3.27 Moderate mechanical damage on Inveraray cross-shaft (see right-hand profile).

Plate 3.28 Severe mechanical damage on Ochiltree market cross, breakage of shaft.



3.6 Selection of climate data

Moisture ingress is the prime factor in stone decay (see Section 2.1.3), thus all climatic factors which influence the degree of water ingress, its evaporation and the cycles of crystallisation and dissolution induced by this are relevant. This would include the level of rainfall, frequency of frost and fog, temperature and the degree of its fluctuation, incidence of direct solar radiation, relative humidity, and exposure to wind and wind speed. However, the climate experienced at each cross is also dependent upon site aspect, topography and shelter due to the built environment, thus these environmental characteristics have also been recorded based upon visits made to the crosses.

Annual average climate data was obtained from 29 climate stations selected from throughout Scotland. Care was taken to ensure that selected climate stations were located as near as possible to the sampled crosses, particularly with regard to latitude due to its effect upon temperature. Additionally, the selection process for climate stations ensured that altitude differences between the stations and corresponding crosses did not exceed 100m, indeed the height difference between the two is most often <50m. The map in Figure 3.3 shows the distribution of selected climate stations and corresponding crosses. The key to the numbering of these is shown in Table 3.3 below along with corresponding altitudes.

Table 3.3 Selected climate stations and corresponding sampled crosses (altitudes shown in metres).

No.	CLIMATE STATION	CORRESPONDING SAMPLED CROSSES
1	Kirkwall (26m)	-
2	Wick (36m)	-
3	Fortrose (5m)	Beauly (5m); Cromarty (5m); Tain (25m)
4	Kinloss (5m)	Duffus (15m)
5	Banff (15m)	Banff (20m)
6	Forehill (41m)	Turriff (45m)
7	Leith Hall (180m)	Dallas (155m)
8	Aberdeen City (52m)	Old Aberdeen (10m)
9	Stonehaven (85m)	Inverbervie (25m)
10	Mylnefield (31m)	Dundee (15m); Rossie (30m)
11	Ardtalnaig (130m)	-
12	Drummond Castle (113m)	Fowlis Wester (135m)
13	Strathallan (41m)	-
14	Belliston (82m)	Cupar (20m)
15	Parkhead (35m)	-
16	Braefoot Bay (43m)	Culross (20m); Inverkeithing (30m)
17	Edinburgh Botanic Gardens (26m)	Edinburgh High Street (80m); Edinburgh Canongate (70m)
18	Haddington (41m)	Ormiston (85m); Pencaitland (85m)
19	Nunraw Abbey (197m)	-
20	Dunbar (23m)	Dunbar (12m)
21	Kelso (34m)	Ancrum (85m)
22	Galashiels (198m)	Bowden (180m)
23	Blyth Bridge (253m)	-
24	Camps Reservoir (295m)	-
25	Dumfries (49m)	-
26	Glenlochar (47m)	-
27	Auchincruive (48m)	Campbeltown (5m); Ochiltree (100m)
28	Paisley (32m)	Houston (35m); Rutherglen (15m)
29	Benmore (12m)	Inveraray (5m)

Figure 3.6 Map showing location of climate stations and corresponding population crosses.

The climatic averages were calculated by the Meteorological Office at the chosen stations over a period ranging between 10 to 41 years, up to December 1998. The following meteorological data types were obtained from each climate station:

- Annual average daily mean temperature in degrees Centigrade, to one decimal place
- Annual average precipitation in mm
- Average annual number of frost days, to one decimal place
- Average annual days of fog, to one decimal place (one climate station had no fog data available)

No annual average wind data was available from the climate stations. Approximate data for average, hourly, mean wind speed (metres per second) was instead derived from a map (BRE Digest 346 part 3, Figure 1, 1989). Relative humidity data was also not supplied by the climate stations and was instead obtained from a map, '*Assessment of Climatic Conditions in Scotland, 3: The Bioclimatic Subregions*', (Birse 1971). This classification scheme comprises five separate levels of relative humidity.

3.7 Data collection and recording procedure

Following the sample selection, the following procedure for data collection and recording was adopted:

- Further to the collection of a basic level of data for all of the surviving crosses, a more detailed level of information was exhaustively sought for the *sampled* market crosses from publications and archived records. This was achieved by using the Internet to query the on-line National Monuments Record for Scotland (NMRS), visiting the NMRS in Edinburgh to consult further publications, and visiting the Historic Scotland Conservation Laboratory (Edinburgh) to consult the Restoration Records.

- A selection of basic field equipment was assembled:

  Printed pro-formas
  Digital camera plus two conventional cameras, all with zoom lenses
  Camera film (standard colour and slide film)
  Telescopic ranging rod, to provide a measurement scale in the photography
  Tape measure and ruler to allow drafting and mapping to scale
  Drawing board with base of graph paper
  Transparent drawing paper
  Masking tape to affix drawing paper to board
  Drawing implements: lead pencils, coloured pencils, eraser
  Notebook
  Compass for labelling the orientation of each monument facade
  Munsell Soil Colour Charts (1975), for classifying the stone colour
  Hydrochloric acid for testing sandstone cement type
  Knife to scrape samples for later analysis (eg for salt or crusty deposits)

Plastic sample bags

- Three of the sampled crosses were subject to a pilot survey (Ancrum and Bowden in the Scottish Borders and Dunbar, E Lothian). At each cross, a scaled elevation sketch was drafted of each orientation. Onto this was mapped the extent of visible decay/soiling types, along with classifications of the decay severity or soiling density. Stone repair, replacement and other interventions were also mapped. The pro-forma was filled in with details of the observed decay, soiling, conservation and environmental data. Photographs were taken of each facade of the monument, including close-ups of examples of decay to help with later validation of their classification. Based upon progress made during the pilot study, a timetable was then constructed for the main fieldwork programme.

- The remaining 24 crosses in the sample were then surveyed. One day was spent surveying each cross, over a period of two months in 1998 (Edinburgh High Street Cross required two days to survey due to its substantial size). The method used during the pilot study was judged adequate and was largely unmodified during the remainder of the survey. The collected data was transferred into the database from the pro-forma.

- Archived drawings and photographs held in the National Monuments Record for Scotland were consulted and compared with photographs taken during the field surveys, in order to provide clues for undocumented intervention episodes and decay/soiling rates.

- A individual report was prepared for each sampled cross, detailing its condition (see examples in Appendix D).

3.8 Review of data collection and recording methodology

3.8.1 Drafting technique

For each monument an elevation drawing was drafted on site of one facade, with the aid of a tape measure and telescopic measuring staff. Generally, the base of the monuments could be represented to scale, but accuracy was decreased for the upper parts due to the lack of means of close-range physical access and consequent difficulties in measurement. Heights were estimated from the ground, with the aid of a telescopic measuring staff. The frequent architectural symmetry of the crosses allowed copies of the initial elevation drawing to be immediately traced and used as the base for mapping decay for the remaining facades of each monument as a time-saving measure. Although the outline of each elevation does vary a little due to weathering, relevant modifications were made to the subsequent drawings to take account of this. Individual stones were delineated in each of the sketched elevations. This accuracy of this method of drafting was considered adequate for the purposes of the mapping, and each elevation was also recorded by photography. Exceptions to this drafting method were Edinburgh High Street, Tain and Dundee market crosses. The facades of Edinburgh High Street cross were sketched and enlarged from a series of photographs prior to the site visit, since its detailed architecture and substantial size were expected to complicate the normal method of drafting on-site. In the case of Tain, the decay and soiling patterns were mapped onto adapted photocopies of a sketch of the monument by Small (1900) due to practical difficulties posed to this particular survey by incessant, heavy rain. Dundee cross could not be accessed during the survey and a fragmentary mapping was instead attempted from existing current photographs (see Section 3.8.5 below). In addition to the elevation mappings, a plan was also drawn of each market cross to map the condition of the upward-facing surfaces. Exceptions were the three crosses visited during the pilot study, at which lack of time prevented the completion of such a plan. Additionally, it has not been possible to construct plans for these three crosses from the photography due to failure of the photographic equipment during the pilot survey (described below in Section 3.8.4).

For market crosses with shafts of an octagonal or circular section, it is acknowledged that survey from four orientations necessarily results in the duplication and oblique-angle recording of some mapped data. However, most of the market crosses have a square or rectangular base section, thus it seemed logical to survey the crosses from four orientations. It was considered that it might be worthwhile adopting a different technique for round or multi-faceted upper parts, eg representing the shaft face as 'rolled-out' in the mapping, such that each part of it could be represented from a perspective consistent to the stone surface. However, this was generally not attempted as it would give a disjointed mapping that would be less comprehensible to the viewer, and more time-consuming to produce. Generally shafts were mapped from four separate orientations. However Turriff cross and the tower-base market cross on Edinburgh High Street were surveyed from eight orientations to correspond with their larger, octagonal plans. All drawings were made at scales of either 1:10 or 1:20 depending upon the size of the monument. The scale most frequently used was 1:10 and in a few cases this demanded the separation of the monument parts on paper. However, the elevation of small and average sized market crosses could generally fit uninterrupted onto an A3 piece of paper at a scale of 1:10.

3.8.2 Decay and soiling classification and mapping

The mapping exercise as a whole proved to be quite time-consuming. Decay/soiling types and corresponding severity/density classifications, as well as visible conservation materials, were mapped onto the base elevation drawing for each facade using coloured pencils and annotation. The identification of decay types was straightforward for the most part; however, some difficulty was experienced in distinguishing between dark-coloured algal soiling and particulate soiling. It was found that some decay and soiling categories were rarely used during the sample survey, eg bird excrement, blistering, dissolution, efflorescence, honeycombs and fungi. It was decided that mapping the full extent of lichen distribution on the monuments accurately would be time-consuming and only of limited value. Often there are dozens of small patches scattered across the facades. Instead the general area affected by lichen was indicated upon the mappings, along with a classification of its density.

3.8.3 Classification of stone properties

Some difficulty was experienced in identifying the sandstone cement type of the sampled crosses. When hydrochloric acid was applied to the sandstone surfaces it was often difficult to judge whether or not the acid fizzed, indicating the presence of calcite or a calcareous cement, despite attempts made to aid the test by gently loosening a few surface grains with a knife beforehand. Ferruginous cements were readily identified by the red colour of the sandstone, and the rare use of argillaceous sandstone was easily identified in one case where the sandstone had a dark brown colour and was of poor durability (Fowlis Wester). Siliceous cements, which are the dominant cement type in durable sandstones, cannot be identified without a microscope. However, their presence could theoretically be deduced in many hard and durable sandstone types. The sandstone grain size on sampled crosses was estimated visually, but the degree of sorting of grain sizes could not easily be identified except in one case where some bands of grains were particularly large in relation to their context (Turriff). The existence or otherwise of inclusions was generally obvious during the site visits, since they tend to consist of sizeable pebbles or lumps of clay.

3.8.4 Photographic survey

A digital camera trialled during the pilot survey was not subsequently used. This was due in part to the relatively limited resolution and zoom capability, and also due to unsuccessful operational experience in which stored images were inexplicably 'lost' prior to their downloading. Two conventional cameras were subsequently used instead. Although colour photography is thought to be less stable than black and white with regard to long-term storage, it was decided that colour photography would nonetheless be more useful for recording stone decay/soiling in the research. This is because sometimes soiling types and patterns cannot easily be distinguished in black and white photography. Slide film was used as well as ordinary camera film, since slides give good resolution when scanned into a computer. Some initial operational difficulties were experienced in the use of the cameras, due to a lack of familiarity with the equipment. The photography for the first three crosses surveyed was largely damaged due to torn film in one camera and to incorrectly loaded film in the other camera, therefore surviving exposures for these crosses are limited in number (Ancrum, Bowden and Dunbar). Additionally, at a later stage in the fieldwork the film 'slipped' inside one camera producing some blank and other 'ghost' images (affecting the photography for Dallas cross). However, there are abundant successful slides and prints for the rest of the sampled crosses.

For each cross, a general, location shot was taken, plus frames of each cross facade and further close-up views of selected interesting or advanced decay/soiling forms. Photographing the upward facing masonry surfaces (eg of the stepped bases) was generally found to be tricky due to the difficulties in finding suitable vantage points. To overcome this, multiple, overlapping photographs were taken in order to illustrate the condition of such surfaces. During some of the surveys, a camera was available which was equipped with a special adjustable lens that could be used to reduce the effects of converging verticals. On other occasions the effect of converging verticals was reduced by adopting a more distant stance and using zoom lenses on 35mm cameras. Data regarding the photographed facade orientations along with frame numbers was recorded in a notebook at the time of photography for ease of later identification. The position of the sun in the sky caused some difficulties when photographing from certain orientations, but this could generally be overcome by photographing the affected facades at a later stage during the day.

3.8.5 Physical access

Some obstacles to physical access to the crosses were experienced. A fieldvisit to Dundee revealed that the market cross had been moved from its site on the street into storage just a few weeks previously, in order to eliminate the risk of damage from building work on an adjacent construction site. In this case the market cross could not be viewed on that day, although a future viewing could be made with prior arrangement. Instead notes were taken from two detailed surveys of the cross which had been commissioned a few weeks previously (June 1998) by the local council. The commissioned surveys include many good quality, close-up photographs which were taken from a scaffold erected around the cross before it was dismantled. These allowed the pro-forma to be completed, and a rough mapping was attempted for parts of the cross based upon the photographs. However, no precise elevation mapping could be undertaken from the photographs because they were frequently close-up views with no indication of the orientation of photography or the location of the stone parts within the monument as a whole.

A few market crosses were enclosed by iron railings. Permission was obtained to enter the enclosure at Dunbar. However, railings at the crosses at Campbeltown, Ormiston and Inverkeithing proved difficult to surmount, and to seek permission and a means of entry in these cases was judged to be too time-consuming, given that only one day was allocated to visit each town in the sample. It was considered that the surveys of these crosses could be conducted adequately from the outside of these railings, which skirted or were bedded in the bottom step, at around one metre distant from the shaft in each case. However, there were difficulties in estimating the sandstone grain size and matching the Munsell colour system accurately in these cases.

In two cases (Dunbar and Tain crosses), some unavoidable difficulty was experienced in viewing the facades located up against sheltering walls.

3.8.6 Local data sources

Local knowledge, which was volunteered by members of the public during many of the fieldvisits, allowed useful additions to the pro-formas. Such information regarding the recent history of certain market crosses was obtained from the public or from local archives at many of the towns visited. Furthermore, locally held photographs were available for consultation for crosses at Bowden, Cupar, Dunbar, Inverbervie and Ochiltree. In return, representatives from local history societies in some towns requested a copy of the survey report. An attempt was made to visit some former weathered components of the Banff cross which had reportedly been recently removed to the town museum; however, it was found that they were still being held several miles away in storage.

3.8.7 Completion of the pro-forma and data entry

The environmental details and stone properties were recorded on the pro-formas during the site visits. However, the decay and soiling details were generally recorded in the pro-forma after the survey due to the limited time available on-site at each cross. This could be achieved with the use of the mappings, since they contained all the information needed for the pro-forma regarding the stone condition. The pro-forma layout and data fields matched those in the data entry form contained in the computer, therefore data entry following the fieldvisits was a straightforward process. Following the data entry for each market cross, a summary report ranging in length from two to five pages was prepared. These described the intervention history, current condition and conservation needs of each cross in a reader-friendly and coherent format. Two examples of these reports are contained in Appendix D and copies of the reports will also be sent to local and national archives as a resource for the future.

3.9 Evidence from archived images

Illustrations contained in publications, and further drawings, paintings and photographs of the sampled crosses held in the archives of the National Monuments Record for Scotland were consulted following the field surveys. It was hoped that evidence from these images could help to elucidate instances and dates of intervention where this data was lacking from the documentary sources (eg episodes of re-siting or the replacement of weathered stone components). Additionally, by comparing the archived photographs with photographs taken during the research it was hoped that clues could be extracted about the rate of advance of decay and soiling on the crosses. The issue of how to investigate decay and soiling rates is further discussed in later chapters, and the details of the evidence provided by archived photographs for individual crosses are contained in the individual survey reports (eg see examples in Appendix D).

3.9.1 Drawings and paintings

The drawings of the sampled crosses in published sources were of limited use (eg Stuart 1856-67; White 1873; Drummond 1860-1; Small 1900). In the antiquarian tradition, the crosses were sketched with the purpose of illustrating the carved art-historical or architectural details, rather than the condition of the stonework. Some artistic licence is evident in the representation of the decay in a drawing of Campbeltown cross. White (1873) did not illustrate the decay at the tip of the cross-head whereas an earlier drawing by Stuart (1856-7) did. There are other occasional inaccuracies in the depiction of the carved details, eg the elevation sketch of Fowlis Wester cross-slab by Stuart 1856-7 shows an incorrect number of carved bosses. Therefore, while such drawings could potentially provide evidence of, for example, when undocumented chips or fractures occurred to the stonework, they cannot be absolutely relied upon as a form of evidence for this. Archives in the National Monuments Record for Scotland also hold antiquarian paintings and elevation sketches for some of the sampled crosses. However, in most cases these images are duplicates of the published drawings and therefore present the same limitations.

3.9.2 Photography

Old photographs and postcards of the sampled crosses held in the archives of the National Monuments Record for Scotland date from as early as 1855 (Inverkeithing) up until the present day. The coverage is varied. One sampled cross had no archived photographs (Dallas), some crosses were represented by just one or two prints, while some of the more historical and prominently sited crosses (eg Inveraray, Edinburgh High Street) were depicted by a substantial number of prints. The old postcards generally did not provide much information regarding stone condition due to poor quality lighting, resolution and reproduction and also due to the lack of close-up views. Sometimes the images had even been doctored, eg colour tints added to the background. Additionally, the dates of the postcards were frequently not recorded.

Photographs from more recent decades were more helpful. However, even in good quality photographs with optimum lighting, it was difficult to judge whether there had been any loss of stone from a monument surface in the periods between photography, since lighting conditions are never exactly replicated. Generally, apparent differences could not be considered conclusive, although they could be used where they support evidence from other sources. A particular problem was that biological soiling does not tend to show up well in black and white photography. Difficulties were therefore experienced in attempting to identify the type of soiling in cases where it was visible in the photographs. In three cases (Ancrum, Beauly and Inverkeithing crosses), consultation of archived photography revealed that parts of these monuments were previously orientated differently to today, a factor of potentially great significance when examining the influence of orientation upon the present decay and soiling patterns upon a monument.

In the case of two recently conserved crosses (eg Ancrum and Beauly), photographs were available for consultation in the Historic Scotland Restoration Records. These depicted the shaft of each cross before and after the conservation material was applied.

3.9.3 Casted evidence

For the Campbeltown cross, a plaster cast dating from around the mid-1800's is held by the National Museums of Scotland. However, enquiries established that the expense and physical effort involved in accessing and viewing the cast in its current storage conditions could not be justified within the framework of the current research. Historical photographs of this monument exist from the early 1900's and these were consulted as an alternative form of evidence to this.

3.10 Summary

A *'convenience sample'* of crosses was selected for further study, with the aim of providing as wide a picture as possible of the whole market cross population. The variables expected to have most influence upon stone decay were adequately represented amongst this sample (eg data of component age, landuse type). Further checks also showed that the values for these variables exhibit a range in the sample that is fairly representative of the broader population. Due to the immense variation, and even unique characteristics, of many of the crosses, their environments and intervention histories, it would not be possible to select a sample which is representative in statistical terms. There were inevitably some 'confounding effects' or unique instances, such that it was not possible to isolate the effects of certain factors in the subsequent analysis due to a lack of comparative situations. For example, the extremely early date of the Fowlis Wester slab and the setting of Rossie cross in an arable field were factors not matched by any of the other market crosses. However, the selected sample was sufficiently varied to provide a good cross-section of the existing population of Scottish market crosses.

The system of decay and soiling classification was developed from the technique pioneered by Fitzner et al (1989; 1992; 1995; 2000). However, due to the high degree of intervention to the crosses, the type of data collected and the subsequent analysis included chronological considerations not incorporated in Fitzner et al's data collection. This included all information that could be gathered from archives regarding the re-siting of the crosses, replacement of component parts, conservation, and changes in land-use type and environment to which each cross had been subject in the past. With the aid of the classification criteria (Table 3.2) and the illustrations of decay and soiling types (Plates 3.1 to 3.32), the developed mapping method could be replicated by another practitioner with limited geological expertise.

Limitations of the methodology include the impossibility of selecting a statistically representative sample due to the unique set of circumstances of each cross. However, the next best solution has been employed, ie to select a 'convenience sample', a representative cross-section of market crosses. The on-site recording method was relatively time-consuming. It is acknowledged that the practitioner may not have time to undertake the exhaustive survey performed on crosses during this research. However obtaining data of high detail and quality inevitably requires a certain investment of time. Mapping and classifying the detailed stonework condition was generally achievable within the allocated fieldwork time of one day per cross. There were difficulties in establishing values for certain of the variables. The data fields recording details of ownership and those for sandstone cement type and grain size were thus of less use than had been expected. There was also a general lack of data available describing previous interventions, and in some cases the date of carving of cross components was unknown. However, this lack of information only affects a small section of the data, and it is therefore not expected to affect the ability of the data to generate meaningful trends when analysed. Another point is that certain of the decay and soiling types were rarely sighted in the sample. Thus blistering, efflorescence, dissolution, bird excrement and honeycomb weathering have a frequency too low to allow statistical analysis. However, the circumstances of the observed cases will nevertheless be examined and commented upon in the next chapter. Other limitations in the methodology were the absence of means to gather measured data of the micro-climate at each cross, ie the temperature and moisture conditions likely to occur on the stone surface. The means to collect this data were not in accordance with the time and budget restraints of the research; however, some of these factors are discussed in the following chapter. A further limitation was the disappointingly low level of evidence that could be extracted regarding changes in weathering and soiling patterns through consulting pictorial evidence (old photographs and drawings). However, such images can nevertheless provide useful information about obvious intervention attempts and can help with the dating of these.

Overall the methodology was appropriate to the subject and sufficient for the purposes of the present analysis and risk assessment. The strengths of the methodology can be summarised as follows. The data collection method for the sampled crosses was rigorous and comprehensive, and drew upon a variety of sources. In addition to the field survey, other information was sought locally, and publications and archived images were consulted exhaustively. The advantages to be gained from seeking out local data sources, especially verbal information from local people and consultation of locally held photographs, should not be underestimated. The sample size is considered to be adequate, being 18% of the population. It is representative of all of the range of values of the key variables. The sample also included monuments with conservation materials, to allow an assessment of their effect. The classification scheme for decay and soiling was found to be workable and appropriate to the weathering features observed during the fieldwork. Just one visit to each cross was adequate to record all of the field data required. Data for several climatic variables was collected, allowing a variety of hypotheses to be tested (see next chapter). The relational database design was flexible, and subsequently enabled a suitably large number of complex queries to be performed, which are described and analysed in the next chapter. It incorporated facilities to record historical data regarding re-siting and the replacement of monument parts. The subdivision of the monuments into their constituent parts allowed a greater range of variables to be tested, eg differences in the component ages, stone properties and architectural characteristics. Overall, the database contains a high level of detail and, supplemented by the individual cross reports, mappings and photography, represents a considerable resource. These could provide valuable 'base-line' data for future investigation of the advance of decay and soiling on the sampled crosses. The drafted mappings in particular provide a very detailed, visual presentation of decay and soiling data, especially with regard to the exact surface distribution of weathering patterns. These mappings will allow distributional changes in the decay and soiling patterns to be monitored and studied in the future.

4 DATA ANALYSIS

4.1 Introduction

The first stage of the data analysis aimed to discover the broad trends evident, by interrogating the database and by constructing charts using *SPSS* statistics software. Section 4.2 discusses these trends, and presents the basic frequencies, ranges and average values of the collected data. It also describes relationships evident in the population and the sample between properties of the crosses and other variables, eg relating to architectural design, construction date, stone properties, location, environment, survival, care and designation.

Following these initial explorative queries, statistical tests were applied to investigate the relationships between individual decay/soiling types and a wide variety of factors of potential influence. Section 4.3 discusses the statistical techniques applied in the research. The statistical testing programme was systematic and objective, such that it was not only the hypothesised relationships that were tested. The frequency, severity and extent of surface distribution of every decay and soiling type was tested in relation to every potential factor of influence. Therefore the results even include some significant correlations for which no hypotheses had been formulated prior to the testing. The tested factors of influence are listed and defined in Section 4.4, including factors of the environment, climate, intervention and monument properties. The test results are presented in a series of tables in Section 4.4. A small proportion of decay/soiling types and factors of influence could not be tested due to their low frequencies, and the characteristics of these are instead discussed in Section 4.5. The results of these tests and analyses form the basis for the risk assessment model developed in chapter 5, in which all statistically significant relationships are systematically discussed.

4.2 Data description of sampled crosses: frequencies, ranges and average values

4.2.1 Date, design and stone properties

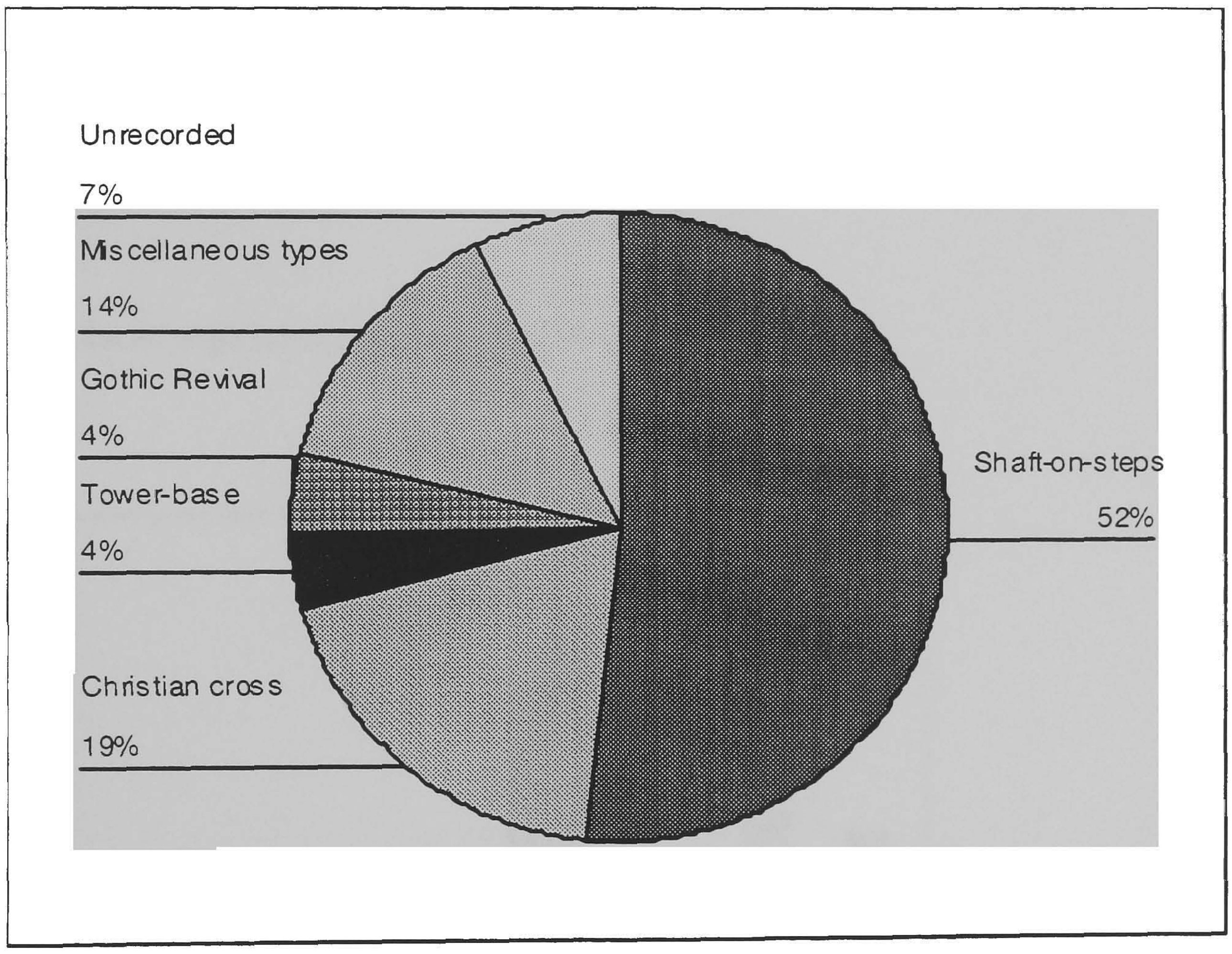
Survival

There are 151 surviving market crosses in Scotland. This represents 69% of the original total of 218 indicated by documentary sources. The sample, for which an increased level of data was collected, consists of 27 representative examples from the population.

Cross design

Most market crosses in the population (52%) are 'traditional' in design, ie they consist of the simple shaft-upon-steps structure with a secular form of finial and usually with a small socket stone. A further 19% of crosses include some form of Christian cross in their design. About 4% are tower-based crosses, and another 4% are Gothic Revival constructions. The other 21% comprise market crosses in a variety of less common forms such as wells, fountains, obelisks and War memorials. The proportion of various cross designs in the selected sample provides a good match with those in the population as a whole. The proportions of cross design types within the population are shown in Figure 4.1 below.

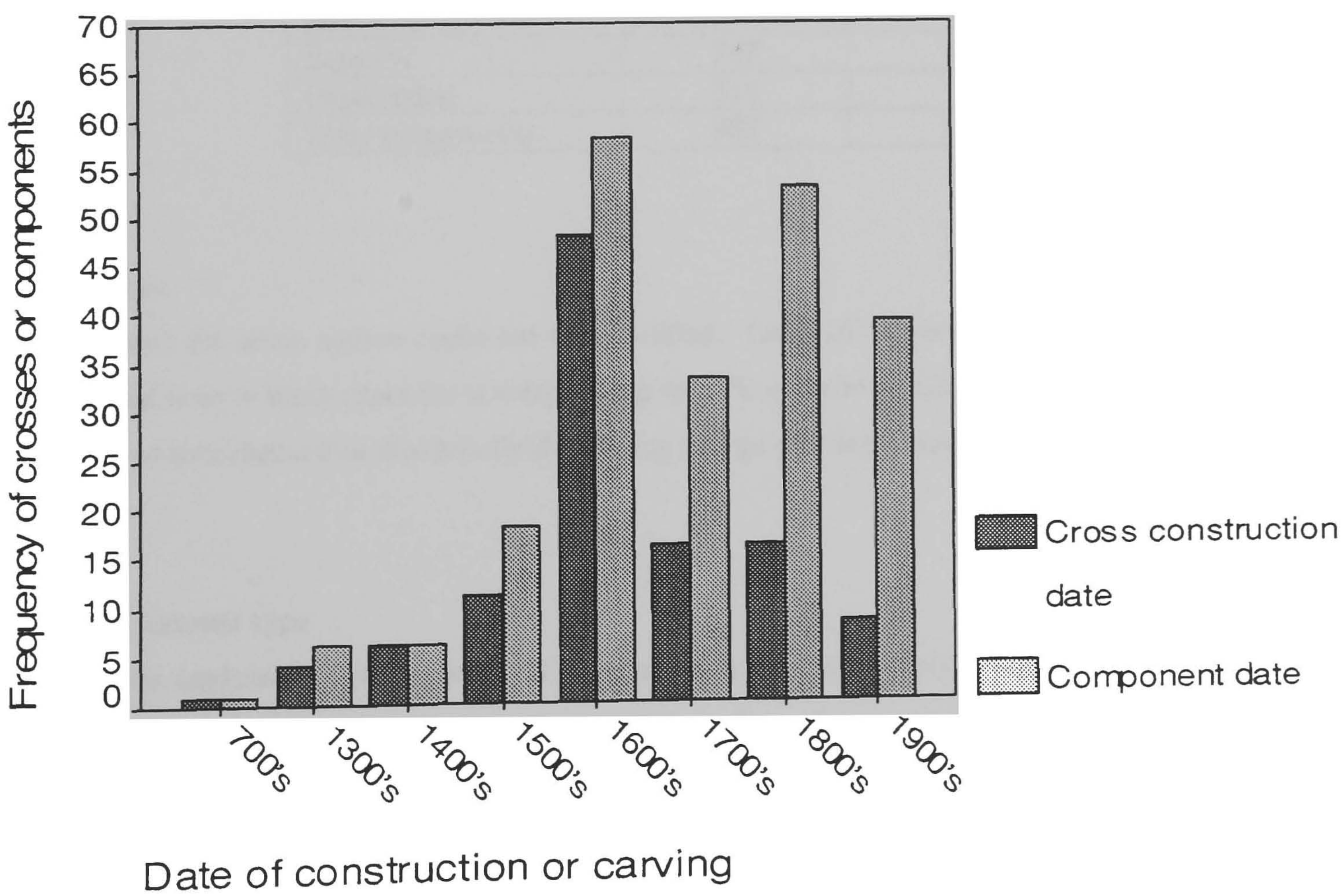
Figure 4.1 Cross designs in the population.



Construction date and date of component carving

For the purposes of this research the 'construction date' of a cross is defined by the earliest dating component of each cross, since the crosses frequently consist of components carved at various dates. Figure 4.2 below shows the construction date (where known) of surviving crosses in the population. The date at which various cross components were carved has also been placed in bars next to this in the chart. The difference between the date profiles shown by the crosses and their components is due to this tendency for some parts to be replaced at later dates. The oldest construction date for a cross in the population is the 700's. In this case, at Fowlis Wester, the market cross is a Pictish cross-slab, re-appropriated and re-sited for use as a market cross in more recent centuries. The next oldest crosses are those which allegedly include components dating from the 1300's, and the centuries following this are represented by an increasing number of crosses, peaking in the 1600's, with the frequency decreasing after this. Note, however, that this does not simply reflect the date of origin of the burghs or even the rise and fall of market-cross building activity through time, since some crosses are replacements of former ones. The construction period covered by the surviving crosses is 1,241 years. Like the cross construction dates, most of the constituent cross components date from the 1600's. The distribution of component dates is skewed as expected, in which 86% of surviving components were carved between 1600-2000 AD, and about 14% were carved between 1300-1600 AD. Older components are less likely to survive today than those carved in more recent centuries. Due to a lack of recorded evidence, the construction date is known for only 110 (73%) of the 151 population crosses, and the date of carving is known for just 214 (44%) of the 483 population components. A greater proportion of older crosses and older components could perhaps be expected if all of the dates were known, since more recent dates are more likely to be recorded in sources than older ones.

Figure 4.2 Date of cross construction and component carvings.



Material of cross components

Often the material from which the components are made could only be established by a site visit, hence this data is mostly only known for the sampled crosses. Of the recorded material types, sandstone is by far the most frequent (representing 74% of all known component material in the population, and 95% of that in the sample). Both sandstone and granite have been used for carving a wide variety of component types. Whinstone has been used for one slab, a socket stone, a shaft and for rough boulders used as market crosses in two cases. Chlorite schist was used for the cross-shafts at Campbeltown and Inveraray. Bronze, iron and marble have each been used for certain finials, and concrete was used for two plinths, a pedestal and one set of steps. Fibreglass has been used for one finial and for a replica slab. The frequencies of components of various material types are shown in the Table 4.1 below.

Table 4.1 Material of cross components

Component material	Frequency of components in population	Frequency of components in sample
Sandstone	125	91
Granite	25	1
Whinstone	5	-
Concrete	4	1
Chlorite Schist	2	2
Bronze	2	-
Fibreglass	2	1
Marble	1	-
Iron	1	-
Subtotal	*167*	*96*
Unrecorded	316	7
Total components	*483*	*103*

Stone source

In most cases the stone source could not be identified. Only 16 components from 11 crosses could be sourced, and even in these cases the corresponding specific quarries could not generally be identified. It is therefore not anticipated that this data field will play a large part in the data analysis and subsequent model building.

Sandstone cement type

Similarly the sandstone cement type could often not be determined. Only 17 components from 10 crosses could be categorised (including only 13 components from the sampled crosses). Often the test for calcareous sandstone, in which hydrochloric acid is applied to the stone surface, yielded ambiguous results. Therefore, classifications were recorded only in the most unambiguous cases and may not be representative of the general picture: seven components were siliceous, six were ferruginous, two were argillaceous, one was calcareous and another was patchy calcareous.

Sandstone grain size

Grain size could only be established by visiting the crosses, since this data was not recorded in the archives consulted. Grain size was identified in the case of 43 components from 25 crosses. It was impossible to categorise grain size for the other components, since their circumstances did not allow close-range inspection (eg elevated pieces such as finials, capitals and friezes, or components inaccessible due to high railings). As shown in Table 4.2 below, the most frequent grain size is Medium, followed by Coarse.

Table 4.2 Sandstone grain size in sample

Sandstone grain size	**Frequency of sampled components**
Fine	6
Fine-to-medium	4
Medium	20
Medium-to-coarse	1
Coarse	12
Unknown	60
Total	*103*

Sandstone sorting

The degree of sorting can be difficult to determine by visual observation. It could only be examined in the case of the visited crosses, since this data is not recorded in the consulted archives. Poor sorting was identified in the case of three components from two crosses, at Turriff and Old Aberdeen. Otherwise the sandstone components appeared to exhibit uniform sorting.

Sandstone inclusions

Amongst the sampled crosses, 17 out of 103 components (17%) showed evidence of having inclusions, such as clay clasts or pebbles.

Original degree of carved detail

As expected, most cross components are fairly plain or have simple, carved, border features (see Table 4.3 below). Note that the appearance of some of the population components is unrecorded and site visits would be required in order to establish the classification for these.

Table 4.3 Degree of carved detail on population and sampled crosses

Degree of carved detail	Frequency of population components	Frequency of sampled components
1 Plain	173	37
2 Plain surface, moulded features	133	35
3 Moderate surface decoration, less intricate infill	36	10
4 Extensive surface ornamentation with elaborate infill	89	20
Unrecorded	51	1*
Total	*482*	*103*

*The degree of original carved detail for one sampled cross component at Duffus could not be established, due to severe erosion which has reduced the finial to a stump.

Materials applied or attached to the crosses

The data for components with applied materials is biased towards visited crosses, since these details are often not recorded in the archives. Paint is the most common type of applied material, and iron brackets, plaques and various iron attachments are also fairly frequent. Many more of the crosses are surrounded by railings, but these often encircle the monument beyond the base. Railings are only recorded as an attachment where they are bedded within the steps. The frequencies of applied or attached materials are shown in Table 4.4 below (note that some components have more than one applied material).

Table 4.4 Frequency of components with applied materials

Applied material	Frequency of population components	Frequency of sampled components
Iron parts	44	15
Paint	12	8
Bronze/copper	21	7
Render	6	6
Lead	7	5
Cement	3	2
Other stone type (eg inset panel)	4	1

Cross design and date of construction

Gothic Revival style crosses tend to date from the 1800's, since this style of architecture flourished in the Victorian period. The few market crosses which are in the form of a well and fountain tended to be built later on, reflecting the diversity of types that were developed and the re-design of others. The three War memorials were built around 1920. Otherwise, the traditional type (ie shaft-upon-steps) exhibits a fairly broad period of construction. The tower-based cross seems to have been a feature of the 1600's; however, the surviving examples have all been latterly modified or reconstructed. There are few market crosses that include Christian iconography post-dating 1698. The later examples are Woodhead cross and the reconstructed Banff cross, and cast replicas at Fowlis Wester and Kirkwall.

Cross design and region

There is little evidence for particular types of cross design being favoured in different regions. The situation is somewhat confused by the fact that today's regional political boundaries are of little relevance to the building of market crosses in the past, and the number of crosses per region varies greatly. However, it is notable that Argyll & Bute is the only region to contain the two re-used Medieval Celtic crosses. Both these crosses are a product of the same school of carving which prevailed in this region in the Medieval period and they exhibit similar design elements, eg creeping vine ornament, Latin inscriptions, Celtic knotwork and saints appear upon both crosses. Three of the four City Councils (Aberdeen, Edinburgh and Glasgow) have tower-based crosses, and a further two examples of this type of cross are located in towns known to be of greater importance in the past in terms of their religious and trading functions (Elgin and Perth). The tower-base type of cross must have demanded greater resources to construct and presumably reflects the wealth of the local patrons and the larger burgh sizes. The three inscribed boulders used as market crosses are all located in Dumfries and Galloway region. It is also notable that most of the crosses in Fife and the Highlands are traditional in design (ie shaft-upon-steps).

Component type and inclusions

Where stone with inclusions appears in the sample it has been used for larger, plainer pieces (eg some steps and shafts), rather than for the more decorated finial and capital pieces. The frequencies of component types in relation to the existence or otherwise of inclusions are shown in Table 4.5 below.

Table 4.5 Frequency of component types with and without inclusions

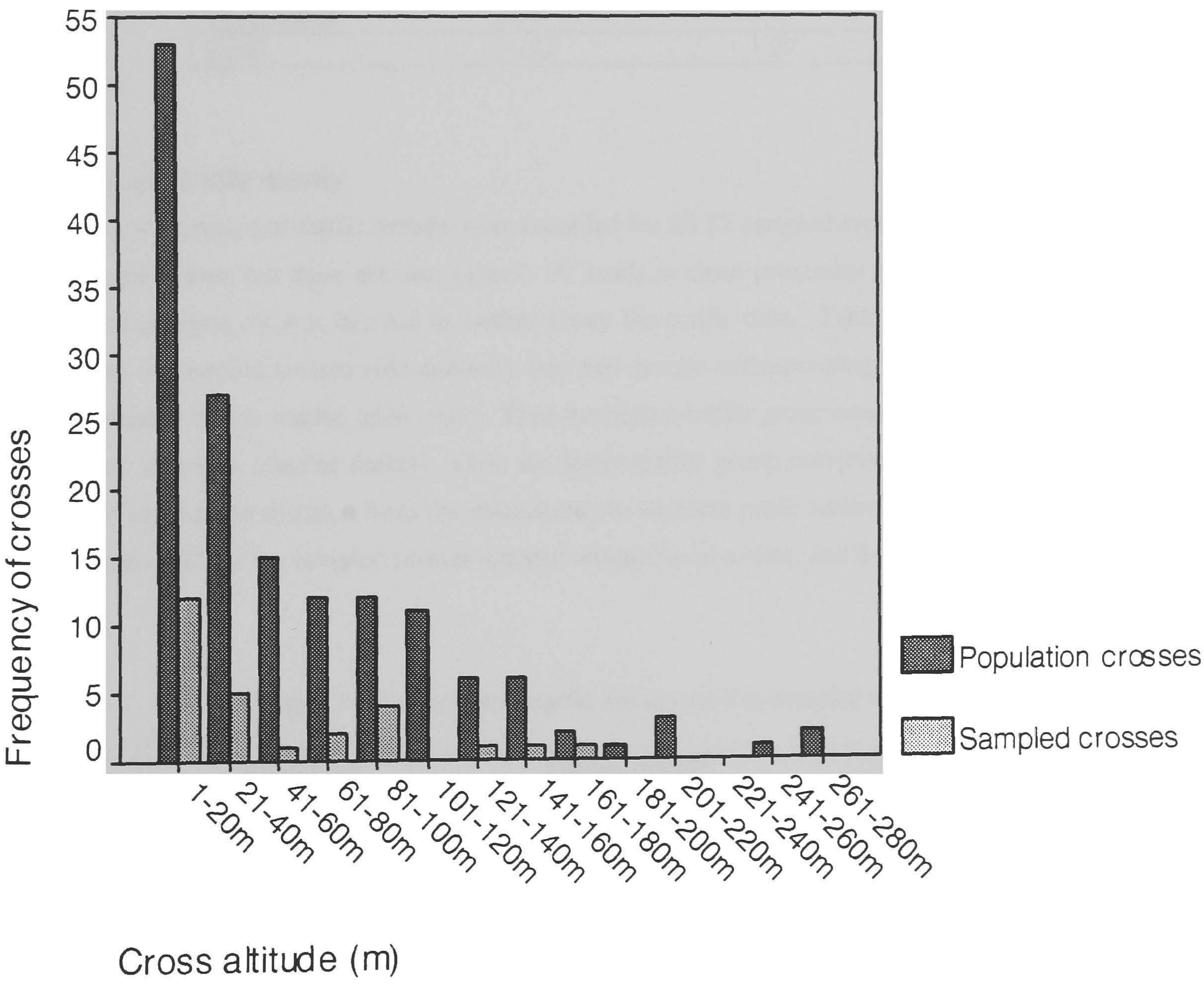
Sampled components	**With inclusions**	**Without inclusions**	*Total*
Shafts	6	20	*26*
Steps	5	22	*27*
Socket stones	3	9	*12*
Slab	1	0	*1*
Plinths	1	0	*1*
Pedestals	1	4	*5*
Capitals, friezes, finials	0	30	*30*
Tower-base	0	1	*1*
Total	17	86	*103*

4.2.2 Location, climate and environment

Cross altitude

Altitude data was derived by consulting maps with 10m interval contours. Population crosses are situated at altitudes of approximately 5m up to 265m over-datum. The spread is skewed with most crosses being situated in the lower altitude ranges, indicative of the low altitudes of many Scottish towns. The median value amongst the population crosses is 40m; however, in the sample the median value is 25m. The altitudes for population and sample crosses are shown in the chart below (Figure 4.3).

Figure 4.3 Altitude of population and sample crosses.



Current land-use type

Land-use type could only be established for 57 of the population components (further field visits would be necessary in order to classify the land-use of the remaining 94). The most common land-use, as expected given the central urban locations of most crosses, was *Pedestrian thoroughfare*, followed by *Roads* (see frequencies in Table 4.6 below).

Table 4.6 Frequency of crosses on different land-use types

Current land-use type	Frequency of population crosses	Frequency of sampled crosses
Pedestrian thoroughfare	18	10
Grassed area	15	6
Roads	12	5
Churchyard/Cemetery	6	3
Indoor	5	2
Arable	1	1
Unrecorded	94	-
Total	*151*	*27*

Road type and traffic density

The nearby road type and traffic density were recorded for all 27 sampled crosses. As expected, most of the roads are *Urban*, but there are also several *'A'* roads in close proximity to some of the monuments. For ease of querying, it was decided to further group the traffic data. Table 4.7 below shows how the frequencies of sampled crosses split naturally into two groups corresponding to higher and lower traffic levels (indicated by the shaded table cells). Thus the higher traffic group consists of *Busy* and *Moderate*, *Urban* and *'A'* roads (shaded darker), while the lower traffic group comprises the *Quiet* roads (shaded lighter). Note that the distance from the monuments to adjacent roads varies from <1m up to 60m, with 67% (18 out of 27) of the sampled crosses situated within 5m of a road, and 8 of these standing within 1m of a road.

Table 4.7 Road type and traffic density next to sampled crosses

Road type	Traffic density			*Totals*
	Busy	Moderate	Quiet	
Urban	4	6	2	*12*
'A' road	2	3	-	*5*
'B' road	-	-	3	*3*
Residential	-	-	3	*3*
Secondary	-	-	4	*4*
Totals	*6*	*9*	*12*	*27*

4.2.3 Care and condition

State of survival

The state of survival could only be established for 111 of the 151 population crosses, shown in Table 4.8 below. Figures in brackets are the % of the known total in the population and sample. It is evident that the survival grades of sampled crosses are representative of those in the general population.

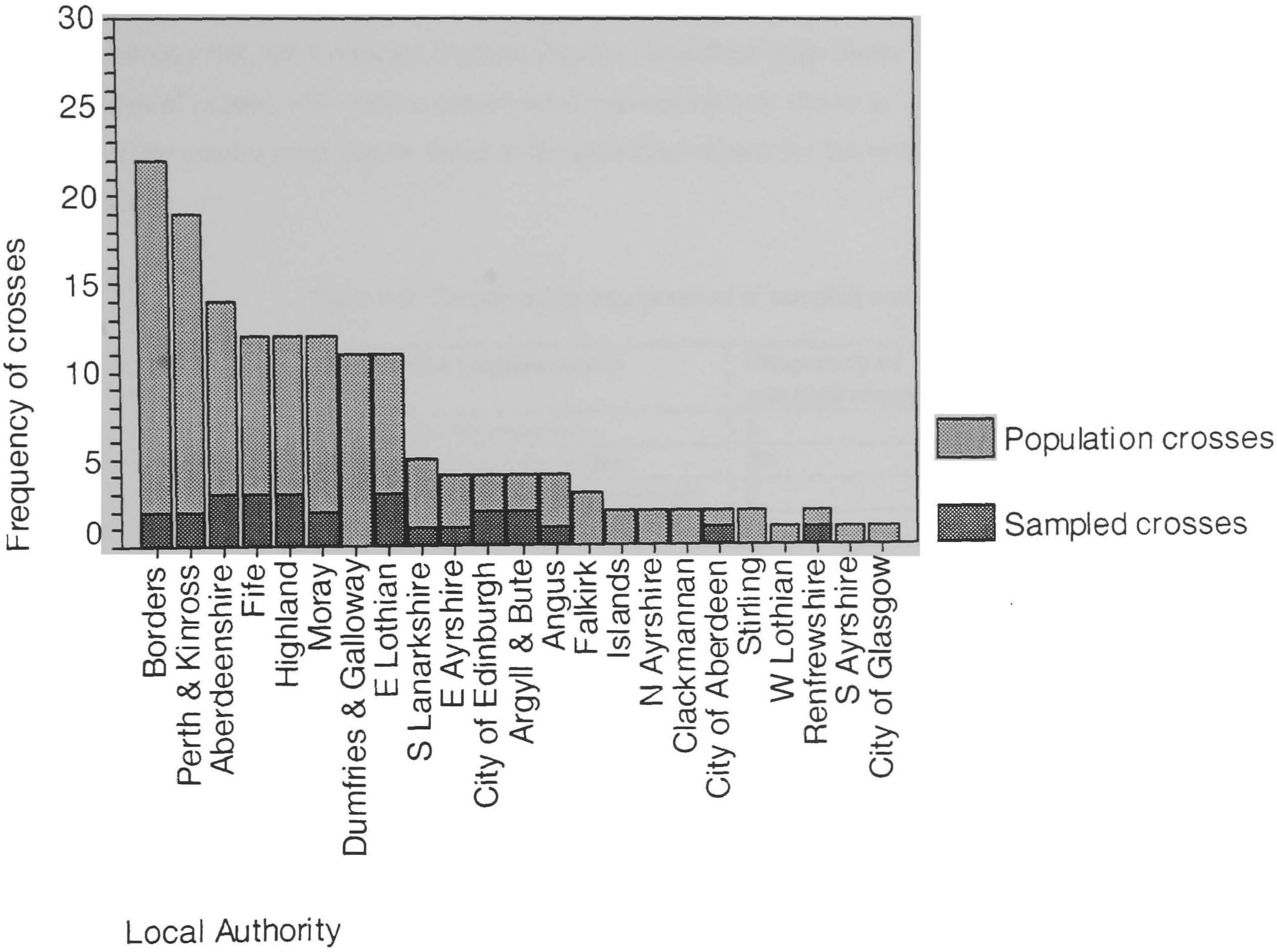
Table 4.8 State of survival of crosses in the population and sample

State of survival	Frequency of population crosses	Frequency of sampled crosses
0: All parts original	24 (22%)	6 (22%)
1: Localised repairs	8 (7%)	1 (4%)
2: Some components replaced/missing plus localised repairs	52 (47%)	12 (44%)
3: Most or all components modified or replaced/missing	27 (24%)	8 (30%)
Total	*111 (100%)*	*27 (100%)*

Care of market crosses

Of the 23 Regional Councils which have market crosses in their care, the Border region is responsible for the greatest proportion of crosses in the population (15% of crosses), followed by Perthshire & Kinross (13% of crosses). A few of the regions have only one cross in their care and there are a few more small but densely populated regions in the Central Belt that have none. The regional councils covering larger geographical areas tend to have the highest numbers of crosses. Exceptions to this observation are East Lothian and Fife which both have a high density of crosses relative to their area. In the case of Fife this can be explained by the high frequency of burghs with maritime functions strung out along this part of the coastline. The frequency of crosses in each region is shown in Figure 4.4 below.

Figure 4.4 Population and sample crosses with corresponding Local Authorities.



National Monuments Record for Scotland

The NMRS lists 130 of the 151 population crosses (86%) as being 'market crosses' or 'town crosses'. The remainder of the population are not defined as such in the NMRS, but were included in the analysis because they have been described as 'market crosses' in other sources (eg Small 1900; Aberdeenshire Sites & Monuments Record 1996; the Listed Buildings Record). The NMRS has excluded certain crosses because they are replicas, others because of their relatively modern date of construction (eg the War memorials designed as market crosses around 1920), and in other cases some diverse architectural types are listed using alternative terminology.

Conservation requirements

The level of conservation required at individual crosses could only be established for sampled crosses, since visits to the crosses are needed in order to obtain this information. Most of the sampled crosses (20) are not in urgent need of repair, but could benefit from intervention such as repointing or weeding of joints. Crosses for which immediate repairs are necessary, in order to slow the advanced decay or to counter serious risk, are Cromarty, Dunbar, Dundee, Edinburgh High Street, Rossie and Ormiston. The frequencies of crosses with various conservation requirements are shown in Table 4.9 below, and further details of the requirements can be found in the individual reports for the sampled market crosses (eg see Appendix D).

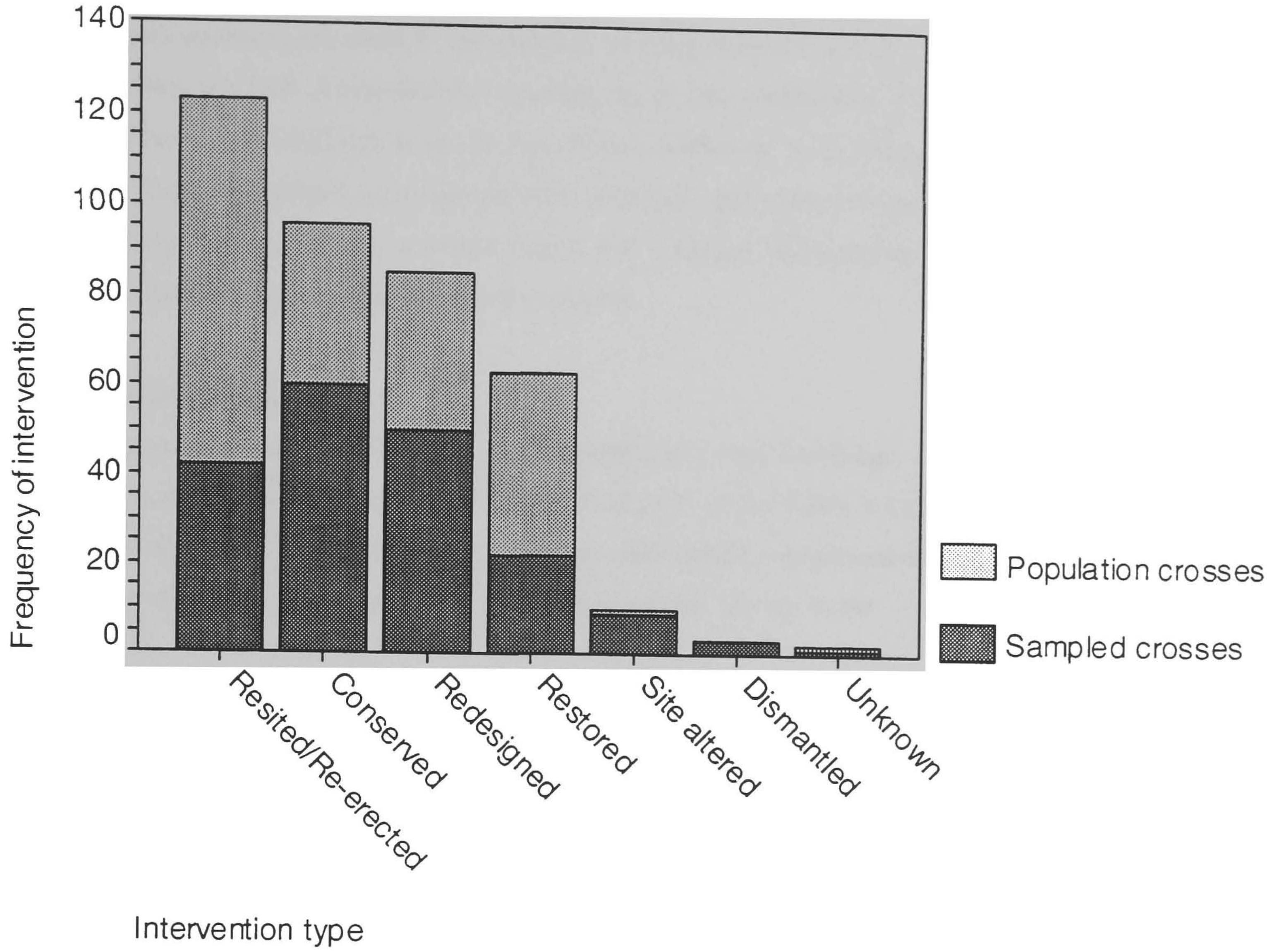
Table 4.9 Conservation requirements of sampled crosses

Conservation requirements	**Frequency of sampled crosses**
A: No repairs necessary	1
B: Localised repairs desirable	20
C: Immediate intervention necessary	6
Total	*27*

Intervention type

Amongst the 382 recorded instances of intervention to the population crosses, re-siting was the most common type of work, reflecting the high level of site redevelopment to which these monuments have been exposed in their mostly urban locations. Attempts at conservation (successful or otherwise) have an encouragingly high frequency. However, it is evident that many of the crosses have also been subject to redesign and restoration attempts, in which parts have been completely replaced with varying regard for their former historical appearance. The frequency of those which have had their 'site altered' is probably much higher in reality than is recorded in the archives. This refers to the re-surfacing of the ground around the base of the cross and the consequent part-burial of base-level components that can sometimes result from this. The relative proportions of intervention types are shown in Figure 4.5 below.

Figure 4.5 Intervention types to which population and sample crosses have been subject.



Resiting frequency

According to the archived information, just over half (57%) of the crosses in the population have *not* been moved since their construction (see Table 4.10 below). The other 43% have all been moved, at a frequency of between one and six times.

Table 4.10 Resiting frequency of crosses

Resiting frequency	Population crosses	Sampled crosses
0	86	9
1	34	7
2	16	4
3	8	3
4	6	3
5	-	-
6	1	1
Total crosses	*151*	*27*

Bodies responsible for intervention

This information could only be derived for a small proportion of cases. Intervention by Historic Scotland was recorded in 31 cases, and by the Local Authorities in 13 cases, otherwise a variety of different local architects and sponsors are cited in the archives as being responsible for various intervention episodes. Generally there is a lack of information regarding the bodies responsible. In reality a number of different people are now often involved in any conservation, restoration or re-siting project, including the Local Authority, Historic Scotland, local conservation architects and stone masons. With regard to field visits, the Ordnance Survey, and to a lesser extent the National Monuments Record for Scotland, have undertaken most of the field checks upon the crosses.

Listed Building designation

Most of the population of crosses (65%) are designated as Listed Buildings. Of those Listed, over half are *Category B*, and about one third are designated *Category A* (see Table 4.11 below for frequencies in the sample and the population). A few of these are additionally categorised due to their relationship to a group of nearby Listed Buildings, and thus have a so-called 'Group Value'.

Table 4.11 Listed Building category of crosses

LB Category	Frequency of population crosses	Frequency of sampled crosses
B	56	14
A	33	8
C (S)	6	2
C	3	1
None	53	2
Total	*151*	*27*

Scheduled status

About one third (34%, or 51 out of 151) of the crosses in the population are Scheduled Ancient Monuments. In the sample a larger proportion are Scheduled (59%, or 16 out of 27).

Listed Building Category and construction date

Category A and B crosses in the population show a fairly even spread of construction dates. However, the C and C(S) categories seem to correspond with a slightly *later* spread of dates, although only a few crosses in the population are classified C/C(S). The Category A group has no crosses later than 1900 in date, while the B group includes two examples from the 1900's. Three of the nine examples in the C/C(S) groups date from the 1900's.

Listed Building Category and conservation requirements

The Listed Building legislation is unfortunately not designed as a system for regularly monitoring the condition of its monuments, but rather for protecting them in the planning stage from risks posed by development, ie works directly affecting the site or fabric of the monument. Conservation requirements could only be established for the sampled crosses. The crosses judged as requiring immediate intervention in order to slow advanced/severe decay comprise three crosses of LB Category A, three crosses of Category B, one cross of Category C, and a further cross with no LB designation. It is therefore evident that the conservation requirement of crosses is a factor independent of their LB Category.

Protective designations and state of survival

The state of survival of crosses similarly shows no proportional relationship to the level of protective designation. Examination of the level of protective designation in relation to state of survival is less relevant, since both are also dependent upon other factors. Statutory protection is only effective during planning applications for works which will directly affect the site or the material of the monument, and has little bearing on the exposure of monuments to natural agents of decay/soiling over long periods of time. However, with regard to Scheduling, the data showed that Scheduled crosses tend to be either older with poorer survival or later with better survival, reflecting to some extent the Scheduling criteria.

Scheduled status and construction date

There are 51 Scheduled crosses among the population of 151 (34%). All of the Scheduled crosses are relatively old, tending to date from the 1700's and earlier.

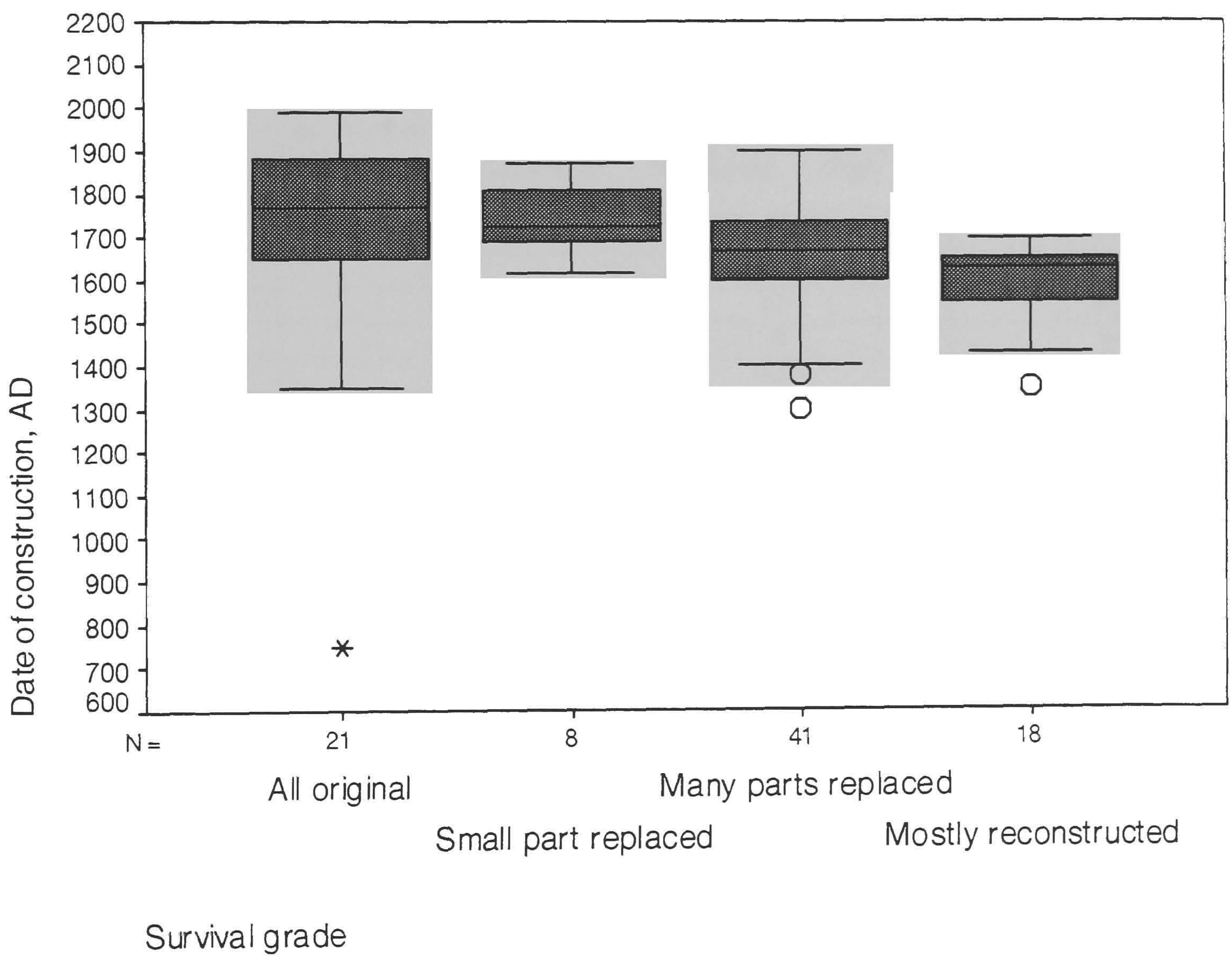
Scheduled status and conservation requirements

Conservation requirements could only be established for the sampled crosses. Like the Listed Building designation, Scheduling does not imply any programme of regular care for the monuments. In fact, 3 of the 6 crosses which require immediate intervention to slow advanced/severe decay forms are Scheduled; 13 out of the 21 for which local repairs would be desirable (eg repointing, weeding etc) are Scheduled, while the cross which requires no intervention (Old Aberdeen) is not Scheduled. Note, however, that there are other factors at play here, eg Scheduled crosses tend to be older in date, thus exposed to greater weathering and more in need of conservation.

Construction date and survival

The state of survival classification indicates the degree of originality, ie the degree to which the monuments have parts replaced or missing. Monuments with earlier dates are expected to have poorer survival, while those with later dates should have better survival. There is, indeed, a slight trend noticeable with regard to this. The boxplot in Figure 4.6 below shows the construction date ranges for crosses, classified according to four levels of survival. It is evident that crosses with poorer survival tend to be of older dates. Each box shows the inter-quartile range for the spread of dates within each survival group, with the median plotted by a line towards the middle of each box. The circles and the asterisk indicate outlying and extreme values respectively. These cases were identified by the SPSS software, according to their distance from the interquartile range in each group. In this example the extreme value is created by Fowlis Wester cross (constructed in the 700's), and the outlying values are Prestwick (1300), Duffus and Houston (both 1300's), and Campbeltown (1380). The total number of crosses for which the date and the state of survival are both known is 110. Site visits would be required in order to establish the state of survival of the rest.

Figure 4.6 State of survival and construction date of population crosses.



Decay and soiling frequencies in the sample

Table 4.12 below lists the frequencies of each decay and soiling type in the sample, along with frequencies of the degree of their severity or density and surface distribution. The frequencies represent the number of cross components affected by the decay or soiling type, each figure arising from a potential maximum value of 103 sampled components. The decay and soiling types are listed in order of their overall frequency, with algae being the most prolific of all the recorded phenomena. It is evident that *'High'* levels of decay severity or soiling density are commonly exhibited by algae, mechanical damage, spalling, crumbling and gypsum black crust. Some other decay/soiling types have a greater tendency to show a lower severity/density on the stone surface, such as lichen, fissures, moss, differential weathering, active granulation, staining, painted graffiti, higher plants, fungi and flakes. With regard to the extent of surface distribution, the decay/soiling types on the whole are more likely to exhibit a *Localised* distribution, and indeed some decay/soiling types were only observed to have a *Localised* distribution. However, in the case of pitting and honeycombs *General* distribution is the more frequent category, due to the commonly extensive nature of these decay types.

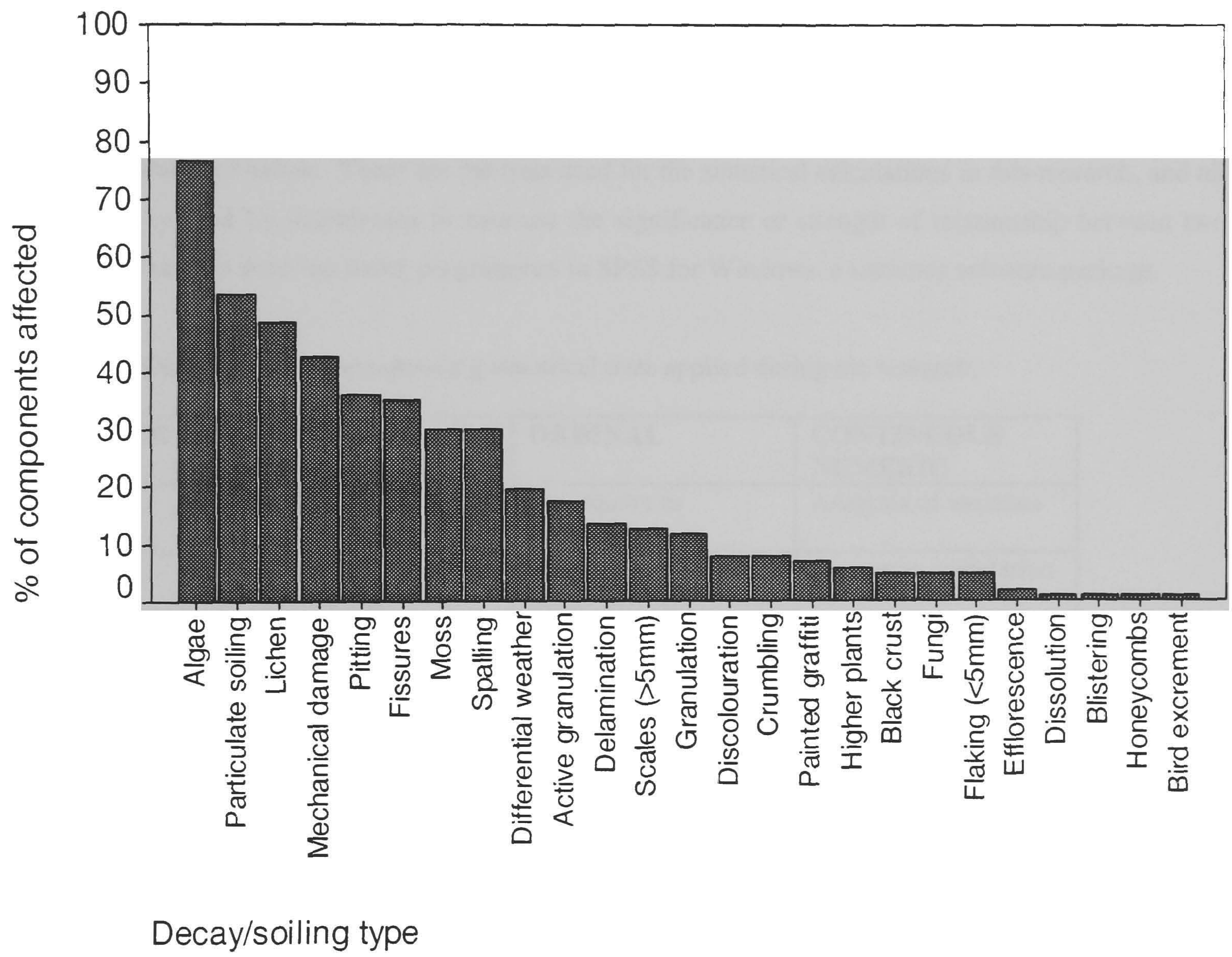
Table 4.12 Frequency of components showing various decay and soiling types in the sample

Decay/soiling type	**Frequency of affected sample components**	**SEVERITY OR DENSITY LEVEL**			**SURFACE DISTRIBUTION**	
		Low/light	**Moderate**	**High**	**Localised**	**General**
Algae	79	27	18	34	47	32
Particulate soiling	55	10	24	21	33	22
Lichen*	50	21	17	12	31	18
Mechanical	44	17	8	19	39	5
Pitting	37	12	18	7	16	21
Fissures	36	14	12	10	36	0
Moss	31	17	7	7	29	2
Spalling	31	4	13	14	29	2
Granulation	27	8	14	5	25	2
Differential weathering	20	9	6	5	16	4
Delamination	14	5	4	5	11	3
Scales (>5mm)	13	3	9	1	13	0
Discolouration	8	6	1	1	8	0
Crumbling	8	2	0	6	8	0
Painted graffiti	7	6	0	1	7	0
Plants	6	4	0	2	5	1
Black crust	5	2	0	3	5	0
Fungi	5	4	1	0	5	0
Flakes (<5mm)	5	3	2	0	5	0
Efflorescence	2	1	0	1	2	0
Dissolution	1	0	0	1	1	0
Blistering	1	0	0	1	1	0
Honeycombs	1	0	1	0	0	1
Bird excrement	1	1	0	0	1	0
Total decay and soiling frequencies	*487*	*176*	*155*	*156*	*373*	*113*

*The lichen distribution values fall one short of the overall total frequency, since in the case of Dundee cross the extent of distribution could not be established. The steps of Dundee cross were not physically accessible and the survey was instead carried out based upon photographs and reports produced by contractors earlier in 1998.

The percentages of cross components that show each decay and soiling type are also illustrated in the chart in Figure 4.7 below.

Figure 4.7 Percentage of components affected by each decay/soiling type in the sample.



The patterns of individual decay and soiling types on the sampled crosses are examined in detail using statistical tests in Section 4.4, and are subject to a detailed discussion in Section 5.2.6.

4.3 Discussion of statistical techniques adopted

The adopted statistical techniques had to be suitable for the data types collected in the survey. The collected data types were mostly ordinal and nominal, along with only a few variables of continuous numeric data type. Investigation of statistical techniques showed the suitability of chi-square tests for nominal and ordinal data, Spearman rank correlation for ordinal data and ordinal v. continuous data, analysis of variance for continuous v. nominal data, and Pearson parametric correlation for continuous data. The statistical test types appropriate for analysing different types of data in the variable pairings are shown in Table 4.13 below. These are the tests used for the statistical calculations in this research, and all are commonly used by statisticians to measure the significance or strength of relationship between two variables. The tests were run using programmes in SPSS for Windows, a statistics software package.

Table 4.13 Data types and corresponding statistical tests applied during the research.

DATA TYPE	**NOMINAL**	**ORDINAL**	**CONTINUOUS NUMERIC**
NOMINAL	Chi-square or Fisher's test	Chi-square or Fisher's test	Analysis of variance
ORDINAL	Chi-square or Fisher's test	Chi-square or Spearman correlation	Spearman correlation
CONTINUOUS NUMERIC	Analysis of variance	Spearman correlation	Pearson correlation

4.3.1 Statistical test types

The chi-square test

The chi-square test is a test of association. It compares actual frequencies with the frequencies that would be expected if there were no association between the two variables. The lower the significance value, the greater the likelihood that there is a relationship between the two variables. For example it was used in the research to indicate if there was a relationship between land-use types and stone decay/soiling types. Such variables in the database, comprising multiple categories of nominal data type (eg land-use type, orientation of facade), were analysed initially by running a chi-square test to check whether the factor as a whole has any effect upon the levels of decay and soiling. Where the chi-square value was of some significance, further tests were run on the individual variables (eg in the case of land-use this involved further investigation of the levels of decay and soiling associated with the specific land-use types, eg roads, pedestrian thoroughfare, grassy land-uses, indoors), thus generating further individual chi-square or Fisher's Test values. However, a major limitation of the chi-square test with regard to the collected research data is that no more than 20% of the expected frequencies in the cross-tabulation can be <5. It rapidly became apparent that the data frequencies in the sample are often unsuitable for the chi-square test, since they are too low in the case of certain decay types and certain weathering agents. Solutions to such a problem commonly include merging data sets to increase frequencies. However it is often not meaningful to merge the categories of data, particularly in the case of the nominal variables (eg component types, decay/soiling types, orientation data, environmental factors). Increasing the sample size would be another solution; however, this was not possible due to limitations of time and funding. However, one other option, chosen in many of the analyses in this research, was to collapse the data sets into two categories for each of the two variables and apply a related test, the Fisher Exact Test.

The Fisher Exact test

Like the chi-square test, the Fisher Exact test compares actual with expected frequencies in order to measure the association between two variables. The test is based upon a 2x2 table of data and is designed to deal with low frequencies. For example, it was used in the sample to measure the degree of density of algae on monuments in areas of low annual precipitation, compared to the density of algae in areas of higher annual precipitation. A requirement is that each variable tested must be divided into two categories eg yes/no, high/low or simply two nominal categories. It is a flexible test that was much used in the research.

Analysis of variance and Kruskal-Wallis test

Continuous numeric data can be tested in relation to another nominal variable (eg in the sample, the relation of component age to Listed Building Category) using analysis of variance. This compares the variation among mean values of the nominal sets with the spread of values within each nominal set. Conditions include that the standard deviation in each data set should be roughly equivalent and the scores independent of one another. Such tests available in the SPSS software include ANOVA and the Kruskal-Wallis test. Upon inspection of the collected data values it was decided that the ANOVA results could be misleading because they are based upon the comparison of mean values of a number of data sets, thus any outliers could distort the results. For example, in the case of component age the Fowlis Wester slab has an age of 1250 years, hundreds of years older than the other crosses, thus the mean of its data set would be skewed due to this. In such cases the Kruskal-Wallis test was found to be more suitable, since it compares median values rather than mean values and it has no distributional assumptions (Wright 1997). A significant test result indicates that at least one of the medians of the nominal sets is different. A boxplot chart can be constructed from this to illustrate the medians and variation in the form of interquartile ranges (eg see previous chart in Figure 4.6).

Spearman rank correlation

The Spearman correlation measures the degree and direction of a relationship between two variables. If one visualises a scatterplot, the Spearman correlation measures the extent to which the plotted points approximate to a straight line. It measures the strength of a positive or negative linear relationship. Due to the low number of variables of continuous numeric data type in the sample, this test was only used in a few cases. When used for factors of continuous data type (eg component age), this test was used to establish the general significance level in relation to each decay/soiling type. Then, in order to fit the trend into the design of the risk assessment model (which requires all variables to be categorised) it was necessary to run tests with the continuous data subdivided into categories (eg component age sub-divided into centuries).

Pearson parametric correlation

There were few instances in which the Pearson correlation test could be applied due to the low number of variables of continuous numeric data type in the sample. The test measures the closeness to a straight-line relationship between two variables of continuous numeric data type. One example of its use was to test the extent to which there is a relationship between the age of the crosses and the frequency of resiting. None of the Pearson correlation tests indicated a statistically significant relationship, thus their results do not feature in the risk assessment model.

4.3.2 Explanation of significance levels

The significance value calculated from statistical tests is the probability that the relationship between the groups arises due to chance. The statistical significance (or 'alpha' level) is conventionally set at 0.05 or 5% probability by statisticians. Thus significance values less than or equal to 0.05 are generally considered to indicate a statistically significant relationship which does not arise due to chance. It is important to remember in test results that a significant correlation does not automatically imply causation, and this issue is discussed with regard to each of the tested relationships in Section 5.2.6 in the Risk Assessment Model Chapter.

4.3.3 Limitations of the statistical techniques as applied in the current research

Significance levels

During the data analysis, it was found that fewer relationships than expected yielded a result of statistical significance. This meant that some decay/soiling types would have to be excluded from the risk assessment since they yielded no relationships of the conventional significance level when tested. Therefore, in constructing the sample risk assessment model it was decided to include relationships with an alpha level ≤ 0.1 (ie those where there is $\leq 10\%$ probability that the relationship arises due to chance).

This decision to allow a slight increase to the alpha level is considered valid by the candidate because it is an arbitrary convention that is sometimes subject to alteration in surveys. This distinction between the relationships that would conventionally be considered true, and those with a slightly greater chance of being accidental, is indicated in the test results presented in Tables 4.15-4.37 later in this section. Those with a ≤0.05 probability value are noted as having a *High* significance, while those with a value of ≤0.1 are labelled as having a *Moderate* significance. Other relationships, which have little or no calculated significance were rejected from further analysis and are not included in the final sample model. Since the relationships considered for inclusion in the model each had a ≤10% probability of arising due to chance, it was theoretically likely that a few of these would be apparent correlations which are statistically invalid. Furthermore, the list of significant relationships could include correlations that do not represent any cause-and-effect mechanism. Thus it was necessary to subject them to a further filtering process, according to the extent to which they were interpreted as supporting the hypothesised decay or soiling processes. In order to justify their rejection or inclusion in the final model, a detailed discussion of the validity of each relationship is presented in Section 5.2.6 of the Risk Assessment Model Chapter. Therefore, the relationships that finally appear in the risk assessment model are those judged to represent direct or secondary cause-and-effect mechanisms.

Comparison of test results

One problem with using a variety of tests is that the significance values produced by different test types cannot be directly compared since they are derived in different ways. This limitation seemed inevitable, since the different data types require different tests. However, for the purposes of comparison the numeric data were also re-classified into ordinal data to allow the application of the chi-square, Fisher's or Spearman correlation test. To enable effective comparison in the sample, the Fisher Exact test was generally used for as many calculations as possible, since this was found to be the most flexible of the testing methods explored during the research. However, nuances between the values of statistical significance are not the most important factor in the risk assessment model, since it is the occurrence rate and amount of material loss observed in the sample which determine the calculated risk, rather than the significance level. The role of the significance values in the present research was as criteria for the initial selection of variable pairs to appear in the risk assessment model. Only variable pairs with significance values of ≤0.1 are included in the risk assessment. In conclusion, the effect of using different test types is considered to have a negligible effect upon the calculated risk values.

Low frequencies

Some variables had such low frequencies that statistical tests were not considered to be applicable, and in such cases the incidence level could instead only be commented upon. Such decay/soiling types include blistering, dissolution, honeycomb weathering and bird excrement, which each have a frequency of only one in the sample (discussed in Section 5.2.6). Factors of influence which also have very low frequencies include land-use as flowerbeds, site aspect, the incidence of chemical stone cleaning and the existence of shelter at the crosses (discussed in Section 4.5).

4.4 Calculated statistical significance values in relation to the formulated hypotheses

4.4.1 Factors of influence

The incidence, degree of severity/density, and the extent of surface distribution of all the observed decay/soiling types in the sample were tested, where appropriate, in relation to up to 28 factors of influence (including factors of environment, climate, intervention, monument parts and stone properties). The factors tested in relation to the decay and soiling patterns are listed and defined in the following Table 4.14.

Table 4.14 Factors of influence used for statistical testing and probability calculations.

Source of influence	Factor of influence	Level of factor of influence	Frequency of associated cross components (out of 103)	Criteria and comments
Climate	Relative humidity	Lower	38	System of classification adopted from a map of bioclimatic zones in Scotland (Birse 1971). *Fairly Humid* (H4) was regarded as the lower humidity category in the statistical tests.
		Higher	65	System of classification adopted from a map of bioclimatic zones in Scotland (Birse 1971). *Perhumid* to *Humid* *(P* and *H1* to *H3)* classifications were taken to represent a higher humidity level. Note that the *Humid* category has the highest frequency of crosses.
	Annual average days of fog	Lower	47	0.7 - 7.0 annual average days of fog (data obtained from the Meteorological Office).
		Higher	55	7.4 - 15.2 annual average days of fog (data obtained from the Meteorological Office).
	Annual average days of frost	Lower	56	27.8 - 44.3 annual average days of frost (data obtained from the Meteorological Office).
		Higher	47	46.7 - 81.5 annual average days of frost (data obtained from the Meteorological Office).
	Annual average daily mean temperature	Lower	53	Annual average of daily mean temperature 7.7 - 8.55 degrees Centigrade (data obtained from the Meteorological Office).
		Higher	50	Annual average of daily mean temperature 8.65 - 9.2 degrees Centigrade (data obtained from the Meteorological Office).
	Windspeed	Lower	44	22.5 - 23.5 hourly mean wind speed (metres per second). These are mapped values, derived from an isogram in BRE Digest 346 Aug 1989 *(The assessment of wind loads Part 3: Wind climate in the United Kingdom, Fig 1, p2).*
		Higher	59	24.0 - 25.5 hourly mean wind speed (metres per second). These are mapped values, derived from an isogram in BRE Digest 346 Aug 1989 *(The assessment of wind loads Part 3: Wind climate in the United Kingdom, Fig 1, p2).*
	Annual average precipitation	Lower	58	570 - 695mm average annual precipitation (data obtained from the Meteorological Office).
		Higher	45	710 - 2317 mm average annual precipitation (data obtained from the Meteorological Office).

Table 4.14 Factors of influence used for statistical testing and probability calculations *(continued)*

Source of influence	Factor of influence	Presence or level of factor of influence	Frequency of associated cross components (out of 103)	Criteria and comments
Environment	Fenced	Yes	27	Eight crosses (comprising 27 components) are enclosed by railings. This group includes Fowlis Wester since it was located outside and fenced until very recently (1991).
		No	76	Unenclosed by railings. Such crosses could be more vulnerable to vandalism and physical impacts.
	Surfaced ground	Yes	81	Paved or metalled ground surface, ie roads or pedestrian thoroughfares. Although these sites have no groundwater, the 'splashback' of rainwater from the hard ground onto lower parts of the monuments can occur.
		No	22	Unpaved ground surface, ie grass or exposed topsoil. The capillary processes which the groundwater allows cause salts and moisture to be introduced upward into the stone.
	Grassy land-use	Yes	33	Grassy land-use types include crosses on communal greens, grass verges, in churchyards and on arable land.
		No	70	Crosses located on roads, pedestrian thoroughfares and indoors.
	Rural land-use	Yes	11	Rural land-use types in the sample comprise the cross at Rossie on arable land, and those at Dallas and Duffus in churchyards in the countryside.
		No	91	Crosses located in towns.
	Low traffic level	Lower	44	'B' roads, Secondary roads, residential roads, and urban roads with low traffic levels.
		Higher	59	'A' roads and urban roads with moderate and busy traffic.
	Proximity to coast	Coastal		*Coastal* and *Very coastal* crosses, ie crosses located <5km of the sea in at least two of the eight compass directions (eg N and NE).
		Inland		*Inland* and *Very inland* crosses, ie all others.

Table 4.14 Factors of influence used for statistical testing and probability calculations *(continued)*

Source of influence	Factor of influence	Presence or level of factor of influence	Frequency of associated cross components (out of 103)	Criteria and comments
Monument part	Exposure of components to the elements	More	49	The more exposed components group consists of finials, friezes, capitals and shafts, and excludes Cromarty, Tain and Dunbar since these monuments are sheltered.
		Less	54	The less exposed components group consists of socket stones, steps, plinths, pedestals and tower base, plus all components at Cromarty, Tain and Dunbar.
	Position of components within the monument	Base level	29	The lowest component of each sampled cross, ie the steps of all crosses. In two cases where the sample crosses had no steps at ground level, alternative base component types were included, ie the pedestal of Cupar cross and Inverbervie plinth. Components that are in this group are largely the same as those that form the group of built components, thus the trends are often the same.
		Elevated	74	All components positioned above the lowest one in each cross.
	Sculpted features	No	26	Mostly comprising the finials of the crosses. Such pieces have a greater surface area to volume ratio, thus there is an increased opportunity for moisture ingress into the stone.
		Yes	77	Built or plain, usually lower, elements of crosses, ie steps, socket stones, shafts.
	Degree of shelter	Sheltered facades	12	Only 3 sampled crosses (12 components) currently stand up against a sheltering wall. Decay/soiling patterns on the sheltered facades (25) of these crosses were compared to those on the components with unsheltered facades.
		Non-sheltered crosses	91	Those not located next to a sheltering wall.
	Components washed by run-off	Yes	78	Components other than shafts. Shafts receive less run-off than other component types, since they are usually crowned by an architectural feature which drains the rainwater away from their face.
		No	25	Shafts, since they are usually crowned by an architectural feature that drains the run-off away from their face.
	Relief-carved components	Yes	25	Such stonework has a greater surface area to volume ratio, thus there is an increased opportunity for moisture ingress into the stone.
		No	78	The lower surface area-to-volume ratio is presumed to allow less opportunity for moisture ingress.
	Components carved with cornices	Yes	10	Cornices function as drip-courses to divert run-off away from the rest of the facade beneath.
		No	93	Surfaces more exposed to run-off.

Table 4.14 Factors of influence used for statistical testing and probability calculation *(continued)*

Source of influence	Factor of influence	Presence or level of factor of influence	Frequency of associated cross components (out of 103)	Criteria and comments
Monument part *(continued)*	Masonry joints	Built components	29	Components built from multiple masonry blocks, including steps, pedestals, plinths and the Edinburgh High Street tower-base. These components are mostly plain and incorporate masonry joints in various states of repair.
		Non-built components	74	Components comprising a single carved stone part with no masonry joints, including most shafts, finials, capitals and socket stones.
	Metal attachments	Iron attachments	11	Components with iron attachments, eg brackets, nails, exposed dowels and railings, which are bedded in the stone.
		Bronze or copper attachments	6	Components with bronze plaques or copper gnoma. Bronze and copper can cause staining due to copper wash. However, none of the components in the sample with such attachments exhibited this effect.
Stone properties	Age of components	Older	43	Component age was initially tested using statistical methods based upon individual values (Kruskal-Wallis test and Spearman Correlation). However, subsequent application of the Fisher Exact test required the division of the components into two age groups. As 260 is the median age in the sample, components >260 years were considered to be amongst the older group.
		Younger	41	Less old components amongst the sampled crosses are <260 years old. Note, however, that the age of carving is known for only 84 components out of 103 in the sample.
	Sandstone cement type	Siliceous	6	Sandstone cement type is difficult to determine without laboratory testing and was recorded for only 13 components in the sample. Siliceous components were identified at Ancrum, Bowden and Dunbar.
		Ferruginous	5	Ferruginous sandstones tend to have a reddish tint, eg components at Beauly and Tain.
		Calcareous	1	Hydrochloric acid produces a fizzing effect when applied to calcareous cement. Calcareous cemented sandstone is more vulnerable to gypsum crust. Turriff cross pedestal was the only component identified as having a (patchy) calcareous cement.
		Argillaceous	1	Argillaceous sandstone is particularly vulnerable to decay such as delamination, due to the effect of expanding clay lenses within the stone. Fowlis Wester slab appears to be of this type.
	Sandstone with inclusions	Yes	16	Sandstone incorporating pieces of clay or pebbles. Such stone may be more vulnerable to certain types of decay if the inclusions are more easily eroded, expandable or detached from the surrounding stone.
		No	75	Sandstone incorporating no pieces of clay or pebbles.
	Sandstone grain size	Coarser	12	*Medium-to-coarse* and *Coarse* grain size. Such sandstone will exhibit greater surface roughness and could be more vulnerable to soiling.
		Finer	9	*Fine* and *Fine-to-medium* grain size (NB as there were 5 categories for sandstone grain size the middle size category, *Medium*, was discounted from the statistical calculations for convenience).

Table 4.14 Factors of influence used for statistical testing and probability calculations *(continued)*

Source of influence	Factor of influence	Presence or level of factor of influence	Frequency of associated cross components (out of 103)	Criteria and comments
Intervention	Maintenance of masonry joints	Repointed built components	9	Built components for which there is evidence of repointing. If the mortar is of a suitable composition, such components incur less moisture ingress since there is no space in the joints for water to gather.
		Non-repointed built components	23	Built components for which there is *no* evidence for repointing. Such components may exhibit gaps in the joints in which water and soil could accumulate, and moss and higher plants could grow.
	Stone-cleaning	Cleaned components	1	Components subject to stone cleaning by chemical methods could be vulnerable to damage due to salt residues. The tower-base of Edinburgh High Street cross was the only component in the sample that had been chemically cleaned.
		Non-cleaned components	102	Components which have never been subject to stone cleaning by chemical methods.
	Re-siting frequency	Higher	29	Components re-sited 3 or more times (ie the cross stands on at least its fourth site)
		Lower	74	Components re-sited 0-2 times (ie the cross stands on its original, first, second or third site).

4.4.2 Statistical test results

Based upon the literature review, various hypotheses were formulated for each decay and soiling type, with regard to their relationship to the factors of influence. These expected trends are shown in the following series of Tables 4.15-4.37 alongside the *actual* trends. In the interests of objectivity, it was not only the formulated hypotheses that were tested. Where appropriate, the frequency, severity and surface extent of all 24 decay and soiling types were tested in relation to every factor of influence, such that a total of approximately 500 statistical tests were run during the analysis. As a result, a number of *unhypothesised* correlations were also discovered - these are included amongst the tabulated results in Tables 4.15-4.37 below. The implications of each relationship are fully discussed in Section 5.2.6 in the Risk Assessment Model chapter.

The following tables containing the test results are grouped according to the general class of decay/soiling, ie biological soiling, non-biological soiling, granular disaggregation, planar disaggregation and fracture types. The factors of influence are grouped within each table according to the general hypothesis which they had been expected to support. For example, algae was expected to be greater upon monuments exposed to more moisture, thus algal growth was tested in relation to factors of a wetter climate, ie greater fog, relative humidity and precipitation. The test results for the soiling/decay incidence, severity/density and surface distribution are all presented in relation to these factors of influence. Where one of the decay/soiling aspects does not vary (eg the surface distribution of black crust is *Localised* in all the observed cases) no test could be applied to its distribution. The non-varying aspects are therefore not shown in the tables. The expected correlation is shown alongside the actual result (a plus or minus sign indicates whether the expected and actual correlations were positive or negative, while '0' indicates that no relationship existed at all). A *High* significance level denotes that the statistical test yielded a probability value of ≤ 0.05, while *Moderate* significance indicates a slightly weaker correlation with a probability of between 0.051 and 0.10. These relationships are emphasised in the tables by shaded cells. Probability values >0.10 were judged to be of no significance and their *significance level* is therefore marked *none* in the tables. Below the table for each decay/soiling type is a short summary of the rationale behind the formulated hypotheses, plus a note about the existence of any limitations upon the data tests with regard to low frequencies. There are 123 relationships which yielded *Moderate* or *High* significance values of ≤ 0.10. Of these, 33 supported the formulated hypotheses, 25 actually opposed the hypotheses, and 65 were relationships for which no hypotheses at all had been formulated prior to the testing.

Biological soiling types

Table 4.15 Data analysis results in relation to hypotheses for algae in the sample

ALGAE						
Mechanism	**Factor of influence**	**Aspect of algae**	**Correlation expected**	**Result**	**Hypothesis supported?**	**Significance level**
Wetter climate	Higher precipitation	Incidence	+	0	N	None
		Density	+	0	N	None
		Distribution	+	+	Y	None
	Higher relative humidity	Incidence	+	-	N	None
		Density	+	-	N	None
		Distribution	+	-	N	None
	Greater days of fog	Incidence	+	0	N	None
		Density	+	+	Y	None
		Distribution	+	+	Y	None
Greater moisture retention	N-facing facades	Incidence	+	0	N	None
		Density	+	0	N	None
		Distribution	+	0	N	None
	W/SW-facing facades	Incidence	-	0	N	None
		Density	-	0	N	None
		Distribution	-	0	N	None
	S-facing facades	Incidence	-	-	N	None
		Density	-	0	N	None
		Distribution	-	0	N	None
	N aspect*	Incidence	+	+	Y	None
		Density	+	+	Y	None
		Distribution	+	-	N	None
	Groundwater	**Incidence**	**+**	**-**	**N**	**High**
		Density	+	-	N	None
		Distribution	+	-	N	None
	Sheltered facades	Incidence	+	+	Y	None
		Density	**+**	**+**	**Y**	**Moderate**
		Distribution	+	+	Y	None
	Washed components	Incidence	+	0	N	None
		Density	**+**	**+**	**Y**	**Moderate**
		Distribution	**+**	**+**	**Y**	**High**
	Repointed components	Incidence	-	+	N	None
		Density	-	-	Y	None
		Distribution	-	+	N	None
	Components carved with cornices	Incidence	-	0	N	None
		Density	-	0	N	None
		Distribution	-	-	Y	None
	Sculpted components	Incidence	+	0	N	None
		Density	**+**	**+**	**Y**	**High**
		Distribution	+	0	N	None
	Exposed components	**Incidence**	**0**	**-**	**N**	**High**
		Density	0	0	Y	None
		Distribution	0	0	Y	None
	Elevated components	Incidence	0	-	N	None
		Density	**0**	**+**	**N**	**High**
		Distribution	0	+	N	None

Table 4.15 Data analysis results in relation to hypotheses for algae in the sample *(continued)*

ALGAE *(continued)*						
Mechanism	**Factor of influence**	**Aspect of algae**	**Correlation expected**	**Result**	**Hypothesis supported?**	**Significance level**
Motor vehicle emissions	Roads land-use	Incidence	+	0	N	None
		Density	+	+	Y	None
		Distribution	+	0	N	None
	Greater traffic level	Incidence	+	+	Y	None
		Density	+	+	Y	None
		Distribution	+	-	N	None
	Orientation of roads	Incidence	+	0	N	None
		Density	+	0	N	None
		Distribution	+	0	N	None
Stone properties	**Coarse-grained sandstone**	Incidence	+	0	N	None
		Density	+	+	Y	**High**
		Distribution	+	-	N	None
	Calcareous cement*	Incidence	-	+	N	None
		Density	-	+	N	None
		Distribution	-	-	Y	None

* Only one cross or component was affected, therefore no statistical test was applied, nevertheless the circumstances of the observed case are indicated in the table.

Hypotheses for algae

Algal growth is very much controlled by the amount of moisture on the stone. Therefore factors indicating a wetter climate may be significant. The orientation of the monument facades, the degree of shelter and architectural characteristics are also relevant with regard to the degree of moisture dealt to the stone and retained by it. Algae is more tolerant of atmospheric pollution than other biological growth types, therefore the degree of algae was tested in relation to nearby vehicular traffic. The literature review also showed that certain stone properties affect algal growth, thus the sandstone grain size and cement type were examined.

Table 4.16 Data analysis results in relation to hypotheses for fungi in the sample.

FUNGI						
Mechanism	**Factor of influence**	**Aspect of fungi**	**Correlation expected**	**Result**	**Hypothesis supported?**	**Significance level**
Unhypothesised correlation	**Groundwater**	**Incidence**	**0**	+	N	**Moderate**
		Density	0	+	N	None

Hypotheses for fungi

No hypotheses were formulated regarding fungi.

Data limitations

Problems were encountered with the identification of fungi in the sample survey. Laboratory tests are normally required to verify the presence of fungi. However, a substance thought to be fungi was recorded on 5 components in the sample. In all cases the surface distribution was very localised thus it was not possible to test for any correlations with regard to fungi distribution. Additionally the observed density level was limited to *Low* and *Moderate*. The low frequencies account for the lack of significant correlations.

Table 4.17 Data analysis results in relation to hypotheses for higher plants in the sample.

HIGHER PLANTS						
Mechanism	**Factor of influence**	**Aspect of plants**	**Correlation expected**	**Result**	**Hypothesis supported?**	**Significance level**
Presence and condition of masonry joints	Repointed components	Incidence	-	-	Y	None
		Density	-	0	N	None
		Distribution	-	0	N	None
	Base components	**Incidence**	+	+	Y	**High**
		Density	+	0	N	None
		Distribution	+	0	N	None
	Built components	**Incidence**	+	+	Y	**High**
		Density	+	0	N	None
		Distribution	+	0	N	None
Non-surfaced land-use	Grassy land-use	Incidence	+	-	N	None
		Density	+	0	N	None
		Distribution	+	0	N	None

Hypotheses for higher plants

The presence of vacant joints and enclaves in the monuments in which soil and moisture can be trapped were expected to be correlated with increased weed growth. Such contexts are usually found in the lower, built components of the crosses. Grassy land-uses were expected to allow greater opportunity for plants to become established on the stonework.

Data limitations

Higher plants had a low frequency in the sample, observed growing on only 6 components. With the exception of one component, all cases had a localised distribution.

Table 4.18 Data analysis results in relation to hypotheses for lichen in the sample.

LICHEN						
Mechanism	Factor of influence	Aspect of lichen	Correlation expected	Result	Hypothesis supported?	Significance level
Drier conditions	**Higher temperature**	**Incidence**	**+**	**-**	**N**	**High**
		Density	+	-	N	None
		Distribution	**+**	**-**	**N**	**High**
	Lower precipitation	Incidence	+	-	N	None
		Density	+	0	N	None
		Distribution	+	0	N	None
	Lower relative humidity	**Incidence**	**+**	**-**	**N**	**High**
		Density	+	-	N	None
		Distribution	**+**	**-**	**N**	**Moderate**
	Less days of fog	Incidence	+	+	Y	None
		Density	+	+	Y	None
		Distribution	**+**	**-**	**N**	**Moderate**
	S-facing facades	Incidence	+	-	N	None
		Density	+	0	N	None
		Distribution	+	0	N	None
	SW/W-facing facades	Incidence	+	-	N	None
		Density	+	0	N	None
		Distribution	+	0	N	None
	W/SW site aspect*	Incidence	+	0	N	None
		Density	+	0	N	None
		Distribution	+	0	N	None
	Exposed components	**Incidence**	**+**	**-**	**N**	**Moderate**
		Density	**+**	**+**	**Y**	**High**
		Distribution	+	-	N	None
	Sculpted components	**Incidence**	**0**	**-**	**N**	**High**
		Density	**0**	**+**	**N**	**High**
		Distribution	0	+	N	None
Less polluted atmosphere	Rural land-use*	Incidence	+	+	Y	None
		Density	+	+	Y	None
		Distribution	+	+	Y	None
	Roads land-use	Incidence	-	0	N	None
		Density	**-**	**-**	**Y**	**High**
		Distribution	-	-	Y	None
	Lower traffic levels	**Incidence**	**+**	**+**	**Y**	**High**
		Density	**+**	**+**	**Y**	**Moderate**
		Distribution	**+**	**+**	**Y**	**High**
Slow colonisation and growth rate	**Older components**	**Incidence**	**+**	**+**	**Y**	**High**
		Density	**+**	**+**	**Y**	**High**
		Distribution	+	0	N	None
Unhypothesised correlations	**Grassy land-use**	**Incidence**	**0**	**+**	**N**	**High**
		Density	0	+	N	None
		Distribution	**0**	**+**	**N**	**Moderate**
	Greater days of frost	Incidence	0	+	N	None
		Density	**0**	**+**	**N**	**High**
		Distribution	**0**	**+**	**N**	**Moderate**

* Only one cross or component was affected, therefore no statistical test was applied therefore no statistical test was applied, nevertheless the circumstances of the observed case are indicated in the table.

Table 4.18 Data analysis results in relation to hypotheses for lichen in the sample *(continued)*.

LICHEN *(continued)*						
Mechanism	**Factor of influence**	**Aspect of lichen**	**Correlation expected**	**Result**	**Hypothesis supported?**	**Significance level**
Unhypothesised correlations *(continued)*	**Coastal site**	**Incidence**	**0**	**-**	**N**	**High**
		Density	0	-	N	None
		Distribution	**0**	**-**	**N**	**High**
	Groundwater	**Incidence**	**-**	**+**	**N**	**High**
		Density	**-**	**+**	**N**	**High**
		Distribution	**-**	**+**	**N**	**High**
	Built components	**Incidence**	**0**	**+**	**N**	**High**
		Density	**0**	**-**	**N**	**High**
		Distribution	0	+	N	None
	Base components	**Incidence**	**0**	**+**	**N**	**High**
		Density	**0**	**-**	**N**	**High**
		Distribution	0	+	N	None
	Relief-carved components	**Incidence**	**0**	**-**	**N**	**Moderate**
		Density	0	+	N	None
		Distribution	0	0	Y	None

Hypotheses for lichen

Lichen can tolerate extremely cold and dry conditions. Therefore it might be found in such contexts in which other biological soiling types grow less easily. These conditions are controlled by climatic variables, the orientation of aspect and monument facades, and architectural features. Lichen is not very tolerant of atmospheric pollution. Thus it was expected to show lower levels in urban contexts, particularly where the monuments are directly exposed to motor vehicle emissions. Correspondingly, the amount and diversity of lichen growth could be greater in rural locations since stone in these locations is less exposed to atmospheric pollution. Most lichens are known to have a slow colonisation and growth rate, thus they were expected to be greater upon older components. A large number of unhypothesised correlations were revealed in the tests and explanations can be offered for some of these relationships (see detailed discussion of trends in Section 5.2.6 in the Risk Assessment Model chapter).

Table 4.19 Data analysis results in relation to hypotheses for moss in the sample.

MOSS						
Mechanism	**Factor of influence**	**Aspect of moss**	**Correlation expected**	**Result**	**Hypothesis supported?**	**Significance level**
Wetter climate	Higher precipitation	Incidence	+	+	Y	None
		Density	+	-	N	None
		Distribution	+	-	N	None
	Higher relative humidity	Incidence	+	+	Y	None
		Density	+	-	N	None
		Distribution	**+**	**-**	**N**	**Moderate**
Wet conditions	Shaded facades	Incidence	+	-	N	None
		Density	+	0	N	None
		Distribution	+	0	N	None
	Exposed components	**Incidence**	**-**	**-**	**Y**	**High**
		Density	-	0	N	None
		Distribution	-			
	Washed components	**Incidence**	**+**	**+**	**Y**	**High**
		Density	+	0	N	None
		Distribution	+	0	N	None
	Sculpted components	**Incidence**	**0**	**-**	**N**	**High**
		Density	0	0	N	None
		Distribution	0	0	N	None
	Groundwater	Incidence	+	+	Y	None
		Density	+	+	Y	None
		Distribution	+	0	N	None
	N-facing facades	Incidence	+	+	Y	None
		Density	+	0	N	None
		Distribution	+	0	N	None
	N site aspect*	Incidence	+	+	Y	None
		Density	+	-	N	None
		Distribution	+	-	N	None
	Lower wind speed	Incidence	+	-	N	None
		Density	+	+	Y	None
		Distribution	+	0	N	None
	W/SW-facing facades	Incidence	-	-	Y	None
		Density	-	0	N	None
		Distribution	-	0	N	None
	W/SW-facing aspect	Incidence	-	0	N	None
		Density	-	0	N	None
		Distribution	-	0	N	None
	S-facing facades	Incidence	-	-	Y	None
		Density	-	0	N	None
		Distribution	-	0	N	None
Presence and condition of masonry joints	**Built components**	**Incidence**	**+**	**+**	**Y**	**High**
		Density	+	-	N	None
		Distribution	+	+	Y	None
	Base components	**Incidence**	**+**	**+**	**Y**	**High**
		Density	+	-	N	None
		Distribution	+	+	Y	None

Table 4.19 Data analysis results in relation to hypotheses for moss in the sample *(continued)*.

MOSS *(continued)*						
Mechanism	**Factor of influence**	**Aspect of moss**	**Correlation expected**	**Result**	**Hypothesis supported?**	**Significance level**
Presence and condition of masonry joints	Repointed components	Incidence	-	-	Y	None
		Density	-	-	Y	None
		Distribution	-	-	Y	None
Unpolluted atmosphere	**Rural land-use**	Incidence	+	+	Y	None
		Density	+	+	Y	**High**
		Distribution	+	0	N	None
	Lower traffic level	Incidence	+	+	Y	None
		Density	+	+	Y	**High**
		Distribution	+	+	Y	None
Non-surfaced land-use	**Grassy land-use**	Incidence	+	+	Y	None
		Density	+	+	Y	**High**
		Distribution	+	+	Y	None
Unhypothesised correlations	**Component age**	Incidence	0	0	N	None
		Density	0	+	N	High
		Distribution	0	+	N	None
	Relief-carved components	**Incidence**	0	-	N	Moderate
		Density	0	-	N	None
		Distribution	0	-	N	None

Hypotheses for moss

Moss requires wet contexts in which to grow. Such conditions might be encouraged by wetter climates. Additionally the presence of vacant joints and enclaves in the monuments in which soil and moisture can be trapped were expected to be correlated with increased moss growth. Moss is not very tolerant of polluted atmospheres, thus less growth was expected in the presence of heavy traffic and in urban contexts. Grassy land-uses were expected to allow greater opportunity for moss to become established on the stonework.

Data limitations

Although moss was frequent upon the sampled crosses, its surface distribution was mostly localised. This can explain the lack of significant correlations with regard to its distribution.

Non-biological soiling types

Table 4.20 Data analysis results in relation to hypotheses for black crust in the sample.

BLACK CRUST						
Mechanism	**Factor of influence**	**Aspect of black crust**	**Correlation expected**	**Result**	**Hypothesis supported?**	**Significance level**
Atmospheric pollution	Greater traffic level	Incidence	+	+	Y	None
		Density	+	+	Y	None
	Orientation of traffic	Incidence	+	0	N	None
		Density	+	0	N	None
	Pavements land-use	Incidence	+	+	Y	None
		Density	+	0	N	None
	Roads land-use	Incidence	+	-	N	None
		Density	+	0	N	None
Unwashed monument parts	Shaded facades	Incidence	+	+	Y	None
		Density	+	+	Y	None
	Components carved with cornices	**Incidence**	**+**	**+**	**Y**	**Moderate**
		Density	+	0	N	None
	Relief-carved components	**Incidence**	**+**	**+**	**Y**	**High**
		Density	+	0	N	None
	Unwashed components	Incidence	+	0	N	None
		Density	+	+	Y	None
Greater aerosol levels	Greater days of fog	Incidence	+	+	Y	None
		Density	+	0	N	None
	Higher relative humidity	Incidence	+	-	N	None
		Density	+	-	N	None
Airflow around stone	Sculpted components	Incidence	+	+	Y	None
		Density	+	-	N	None
Vulnerable stone type	Calcareous cement*	Incidence	+	-	N	None
		Density	+	0	N	None
Unhypothesised correlation	**Coastal siting**	**Incidence**	**0**	**+**	**N**	**Moderate**
		Density	0	0	Y	None

* Only one component was relevant, thus no statistical test was applied, therefore no statistical test was applied, nevertheless the circumstances of the observed case are indicated in the table.

Hypotheses for black crusts

The particulates absorbed by crusts were expected to be greater in contexts of high traffic levels. Black crusts usually form on unwashed areas of stonework. Therefore, certain architectural features which incorporate unwashed zones should dictate the presence of black crust. Aerosols (fog and humidity) can aid the transport of particulates onto such areas of the monuments, therefore greater levels of these climatic variables could show a correlation with greater black crust. Another hypothesis tested (from Whalley, Smith & Magee 1992), was that sculpted parts show thicker crusts due to the intracacies in airflow, and thus variations in the amount of dry depostion, around the stone. Finally, the sandstone cement type could affect the black crust observed in the sample, since calcareous cement provides a source of calcium necessary for black crust formation.

Data limitations

Black crust has a very low frequency in the sample (observed on just 5 components). Additionally, it occurs with a very localised surface distribution in all observed cases. Due to this, it was not possible to test for any correlations with regard to the crust distribution. Trends regarding the low or high density of black crust are also insignificant due to the low overall frequency.

Table 4.21 Data analysis results in relation to hypotheses for efflorescence in the sample.

EFFLORESCENCE						
Mechanism	**Factor of influence**	**Aspect of efflorescence**	**Correlation expected**	**Result**	**Hypothesis supported?**	**Significance level**
Moist conditions with slow evaporation conditions	Lower temperature	Incidence	+	+	Y	None
		Density	+	0	N	None
	Lower wind speed	Incidence	+	+	Y	None
		Density	+	0	N	None
	Higher relative humidity	Incidence	+	-	N	None
		Density	+	0	N	None
	Greater days of fog	Incidence	+	-	N	None
		Density	+	0	N	None
	Higher precipitation	Incidence	+	-	N	None
		Density	+	0	N	None
	N-facing facades	Incidence	+	0	N	None
		Density	+	0	N	None
	W/SW-facing facades	Incidence	-	0	N	None
		Density	-	0	N	None
	W/SW aspect	Incidence	-	0	N	None
		Density	-	0	N	None
Capillary moisture and salts	Groundwater	Incidence	+	-	N	None
		Density	+	0	N	None
Atmospheric pollution	Greater traffic levels	Incidence	+	+	Y	None
		Density	+	0	N	None
	Orientation of roads	Incidence	+	0	N	None
		Density	+	0	N	None
De-icing salts	Pavements land-use	Incidence	+	+	Y	None
		Density	+	0	N	None
	Roads land-use	Incidence	+	-	N	None
	Coastal setting	Incidence	+	+	Y	None
		Density	+	0	N	None
Inappropriate intervention	Chemical cleaning residues	Incidence	+	+	Y	None
		Density	+	0	N	None

Hypotheses for efflorescence

Efflorescence requires moist conditions along with slow evaporation. Several climatic variables as well as the orientation of aspect and facades could be expected to affect these conditions. The efflorescing salts could originate from a number of sources, therefore the introduction of salts due to capillary processes, motor vehicle emissions, de-icing salts, atmospheric sea-salts and cleaning residues was examined. Laboratory tests indicated that the efflorescing salts could be due to cleaning residues (see Section 4.5.2.5).

Data limitations

In the sample two components from just one cross (Edinburgh High Street) have efflorescence. Therefore, the frequency of efflorescence is too low to allow adequate investigation in the sample or any extrapolation. Although the hypotheses and the circumstances of the observed efflorescence are indicated in the table above, *no statistical tests were run.* The density of efflorescence is low on one component and high on the other, while the surface distribution is localised in both cases.

Table 4.22 Data analysis results in relation to hypotheses for graffiti in the sample.

GRAFFITI						
Mechanism	**Factor of influence**	**Aspect of graffiti**	**Correlation expected**	**Result**	**Hypothesis supported?**	**Significance level**
Ease of public access	Urban land-use type	Incidence	+	+	Y	None
		Severity	+	0	N	None
	Monument fenced-off	Incidence	-	+	N	None
		Severity	-	0	N	None

Hypotheses for graffiti

Levels of graffiti are presumed to be related to the ease with which the monument can be accessed by the public. Monuments located in towns are therefore expected to be vulnerable. Those which are fenced-off are more difficult to access.

Data limitations

Graffiti has a low frequency in the sample (observed on just 7 components). Additionally, it occurs with a localised surface distribution in all observed cases. Due to this, it was not possible to test for any correlations with regard to the surface extent of graffiti.

Table 4.23 Data analysis results in relation to hypotheses for particulate soiling in the sample.

PARTICULATE SOILING						
Mechanism	**Factor of influence**	**Aspect of soiling**	**Correlation expected**	**Result**	**Hypothesis supported?**	**Significance level**
Atmospheric pollution	Higher traffic levels	Incidence	+	+	Y	None
		Density	+	0	N	None
		Distribution	+	-	N	None
	Orientation of traffic	Incidence	+	-	N	None
		Density	+	0	N	None
		Distribution	+	0	N	None
	Roads land-use	**Incidence**	+	+	Y	**High**
		Density	+	+	Y	None
		Distribution	+	+	Y	None
	Pavements land-use	Incidence	+	0	N	None
		Density	+	-	N	None
		Distribution	+	0	N	None
Windblown soil/dirt	Flowerbeds land-use	Incidence	+	0	N	None
		Density	+	0	N	None
		Distribution	+	0	N	None
	Base components	**Incidence**	+	+	Y	**High**
		Density	+	-	N	None
		Distribution	+	0	N	None
	Built components	**Incidence**	+	+	Y	**High**
		Density	+	0	N	None
		Distribution	+	0	N	None
Wetter climate	**Higher precipitation**	Incidence	+	+	Y	None
		Density	+	-	N	Moderate
		Distribution	+	-	N	None
	Greater days of fog	Incidence	+	-	N	None
		Density	+	-	N	None
		Distribution	+	0	N	None
	Higher relative humidity	Incidence	+	+	Y	None
		Density	+	-	N	None
		Distribution	+	-	N	None
Moisture retention	Washed components	Incidence	+	-	N	None
		Density	+	-	N	None
		Distribution	+	-	N	None
Unhypothesised correlations	W/SW-facing facades	Incidence	+	0	N	None
		Density	+	0	N	None
		Distribution	+	0	N	None
	Exposed components	**Incidence**	+	-	N	**High**
		Density	+	0	N	None
		Distribution	+	+	Y	None
	Higher temperature	**Incidence**	0	+	N	**High**
		Density	0	+	N	None
		Distribution	0	0	Y	None
	Older components	**Incidence**	0	-	N	**High**
		Density	0	+	N	None
		Distribution	0	-	N	None

Table 4.23 Data analysis results in relation to hypotheses for particulate soiling in the sample *(continued)*.

PARTICULATE SOILING *(continued)*						
Mechanism	**Factor of influence**	**Aspect of soiling**	**Correlation expected**	**Result**	**Hypothesis supported?**	**Significance level**
Unhypothesised correlations *(continued)*	**Groundwater**	**Incidence**	**0**	**-**	**N**	**High**
		Density	0	-	N	None
		Distribution	0	-	N	None
	Greater days of frost	**Incidence**	**0**	**-**	**N**	**High**
		Density	0	+	N	None
		Distribution	0	0	Y	None
	Relief-carved components	**Incidence**	**0**	**-**	**N**	**Moderate**
		Density	0	0	Y	None
		Distribution	0	+	N	None

Hypotheses for particulate soiling

Particulate soiling can originate from motor vehicle emissions. Therefore, high levels of nearby traffic were expected to be a significant factor with regard to the degree of soiling. There could be a greater degree of windblown soil/dirt nearer ground level, thus it was thought that components at lower levels might show greater particulate soiling. Furthermore, such components are often built and therefore have masonry joints which can trap the windblown particles. Crosses sited in flowerbeds with exposed topsoil were also expected to show greater soiling due to windblown soil particles. Particulate soiling is often deposited heavily on washed areas of stone. However, it can be deposited more extensively across stone surfaces when carried by aerosols (ie higher levels of fog and relative humidity). Therefore, climatic variables relating to moisture could be significant. Several unhypothesised correlations were found to be significant when tested in relation to particulate soiling. Explanations of these relationships is provided in the detailed discussion in Section 5.2.6 in the Risk Assessment Model chapter.

Table 4.24 Data analysis results in relation to hypotheses for staining in the sample.

STAINING						
Mechanism	**Factor of influence**	**Aspect of staining**	**Correlation expected**	**Result**	**Hypothesis supported?**	**Significance level**
Staining from metal attachments	**Iron attachments**	**Incidence**	**+**	**+**	**Y**	**High**
		Severity	+	0	N	None
	Bronze/copper attachments	Incidence	+	-	N	None
		Severity	+	0	N	None
Vulnerable component types	**Exposed components**	**Incidence**	**0**	**-**	**N**	**High**
		Severity	0	0	Y	None
	Base components	**Incidence**	**0**	**+**	**N**	**High**
		Severity	0	-	N	None
	Built components	**Incidence**	**0**	**+**	**N**	**High**
		Severity	0	-	N	None

Hypotheses for staining

Staining in the sample was defined as arising due to metal attachments and not discolouration due to natural iron traces in the sandstone. Staining could therefore arise due to copper washing or rusting iron, from various attachments to the stonework. Certain component types, which commonly tend to exhibit certain types of attachments (eg plaques and staples attached to lower components in the crosses), were expected to show greater incidences of staining.

Data limitations

Staining occurs with a very localised surface distribution in all observed cases in the sample. Due to this, it was not possible to test for any correlations with regard to its distribution.

Granular disaggregation types

Table 4.25 Data analysis results in relation to hypotheses for crumbling in the sample.

CRUMBLING						
Mechanism	**Factor of influence**	**Aspect of crumbling**	**Correlation expected**	**Result**	**Hypothesis supported?**	**Significance level**
Frequent wetting and drying cycle	**Higher relative humidity**	**Incidence**	+	-	N	**High**
		Severity	+	-	N	None
	Higher temperature	Incidence	+	0	N	None
		Severity	+	+	Y	None
	Higher precipitation	Incidence	+	-	N	None
		Severity	+	-	N	None
	Greater days of fog	**Incidence**	+	+	Y	**High**
		Severity	+	0	N	None
	Higher wind speed	Incidence	+	+	Y	None
		Severity	+	+	Y	None
	SW- or W-facing facades	Incidence	+	0	N	None
		Severity	+	0	N	None
	SW- or W-facing aspect	Incidence	+	-	N	None
		Severity	+	0	N	None
	S-facing facade	Incidence	+	0	N	None
		Severity	+	0	N	None
	S-facing site aspect	Incidence	+	0	N	None
		Severity	+	0	N	None
	Exposed components	**Incidence**	+	-	N	**High**
		Severity	+	0	N	None
	Washed components	**Incidence**	+	-	N	**Moderate**
		Severity	+	0	N	None
	Repointed components	Incidence	-	0	N	None
		Severity	-	0	N	None
	Component carved with cornices	Incidence	+	+	N	None
		Severity	+	-	N	None
Capillary salts and moisture	Groundwater	Incidence	+	-	N	None
		Severity	+	0	N	None
De-icing salts	Roads land-use	Incidence	+	0	N	None
		Severity	+	0	N	None
	Pavements land-use	Incidence	+	+	Y	None
		Severity	+	+	Y	None
	Base components	Incidence	+	0	N	None
		Severity	+	-	N	None
Atmospheric salts	Higher traffic level	Incidence	+	+	Y	None
		Severity	+	0	N	None
	Coastal sites	Incidence	+	+	Y	None
		Severity	+	0	N	None
Unhypothesised correlations	**Higher frost level**	**Incidence**	-	+	N	**Moderate**
		Severity	-	0	N	None

Hypotheses for crumbling

Crumbling is a symptom of salt decay. Salts in stone cause decay due to wetting and drying cycles, in which the salts crytallise and expand causing pressure within the pores of the stone. Frequent wetting and drying cycles allow more frequent crystallisation and therefore increased decay. Many climatic variables which affect the degree of moisture dealt to the stone and its subsequent evaporation could therefore be significant with regard to the frequency of wetting and drying cycles and the observed salt decay. Additionally, the orientation of aspect and facades, and the position and nature of components within the monuments influence the degree to which the stone receives and retains moisture. The observed cases of salt decay could also show a correlation with particular salt sources. Thus the possibilities of salts introduced from the ground due to capillary processes, from de-icing salts, atmospheric sea salt or motor exhaust emissions were examined.

Data limitations

Crumbling occurs with a very localised surface distribution in all cases in the sample. Due to this, it was not possible to test for any correlations with regard to crumbling distribution. Additionally, the overall frequency of crumbling in the sample is low (occurring on just 8 components).

Table 4.26 Data analysis results in relation to hypotheses for differential weathering in the sample.

DIFFERENTIAL WEATHERING						
Mechanism	**Factor of influence**	**Aspect of weathering**	**Correlation expected**	**Result**	**Hypothesis supported?**	**Significance level**
Unhypothesised correlations	**Higher wind speed**	**Incidence**	**0**	**+**	**N**	**High**
		Severity	0	0	Y	None
		Distribution	0	+	N	None
	Sandstone with inclusions	**Incidence**	**0**	**+**	**N**	**High**
		Severity	**0**	**-**	**N**	**Moderate**
		Distribution	0	0	Y	None
	Exposed components	**Incidence**	**0**	**-**	**N**	**High**
		Severity	0	+	N	None
		Distribution	0	0	Y	None
	Washed components	Incidence	0	+	N	None
		Severity	**0**	**-**	**N**	**High**
		Distribution	0	0	Y	None
	Base components	Incidence	0	+	N	None
		Severity	**0**	**-**	**N**	**High**
		Distribution	0	-	N	None
	Built components	Incidence	0	+	N	None
		Severity	**0**	**-**	**N**	**High**
		Distribution	0	-	N	None
	Repointed components	**Incidence**	**0**	**+**	**N**	**Moderate**
		Severity	0	-	N	None
		Distribution	0	+	N	None
	Sculpted components	**Incidence**	**0**	**-**	**N**	**Moderate**
		Severity	0	0	Y	None
		Distribution	0	-	N	None

Hypotheses for differential weathering

No hypotheses had been formulated with regard to the degree of differential weathering. It is primarily influenced by the stone properties, since this decay is characterised by the increased erosion of softer layers in the sandstone. All of the significant relationships are therefore unhypothesised correlations and are individually examined in the detailed discussion in Section 5.2.6 in the Risk Assessment Model chapter.

Table 4.27 Data analysis results in relation to hypotheses for dissolution in the sample.

DISSOLUTION						
Mechanism	**Factor of influence**	**Aspect of dissolution**	**Correlation expected**	**Result**	**Hypothesis supported?**	**Significance level**
Vulnerable stone properties	Calcareous cement	Incidence	+	+	Y	None
		Severity	+	0	N	None
		Distribution	+	0	N	None
Atmospheric pollution	Roads land-use	Incidence	+	+	Y	None
		Severity	+	0	N	None
		Distribution	+	0	N	None

Hypotheses for dissolution

The literature review showed that calcareous cemented sandstones are vulnerable to dissolution. The process is aided by sulphur-based acids which could be greater in contexts of heavy road traffic.

Data limitations

Only one component in the sample has dissolution (Turriff market cross pedestal), therefore *no statistical tests were applied.* Instead the table indicates the circumstances of its occurrence in relation to the hypotheses.

Table 4.28 Data analysis results in relation to hypotheses for granulation in the sample.

GRANULATION						
Mechanism	**Factor of influence**	**Aspect of granulation**	**Correlation expected**	**Result**	**Hypothesis supported?**	**Significance level**
Frequent wetting and drying cycle	Higher relative humidity	Incidence	+	-	N	None
		Severity	+	-	N	None
		Distribution	+	0	N	None
	Higher temperature	Incidence	+	+	Y	None
		Severity	+	+	Y	None
		Distribution	+	0	N	None
	Higher precipitation	Incidence	+	+	Y	None
		Severity	+	-	N	None
		Distribution	+	0	N	None
	Greater days of fog	Incidence	+	-	N	None
		Severity	+	-	N	None
		Distribution	+	0	N	None
	Higher wind speed	Incidence	+	0	N	None
		Severity	+	0	N	None
		Distribution	+	0	N	None
	SW- or W-facing facades	Incidence	+	0	N	None
		Severity	+	0	N	None
		Distribution	+	0	N	None
	SW- or W-facing aspect	Incidence	+	0	N	None
		Severity	+	0	N	None
		Distribution	+	0	N	None
	S-facing site aspect	Incidence	+	0	N	None
		Severity	+	0	N	None
		Distribution	+	0	N	None
	S-facing facade	Incidence	+	0	N	None
		Severity	+	0	N	None
		Distribution	+	0	N	None
	Exposed components	**Incidence**	+	-	**N**	**Moderate**
		Severity	+	0	N	None
		Distribution	+	-	N	None
	Washed components	Incidence	+	-	N	None
		Severity	+	0	N	None
		Distribution	+	+	Y	None
	Components carved with cornices	Incidence	-	+	N	None
		Severity	-	+	N	None
		Distribution	-	+	N	None
	Repointed components	Incidence	-	0	N	None
		Severity	-	0	N	None
		Distribution	-	0	N	None
Capillary salts and moisture	Groundwater	Incidence	+	+	N	None
		Severity	+	-	N	None
		Distribution	+	0	N	None

Table 4.28 Data analysis results in relation to hypotheses for granulation in the sample *(continued)*.

GRANULATION *(continued)*						
Mechanism	**Factor of influence**	**Aspect of granulation**	**Correlation expected**	**Result**	**Hypothesis supported?**	**Significance level**
De-icing salts	Roads land-use	Incidence	+	+	Y	None
		Severity	+	-	N	None
		Distribution	+	0	N	None
	Pavements land-use	Incidence	+	-	N	None
		Intensity	+	+	Y	None
		Distribution	+	0	N	None
	Base components	Incidence	+	+	Y	None
		Severity	+	-	N	None
		Distribution	+	0	N	None
Atmospheric salts	Higher traffic level	Incidence	+	0	N	None
		Severity	+	+	Y	None
		Distribution	+	0	N	None
	Coastal site	Incidence	+	-	N	None
		Severity	+	0	N	None
		Distribution	+	0	N	None

Hypotheses for granulation

Granulation is a symptom of salt decay. Salts in stone cause decay due to wetting and drying cycles, in which the salts crystallise and expand causing pressure within the pores of the stone. Frequent wetting and drying cycles allow more frequent crystallisation and therefore increased decay. Many climatic variables which affect the degree of moisture dealt to the stone and its subsequent evaporation could therefore be significant. Additionally, the orientation of aspect and facades, and the position and nature of components within the monuments influence the degree to which the stone receives and retains moisture. The observed cases of salt decay could also show a correlation with particular salt sources. Thus the possibilities of salts introduced from the ground due to capillary processes, from de-icing salts, atmospheric sea salt or motor exhaust emissions were examined.

Table 4.29 Data analysis results in relation to hypotheses for honeycombs in the sample.

HONEYCOMB WEATHERING						
Mechanism	**Factor of influence**	**Aspect of honeycombs**	**Correlation expected**	**Result**	**Hypothesis supported?**	**Significance level**
Atmospheric sea-salt	Coastal site	Incidence	+	-	N	None
Greater direct solar incidence	S-facing facades	Incidence	+	0	N	None
	S-facing site aspect	Incidence	+	-	N	None
Exposure to wind	W/SW-facing facades	Incidence	+	0	N	None
	W/SW-facing site aspect	Incidence	+	0	N	None
	Higher wind speed	Incidence	+	+	Y	None

Hypotheses for honeycomb weathering

Exposure to atmospheric sea-salt, direct sunlight and wind are thought to be factors in honeycomb weathering. These factors are also influenced by the orientation of the site aspect and monument facades.

Data limitations

Only one cross in the sample (Ormiston) exhibited honeycomb weathering, therefore *no statistical tests were applied.* However, the circumstances of its occurrence are presented in the table above in relation to the hypotheses. In the observed case the honeycombs were of moderate severity and with a general distribution across the surface of the cross shaft.

Table 4.30 Data analysis results in relation to hypotheses for pitting in the sample.

PITTING						
Mechanism	**Factor of influence**	**Aspect of pitting**	**Correlation expected**	**Result**	**Hypothesis supported?**	**Significance level**
Stone properties	Sandstone with inclusions	Incidence	+	+	Y	None
		Severity	+	0	N	None
		Distribution	+	0	N	None
	Older components	**Incidence**	+	+	Y	**Moderate**
		Severity	+	+	Y	**High**
		Distribution	+	+	Y	**Moderate**
Unhypothesised correlations	**Repointed components**	**Incidence**	**0**	+	N	**High**
		Severity	0	-	N	None
		Distribution	0	+	N	None
	Higher traffic levels	**Incidence**	**0**	-	N	**High**
		Severity	0	-	N	None
		Distribution	0	-	N	None
	Greater days of fog	**Incidence**	**0**	-	N	**High**
		Severity	0	-	N	None
		Distribution	**0**	-	N	**High**
	Relief-carved components	**Incidence**	**0**	-	N	**High**
		Severity	0	0	N	None
		Distribution	0	+	N	None
	Sculpted components	**Incidence**	**0**	-	N	**Moderate**
		Severity	0	0	Y	None
		Distribution	0	+	N	None
	Higher temperature	**Incidence**	**0**	+	N	**High**
		Severity	0	+	N	None
		Distribution	**0**	+	N	**Moderate**
	Higher relative humidity	**Incidence**	**0**	+	N	**Moderate**
		Severity	0	0	Y	None
		Distribution	0	+	N	None
	Groundwater	**Incidence**	**0**	+	N	**High**
		Severity	0	0	N	None
		Distribution	0	+	N	None
	Coastal setting	**Incidence**	**0**	-	N	**High**
		Severity	0	0	Y	None
		Distribution	**0**	-	N	**Moderate**

Hypotheses for pitting

The occurrence of pitting is largely dictated by the stone properties. It can be caused by the erosion of clay clasts or pebble inclusions, or other numerous pockets of softer material in the sandstone. It is a slow process which could be expected to increase with component age. However, most of the relationships found to be significant are unhypothesised correlations. These are examined individually in the detailed discussion in Section 5.2.6 in the Risk Assessment Model chapter.

Planar disaggregation types

Table 4.31 Data analysis results in relation to hypotheses for delamination in the sample.

DELAMINATION						
Mechanism	**Factor of influence**	**Aspect of delamination**	**Correlation expected**	**Result**	**Hypothesis supported?**	**Significance level**
Bedding plane alignment	Slabs*	Incidence	+	+	Y	None
		Severity	+	+	Y	None
		Distribution	+	+	Y	None
	Cross shafts	Incidence	+	+	Y	None
		Severity	+	+	Y	None
		Distribution	+	+	Y	None
Capillary moisture	Groundwater	Incidence	+	-	N	None
		Severity	+	-	N	None
		Distribution	+	-	N	None
Unhypothesised correlations	**Sandstone with inclusions**	**Incidence**	**0**	**+**	**N**	**High**
		Severity	0	0	Y	None
		Distribution	0	0	Y	None
	Older components	**Incidence**	**0**	**+**	**N**	**High**
		Severity	0	0	Y	None
		Distribution	**0**	**+**	**N**	**Moderate**
	Higher temperature	**Incidence**	**0**	**-**	**N**	**High**
		Severity	0	0	Y	None
		Distribution	0	0	Y	None

* Only one component was affected, therefore no statistical test was applied. However, the circumstances of the observed case are indicated in relation to the hypothesis.

Hypotheses for delamination

Delamination occurs when sandstone is face-bedded, therefore shafts and slabs should be vulnerable to this decay. The movement of moisture up through the stone from the ground by capillary processes could cause increased delamination. However, the significant relationships found during the tests were not anticipated by the hypotheses. These are examined in the detailed discussion in Section 5.2.6 in the Risk Assessment Model chapter.

Table 4.32 Data analysis results in relation to hypotheses for blistering in the sample.

BLISTERING						
Mechanism	**Factor of influence**	**Aspect of blistering**	**Correlation expected**	**Result**	**Hypothesis supported?**	**Significance level**
Unsuitable conservation	Chemical cleaning	Incidence	+	+	Y	None
		Severity	+	0	N	None
		Distribution	+	0	N	None
Frequent wetting and drying cycle	Higher relative humidity	Incidence	+	-	N	None
		Severity	+	0	N	None
		Distribution	+	0	N	None
	Higher temperature	Incidence	+	+	Y	None
		Severity	+	0	N	None
		Distribution	+	0	N	None
	Higher precipitation	Incidence	+	-	N	None
		Severity	+	0	N	Nlne
		Distribution	+	0	N	None
	Greater days of fog	Incidence	+	-	N	None
		Severity	+	0	N	None
		Distribution	+	0	N	None
	Higher wind speed	Incidence	+	-	N	None
		Severity	+	0	N	None
		Distribution	+	0	N	None
	W/SW-facing facades	Incidence	+	0	N	None
		Severity	+	0	N	None
		Distribution	+	0	N	None
	W/SW site aspect	Incidence	+	0	N	None
		Severity	+	0	N	None
		Distribution	+	0	N	None
	S-facing facade	Incidence	+	0	N	None
		Severity	+	0	N	None
		Distribution	+	0	N	None
	Exposed components	Incidence	+	0	N	None
		Severity	+	0	N	None
		Distribution	+	0	N	None
	Washed components	Incidence	+	0	N	None
		Severity	+	0	N	None
		Distribution	+	0	N	None
	Repointed components	Incidence	-	+	N	None
		Severity	-	0	N	None
		Distribution	-	0	N	None
	Components carved with cornices	Incidence	+	+	Y	None
		Severity	+	0	N	None
		Distribution	+	0	N	None
Presence and condition of masonry joints	Built components	Incidence	+	+	Y	None
		Severity	+	0	N	None
		Distribution	+	0	N	None
	Repointed components	Incidence	-	+	N	None
		Severity	-	0	N	None
		Distribution	-	0	N	None

Hypotheses for blistering

Blistering is a symptom of salt decay. Salts can be introduced from a number of different sources. However, laboratory tests confirmed that the blistering observed in the sample originated due to salts from chemical cleaning residues. Salt decay advances with frequent wetting and drying cycles, which could be affected by a number of climatic variables, orientation of aspect and monument facades, and certain architectural features. Blistering can be common around the area of masonry joints due to the trapping of water and salts in such areas of the stonework. This can result from the use of a less porous mortar. However, the observed case in the sample was found to be caused by the joint material having absorbed a greater amount of salt during the chemical cleaning.

Data limitations

Only one component in the sample has blistering (Edinburgh High Street cross), therefore *no statistical tests were applied.* The circumstances of the blistering case are instead shown in the table above in relation to the hypotheses.

Table 4.33 Data analysis results in relation to hypotheses for flaking in the sample.

FLAKING						
Mechanism	**Factor of influence**	**Aspect of flaking**	**Correlation expected**	**Result**	**Hypothesis supported?**	**Significance level**
Frequent wetting and drying cycle	**Higher relative humidity**	**Incidence**	**+**	**-**	**N**	**Moderate**
		Severity	+	0	N	None
	Higher temperature	Incidence	+	0	N	None
		Severity	+	0	N	None
	Higher precipitation	Incidence	+	0	N	None
		Severity	+	0	N	None
	Greater days of fog	Incidence	+	+	Y	None
		Severity	+	0	N	None
	Higher wind speed	Incidence	+	0	N	None
		Severity	+	0	N	None
	SW- or W-facing facades	Incidence	+	0	N	None
		Severity	+	0	N	None
	SW- or W-facing aspect	Incidence	+	-	N	None
		Severity	+	0	N	None
	S-facing facade	Incidence	+	0	N	None
		Severity	+	0	N	None
	S-facing site aspect	Incidence	+	-	N	None
		Severity	+	0	N	None
	Exposed components	Incidence	+	0	N	None
		Severity	+	+	Y	None
	Washed components	Incidence	+	0	N	None
		Severity	+	-	N	None
	Repointed components	Incidence	-	-	Y	None
		Severity	-	0	N	None
	Components carved with cornices	Incidence	+	0	N	None
		Severity	+	0	N	None
Capillary salts and moisture	Groundwater	Incidence	+	-	N	None
		Severity	+	0	N	None
De-icing salts	Roads land-use	Incidence	+	+	Y	None
		Severity	+	0	N	None
	Pavements land-use	Incidence	+	+	Y	None
		Severity	+	+	Y	None
	Base components	Incidence	+	+	Y	None
		Severity	+	-	N	None
Atmospheric salts	Higher traffic level	Incidence	+	+	Y	None
		Severity	+	0	N	None
	Coastal sites	Incidence	+	0	N	None
		Severity	+	0	N	None

Hypotheses for flaking

Flaking is a symptom of salt decay. Salts in stone cause decay due to wetting and drying cycles, in which the salts crytallise and expand causing pressure within the pores of the stone. Frequent wetting and drying cycles allow more frequent crystallisation and therefore increased decay. Many climatic variables which affect the degree of moisture dealt to the stone and its subsequent evaporation could therefore be significant with regard to the frequency of wetting and drying cycles and the observed salt decay.

Additionally, the orientation of aspect and facades, and the position and nature of components within the monuments influence the degree to which the stone receives and retains moisture. The observed cases of salt decay could also show a correlation with particular salt sources. Thus the possibilities of salts introduced from the ground due to capillary processes, from de-icing salts, atmospheric sea salt or motor exhaust emissions were examined.

Data limitations

The overall frequency of flaking in the sample was very low (5 components). Additionally, it occurred with a very localised surface distribution in all observed cases. Due to this, it was not possible to test for any correlations with regard to the extent of flaking distribution. The severity level also showed limited variation. No instances of *High* severity flaking were recorded in the sample, instead only *Low* and *Moderate* severity levels were recorded. The low overall frequency and lack of variation accounts to some extent for the lack of significant correlations for flaking.

Table 4.34 Data analysis results in relation to hypotheses for scaling in the sample.

SCALING						
Mechanism	**Factor of influence**	**Aspect of scaling**	**Correlation expected**	**Result**	**Hypothesis supported?**	**Significance level**
Frequent wetting and drying cycle	Higher relative humidity	Incidence	+	-	N	None
		Severity	+	-	N	None
	Higher temperature	Incidence	+	+	Y	None
		Severity	+	0	N	None
	Higher precipitation	Incidence	+	0	N	None
		Severity	+	0	N	None
	Greater days of fog	Incidence	+	0	N	None
		Severity	+	0	N	None
	Higher wind speed	Incidence	+	0	N	None
		Severity	+	0	N	None
	SW- or W-facing facades	Incidence	+	-	N	None
		Severity	+	0	N	None
	SW- or W-facing aspect	Incidence	+	-	N	None
		Severity	+	0	N	None
	S-facing facade	Incidence	+	-	N	None
		Severity	+	0	N	None
	S-facing site aspect	Incidence	+	-	N	None
		Severity	+	0	N	None
	Exposed components	Incidence	+	-	N	None
		Severity	+	0	N	None
	Washed components	Incidence	+	-	N	None
		Severity	+	0	N	None
	Repointed components	Incidence	-	0	N	None
		Severity	-	0	N	None
	Components carved with cornices	Incidence	+	0	N	None
		Severity	+	0	N	None
Frosty conditions	Greater days of frost	Incidence	+	0	N	None
		Severity	+	0	N	None
Capillary salts and moisture	**Groundwater**	**Incidence**	**+**	**-**	**N**	**Moderate**
		Severity	+	0	N	None
De-icing salts	Roads land-use	Incidence	+	-	N	None
		Severity	+	-	N	None
	Pavements land-use	**Incidence**	**+**	**+**	**Y**	**Moderate**
		Severity	+	0	N	None
	Base components	Incidence	+	+	Y	None
		Severity	+	-	N	None
Atmospheric salts	Higher traffic level	Incidence	+	0	N	None
		Severity	+	0	N	None
	Coastal sites	**Incidence**	**+**	**+**	**Y**	**High**
		Severity	+	0	N	None
Unhypothesised correlation	**Sculpted components**	**Incidence**	**0**	**-**	**N**	**High**
		Severity	0	0	Y	None

Hypotheses for scaling

Scaling is a symptom of salt decay. Salts in stone cause decay due to wetting and drying cycles, in which the salts crytallise and expand causing pressure within the pores of the stone. Frequent wetting and drying cycles allow more frequent crystallisation and therefore increased decay. Many climatic variables which affect the degree of moisture dealt to the stone and its subsequent evaporation could therefore be significant with regard to the frequency of wetting and drying cycles and the observed salt decay. Additionally, the orientation of aspect and facades, and the position and nature of components within the monuments influence the degree to which the stone receives and retains moisture. The observed cases of salt decay could also show a correlation with particular salt sources. Thus the possibilities of salts introduced from the ground due to capillary processes, from de-icing salts, atmospheric sea salt or motor exhaust emissions were examined.

Data limitations

Scaling occurs with a very localised surface distribution in all observed cases. Due to this, it was not possible to test for any correlations with regard to the extent of scaling distribution.

Table 4.35 Data analysis results in relation to hypotheses for spalling in the sample.

SPALLING						
Mechanism	**Factor of influence**	**Aspect of spalling**	**Correlation expected**	**Result**	**Hypothesis supported?**	**Significance level**
Frequent wetting and drying cycle	Higher relative humidity	Incidence	+	+	Y	None
		Severity	+	+	Y	None
		Distribution	+	0	N	None
	Higher temperature	Incidence	+	0	N	None
		Severity	+	0	N	None
		Distribution	+	-	N	None
	Higher precipitation	Incidence	+	0	N	None
		Severity	+	0	N	None
		Distribution	+	0	N	None
	Greater days of fog	Incidence	+	+	Y	None
		Severity	+	0	N	None
		Distribution	+	+	Y	None
	Higher wind speed	**Incidence**	+	-	N	**Moderate**
		Severity	+	-	N	None
		Distribution	+	0	N	None
	SW- or W-facing facades	Incidence	+	+	Y	None
		Severity	+	0	N	None
		Distribution	+	0	N	None
	SW- or W-facing aspect	Incidence	+	+	Y	None
		Severity	+	+	Y	None
		Distribution	+	0	N	None
	S-facing facades	Incidence	+	+	N	None
		Severity	+	0	N	None
		Distribution	+	0	N	None
	S-facing site aspect	Incidence	+	+	Y	None
		Severity	+	0	N	None
		Distribution	+	-	N	none
	Exposed components	Incidence	+	0	N	None
		Severity	+	0	N	None
		Distribution	+	0	N	None
	Washed components	Incidence	+	-	N	None
		Severity	+	-	N	None
		Distribution	+	0	N	None
	Masonry joints not repointed (increased water ingress)	Incidence	+	0	N	None
		Severity	+	0	N	None
		Distribution	+	+	Y	None
	Components carved with cornices	Incidence	+	+	Y	None
		Severity	+	+	Y	None
		Distribution	+	-	N	None
Capillary salts and moisture	Groundwater	Incidence	+	-	N	None
		Severity	+	0	N	None
		Distribution	+	0	N	None

Table 4.35 Data analysis results in relation to hypotheses for spalling in the sample *(continued)*.

SPALLING *(continued)*						
Mechanism	**Factor of influence**	**Aspect of spalling**	**Correlation expected**	**Result**	**Hypothesis supported?**	**Significance level**
De-icing salts	Roads land-use	Incidence	+	+	Y	None
		Severity	+	+	Y	None
		Distribution	+	0	N	None
	Pavements land-use	Incidence	+	0	N	None
		Severity	+	+	Y	None
		Distribution	+	0	N	None
	Base components	Incidence	+	0	N	None
		Severity	+	+	Y	None
		Distribution	+	0	N	None
Atmospheric salts	Higher traffic level	Incidence	+	0	N	None
		Severity	+	0	N	None
		Distribution	+	0	N	None
	Coastal sites	Incidence	+	+	Y	None
		Severity	+	0	N	None
		Distribution	+	0	N	None
Unhypothesised correlation	**Sandstone with inclusions**	**Incidence**	**0**	**+**	**N**	**High**
		Severity	0	+	N	None
		Distribution	0	0	N	None
	Older components	Incidence	0	-	N	None
		Severity	**0**	**-**	**N**	**Moderate**
		Distribution	0	0	Y	None
	Relief-carved components	Incidence	0	+	Y	None
		Severity	**0**	**-**	**N**	**High**
		Distribution	**0**	**+**	**Y**	**Moderate**

Hypotheses for spalling

Spalling is a symptom of salt decay. Salts in stone cause decay due to wetting and drying cycles, in which the salts crytallise and expand causing pressure within the pores of the stone. Frequent wetting and drying cycles allow more frequent crystallisation and therefore increased decay. Many climatic variables which affect the degree of moisture dealt to the stone and its subsequent evaporation could therefore be significant with regard to the frequency of wetting and drying cycles and the observed salt decay. Additionally, the orientation of aspect and facades, and the position and nature of components within the monuments influence the degree to which the stone receives and retains moisture. The observed cases of salt decay could also show a correlation with particular salt sources. Thus the possibilities of salts introduced from the ground due to capillary processes, from de-icing salts, atmospheric sea salt or motor exhaust emissions were examined.

Data limitations

Spalling occurs with a very localised surface distribution in all but two cases in the sample. This lack of variation accounts to some extent for the lack of significant relationships regarding spalling distribution.

Fracture types

Table 4.36 Data analysis results in relation to hypotheses for fissures in the sample.

FISSURES						
Mechanism	**Factor of influence**	**Aspect of fissures**	**Correlation expected**	**Result**	**Hypothesis supported?**	**Significance level**
Iron oxidation	Components with iron attachments	Incidence	+	0	N	None
		Severity	+	0	N	None
Frosty conditions	Greater days of frost	Incidence	+	+	Y	None
		Severity	+	0	N	None
	Exposed components	**Incidence**	**+**	**-**	**N**	**High**
		Severity	+	+	Y	None
	Sculpted components	**Incidence**	**+**	**-**	**N**	**High**
		Severity	+	+	Y	None
	Components carved with cornices	Incidence	+	0	N	None
		Severity	+	-	N	None
Vulnerability to impact	Roads land-use	Incidence	+	0	N	None
		Severity	+	+	Y	None
	Greater traffic levels	Incidence	+	0	N	None
		Severity	+	-	N	None
	High re-siting frequency	Incidence	+	0	N	None
		Severity	+	0	N	None
	Monument fenced-off	Incidence	-	0	N	None
		Severity	-	0	N	None
	Older components	Incidence	+	0	N	None
		Severity	+	0	N	None
Unhypothesised correlations	**Greater days of fog**	Incidence	0	+	N	None
		Severity	**0**	**+**	**N**	**High**
		Distribution	0	0	Y	None
	Groundwater	Incidence	+	+	Y	None
		Severity	+	+	Y	None
	Base components	**Incidence**	**0**	**+**	**N**	**High**
		Severity	0	-	N	None
	Built components	**Incidence**	**0**	**+**	**N**	**High**
		Severity	0	-	N	None
	Higher precipitation	**Incidence**	**0**	**-**	**N**	**Moderate**
		Severity	0	-	N	None
	Relief-carved components	**Incidence**	**0**	**-**	**N**	**Moderate**
		Severity	0	-	N	None

Hypotheses for fissures

Fissures can be caused by the oxidation and expansion of rusting iron components, such as dowels and cramps. Frost can also results in fissures, and more exposed stone parts were expected to be vulnerable to this. Like mechanical damage, fissures can be caused by impacts. Therefore monuments located in urban contexts, and particularly those in close proximity to roads and heavy traffic, could show a greater degree of fissures. Older and unfenced crosses, and those with higher re-siting frequencies, have also had a greater opportunity for impacts and could thus be expected to show a greater degree of fissures. A number of unhypothesised correlations were found to be significant. These relationships are examined in the detailed discussion in Section 5.2.6 in the Risk Assessment chapter.

Data limitations

Fissures occur with a localised surface distribution in all observed cases in the sample. Due to this, it was not possible to test for any correlations with regard to the distribution of fissures.

Table 4.37 Data analysis results in relation to hypotheses for mechanical damage in the sample.

MECHANICAL DAMAGE						
Mechanism	**Factor of influence**	**Aspect of damage**	**Correlation expected**	**Result**	**Hypothesis supported?**	**Significance level**
Vulnerability to impact	Monument fenced-off	Incidence	-	0	N	None
		Severity	-	0	N	None
		Distribution	-	0	N	None
	Urban land-use type	Incidence	+	0	N	None
		Severity	+	0	N	None
		Distribution	+	+	Y	None
	Greater traffic levels	Incidence	+	+	Y	None
		Severity	+	+	Y	None
		Distribution	+	0	N	None
	High re-siting frequency	Incidence	+	0	N	None
		Severity	**+**	**+**	**Y**	**High**
		Distribution	+	0	N	None
	Older components	Incidence	+	+	Y	None
		Severity	+	+	Y	None
		Distribution	+	0	N	None
Frosty conditions	Greater days of frost	Incidence	+	0	N	None
		Severity	+	0	N	None
		Distribution	+	-	N	None
	Exposed components	Incidence	+	0	N	None
		Severity	+	+	Y	None
		Distribution	+	0	N	None
	Sculpted components	Incidence	+	-	N	None
		Severity	+	+	Y	None
		Distribution	+	0	N	None
Neglect of masonry joints	**Repointed components**	**Incidence**	**-**	**+**	**N**	**High**
		Severity	-	-	Y	None
		Distribution	-	+	N	None
Unhypothesised correlations	**Greater precipitation**	**Incidence**	**0**	**+**	**N**	**High**
		Severity	0	0	Y	None
		Distribution	0	0	Y	None
	Higher wind speed	**Incidence**	**0**	**+**	**N**	**Moderate**
		Severity	0	-	N	None
		Distribution	0	+	N	None
	Greater days of fog	**Incidence**	**0**	**-**	**N**	**Moderate**
		Severity	0	0	Y	None
		Distribution	0	0	Y	None
	Higher relative humidity	**Incidence**	**0**	**+**	**N**	**Moderate**
		Severity	0	-	N	None
		Distribution	0	+	N	None
	Sculpted parts	**Incidence**	**0**	**-**	**N**	**Moderate**
		Severity	0	+	N	None
		Distribution	0	0	Y	None
	Older components	Incidence	0	+	N	None
		Severity	**0**	**+**	**N**	**Moderate**
		Distribution	0	+	N	None

Hypotheses for mechanical damage

Mechanical damage is episodic and can be caused by impacts or even severe frost. Monuments which are not fenced-off, and those which are sited in urban contexts and in close proximity to heavy traffic are more vulnerable to impacts and may show a greater degree of mechanical damage. Additionally, the act of removing the monuments provides increased opportunity for breakage, therefore those which have been re-sited more frequently could show greater mechanical damage. Older components have also been vulnerable to increased opportunities for impacts. Frequent frost could cause a greater degree of mechanical damage, and exposed stone pieces were expected to be most vulnerable to frost damage. Masonry joints which have not been maintained could harbour pockets of water which could lead to greater frost damage. Vacant masonry joints could also render a monument less stable and more liable to incur greater damage from any impact. There are several unhypothesised correlations revealed as significant during the tests. These relationships are examined in the detailed discussion in Section 5.2.6 in the Risk Assessment Model chapter.

All of the significant test results for each decay and soiling types are discussed systematically in the following chapter (Section 5.2.6), in order to justify their inclusion or rejection from the subsequent risk assessment model.

4.5 Discussion of untested environmental and conservation variables

4.5.1 Environmental variables

Annual average climatic data was obtained from a selection of 19 climate stations near to the sampled crosses. However, it is likely that the actual climate experienced at the site of the corresponding crosses varies somewhat from this. Urban environments are known to generate warmer temperatures and more turbulent wind patterns, although the effect of this on the sampled crosses is probably limited since many are situated in relatively small settlements. Factors of topography, aspect and the built environment can affect the climate in a very localised way, such that a microclimate could be produced at each monument site. Many of these factors controlling the microclimate are too infrequent to allow statistical testing of their relationship to the decay/soiling patterns. However, they have been investigated and are discussed below.

4.5.1.1 Shelter

A few of the crosses in the sample have been subject to various degrees of shelter. Currently two crosses are being stored indoors, a further three stand up against a building wall outdoors, and two were previously stored indoors temporarily. A wall could shelter a monument from some of the prevailing wind, driving rain and direct solar incidence. However, it also creates a microclimate in which local wind pressure and suction patterns are generated around the cross. Due to various cross designs, orientation and built environmental features, each case is unique and needs individual consideration if the effects of shelter upon the condition of a cross are to be analysed. Each sheltered cross is examined below. Regarding the effect of indoor shelter, the removal of historical stonework indoors is usually a last resort, when its condition is badly deteriorating or even beyond repair. It is widely presumed that removal indoors allows existing decay to become virtually stabilised and biological growths to be desiccated.

Sheltering wall

Since 1913, **Dunbar** cross has stood close to the angle of a building, with a wall 0.5m E and another 2m N of the cross. The stepped base has stood here since it was first carved, although the other upper monument parts were transferred here from other, earlier sites. **Tain** cross has stood within the angle of a building for about 105 years. The shaft, capital and finial are 105 years old and have not occupied any other site (although note that the shaft is entirely covered with render and the condition of its stonework is thus obscured). The socket stone is much older (about 550 years old) and was moved here from a nearby site in the town centre. The angle of the building lies less than 1m to the E of the cross, and the walls also shelter the N and S sides of the cross to a slightly less extent. Since 1772 **Cromarty** cross has stood about 0.5m from a building wall such that its SW side is sheltered. The steps abut the wall and were built in 1772; however, the shaft, capital and finial date from 1578 and were previously sited nearer the harbour. This cross may show a different level of decay/soiling upon its SW side, due to the shelter from the prevailing wind.

The decay and soiling patterns on these sheltered facades were compared with those on unsheltered facades of other crosses. In order of magnitude, crumbling, differential weathering and algae all show a *higher* incidence rate upon sheltered orientations. Black crust also has a higher incidence rate on sheltered components but, although this trend was expected, its overall frequency in the sample was low and the incidence is entirely biased towards the components at just one monument (Dunbar). The greater occurrence of algae was expected, since sheltered facades tend to be wetter as they are less exposed to direct wind and sunlight. Note that algae also have a greater *density* and surface extent on the sheltered facades. There is a *lower* incidence of lichen on sheltered facades. This can be explained by the fact that lichen favour relatively dry conditions. Where there is greater algal growth on sheltered stone, the conditions are likely to be too wet for extensive lichen growth. Mechanical damage and painted graffiti show a lower incidence rate upon the orientations sheltered by nearby building walls. These trends were expected, since such facades are less easily accessible to the public. There are also *lower* incidences of particulate soiling, moss, spalling, pitting and delamination, which are less easily explained. However, the frequency of sheltered facades in the sample is rather low to allow any extrapolation. Additionally, the situation is confused by the fact that some components were previously located at unsheltered sites.

Indoor storage

Fowlis Wester cross-slab was removed indoors permanently in 1991. It was expected that both the soiling and erosion of this stone would be arrested in 1991 by the removal indoors; however, these effects may be difficult to see currently due to the relatively short length of time indoors of 7 years at the time of the survey. Note that this slab cannot easily be compared to the other crosses in the sample for the purposes of analysis, because it is by far the oldest, dating from the eighth century AD. Additionally it is unusual in being carved from an argillaceous sandstone type which tends to be relatively vulnerable to decay. Old photographs were consulted in order to examine any changes shown in the decay and soiling over time. However, no specific differences could be detected between the current condition of the slab compared with the 'before' photos from 1927, 1967, 1986 and 1991. The severe delamination of the stone is now probably relatively stable since it has been moved indoors, despite the existence of some large, loose scales. However, the biological soiling does not seem to have been totally desiccated, since there is a light, microscopic growth of fungi across the surface of the slab, presumably encouraged by the atmosphere in the church and fed by existing dead micro-organisms on the stone.

Dundee market cross was removed indoors for a proposed period of 3 years in 1998. However, the data recorded for this cross was extracted from photographs and reports prepared by consultants immediately prior to its removal, therefore any effect generated by its current siting indoors cannot be considered in this query. However, the shaft was previously stored indoors for a period of 17 years "covered with stones and rubbish", between 1857-74, and during this time it may therefore have escaped a very small amount of further soiling and decay. However, the condition of the shaft now does not really support this, and indeed it seems that the incidents of removal themselves were responsible for an increased amount of damage to the shaft. The carving has been chipped at various points, spalling is apparent at the base and top, cracks are apparent at the base and around the centre. Further damage occurred just after the 1998 photography, during its dismantling. The shaft split and had to be sawed in half to avoid additional damage.

Certain of the shaft sections from **Cupar** market cross lay "in some neglected corner" for 24 years (between 1788-1812), thus these pieces may have escaped a little of the soiling and decay. However, there is no evidence of any such effect.

In conclusion, the sample data did not indicate much effect upon the decay/soiling patterns on crosses due to indoor storage. Instead the cases illustrate how acts of removal can introduce the opportunity for breakage, and that fungi might grow on stone surfaces indoors in certain conditions. For adequate investigation, a greater number of cases would be required and the stone condition would need to be monitored and recorded over a longer period of time.

4.5.1.2 Aspect of site

11 of the 27 sampled crosses are sited on land with an aspect. In 4 of these cases the aspect is only very slight, ie the slope of the land is very gradual. The aspect is frequently E, and to a lesser extent SE and S (see aspects listed in Table 4.38 below). Each case requires individual consideration to ascertain the extent to which the effects of aspect are countered by the immediate built environment. In the sample the built environment does not generally seem to encroach sufficiently to counter the effects of the aspect except in the case of Culross. Although the site of Culross has a SW aspect, buildings close to the cross on the SW side may have the effect of lessening the force of the prevailing wind. There is some evidence

that aspect might be a factor in salt decay in the sample; however, the frequencies involved are too low to allow extrapolation.

Table 4.38 Aspect of site of sampled crosses

Aspect	Frequency of crosses	Cross locations	Hypotheses
E	5	Ancrum, Banff, Edinburgh High Street, Edinburgh Canongate, Ochiltree	None
SE	2	Dundee, Inverbervie (both on a very slight, general slope only)	None
S	2	Fowlis Wester (former site), Turriff	Greater solar incidence, which could encourage greater wetting and drying cycles, and thus greater salt decay and honeycomb weathering.
SW	1	Culross	Exposed to prevailing wind, which could encourage greater wetting and drying cycles, thus greater salt decay, and honeycomb weathering.
NE	1	Tain	Less solar incidence and less prevailing wind, thus greater moisture retained in the stone. Greater algae and moss, and less salt decay could be expected.

S aspect: Turriff and Fowlis Wester (former site)

Turriff cross is located on a level site on the side of a general S-facing slope, which receives greater solar incidence and perhaps more frequent wetting-drying cycles. In support of the hypothesis, this cross shows a substantial amount of salt decay. Patches of severe spalling, granulation and crumbling are evident on the cross. Other significant features of this cross are dense patches of algal growth, and moderate-to-severe pitting; however, these are not considered to be due to the aspect of the Turriff cross. Fowlis Wester cross was formerly located on the level village square, on a generally S-facing slope. However, there is little salt decay on this cross to support the hypothesis. The slab has some localised traces of spalling, otherwise the severe and extensive delamination and pitting are likely to be due to the vulnerable sandstone type.

SW aspect: Culross

A cross with a SW aspect will be more exposed to the prevailing wind and could perhaps experience more frequent wetting/drying cycles. The hypothesis is supported somewhat, since there is evidence of salt decay. Spalling has a high incidence and intensity on the cross components, and granulation is also visible on one component. The other salt decay types are absent; however, it is quite likely that some flaking and scaling may have preceded the spalling and are no longer visible. Blistering and honeycombs are also absent; however, they are very rare within the sample as a whole. There is a higher than average degree of pitting at this monument, but this may be due to the stone type of this monument. Particulate soiling is also particularly dense upon the cross; however, this is not likely to be caused by the site aspect.

NE aspect: Tain

The hypotheses of greater algae and moss, and less salt decay, are partly supported by this monument. There is little salt decay with the exception of a small crumbled area (low severity and localised), which may be due to, or aggravated by, a render coating upon the shaft. All the components feature algal growth, mostly high density, but localised in surface extent upon washed areas. Moss occurs on two components; however, it has a localised distribution with low density.

4.5.1.3 Topography

Local topographic features could affect the climate at each cross site. Site aspect has already been discussed. But further to this, maps were consulted to investigate whether any significant topographical features existed in each vicinity, which might affect the climate at the crosses. Instances were sought in which sampled towns were situated in valleys or next to hills. Like aspect, these features could potentially affect the solar incidence, prevailing wind, fog and frost experienced at each site. However, in conclusion there were little topographic features other than aspect that could be considered to have such an effect within the sample.

4.5.1.4 Flowerbeds

Where crosses are situated in a flowerbed the amount of particulate soiling on lower components could be increased due to wind-blown soil/dirt. Flowerbeds have been constructed around two crosses in the sample. At **Pencaitland** a flowerbed currently abuts the base of the cross on two sides, although the date at which the flowerbed was laid cannot be established. At **Dunbar** cross a flowerbed existed around the cross base for an unknown period earlier this century (photographs indicate around 1951). On the Dunbar steps, particulate soiling is currently dense but localised. However, there is no evidence to indicate, or any means to prove, that the degree of particulate soiling apparent on the steps today has been affected by the former construction of a flowerbed around this monument. On the Pencaitland steps, particulate soiling is of a moderate density and is generally distributed on all facades. The flowerbed abuts the W and N facades of the steps, but the soiling is no heavier on these facades. It actually appears most dense and has a looser, dusty consistency on the S side, which neither abuts the flowerbed nor faces the road. Thus there is again no evidence to indicate that the flowerbed has caused an increased level of particulate soiling on the facades which it abuts. The results of investigating the effect of flowerbed sites do not tend to support the hypothesis; however, the frequency in the sample is too low for an adequate investigation.

4.5.2 The effect of conservation materials

In addition to routine repointing, 14 of the 27 crosses in the sample have evidence for the application of repair material. Based upon the field observations the material used in most cases is a porous mortar mixture, usually used for rejoining broken masonry fragments or for infilling various holes in the masonry. However, in the case of at least 4 monuments an epoxy resin mixture has been used.

4.5.2.1 Epoxy resin repairs

It is quite common these days to secure newly-doweled joints of carved masonry with epoxy resin, since it has very strong adhesive properties. Its use over the years has not always been explicitly recorded in conservation documentation, thus there may be further cases of its use in the sample where the application is internal and not visible. It has been used to secure certain masonry joints on the crosses at Beauly, Dundee and Turriff. It has also been used to infill some holes on the shaft of Beauly cross, and to secure detaching delamination on the Ancrum shaft. Epoxy resin tends to be used for securing only very small areas of masonry, since it is non-porous and can cause water to be trapped if used over a large area.

The **Beauly** cross shaft underwent conservation in 1987 in which all sections were rejoined with a steel rod, secured with epoxy resin, then refaced with a matching soft mortar. The stone around the joint areas had already been eroded inwards due to severe delamination prior to this repair. The mortar has since rapidly eroded, and the new, lowest shaft section has eroded inward a little around the new joint. The resin patches are also a little loose in places, and it is unclear whether the resin has receded or whether the stone around it has receded. Therefore the evidence for actual stone erosion due to the resin repair is inconclusive. Plate 4.1 shows a section of the resin repair on Beauly shaft.

The **Ancrum** shaft underwent repairs in the Historic Scotland Conservation Laboratory in 1969. Resin repairs are still visible on the W side of the shaft today, where they appear to be holding the delaminating scales in place. The resin has not appeared to cause any adjacent decay on the shaft; however, it is unclear whether it has been totally successful. Lower down, delamination and scaling currently continue

Plate 4.1 Epoxy resin used to strengthen the join between shaft sections on Beauly market cross.

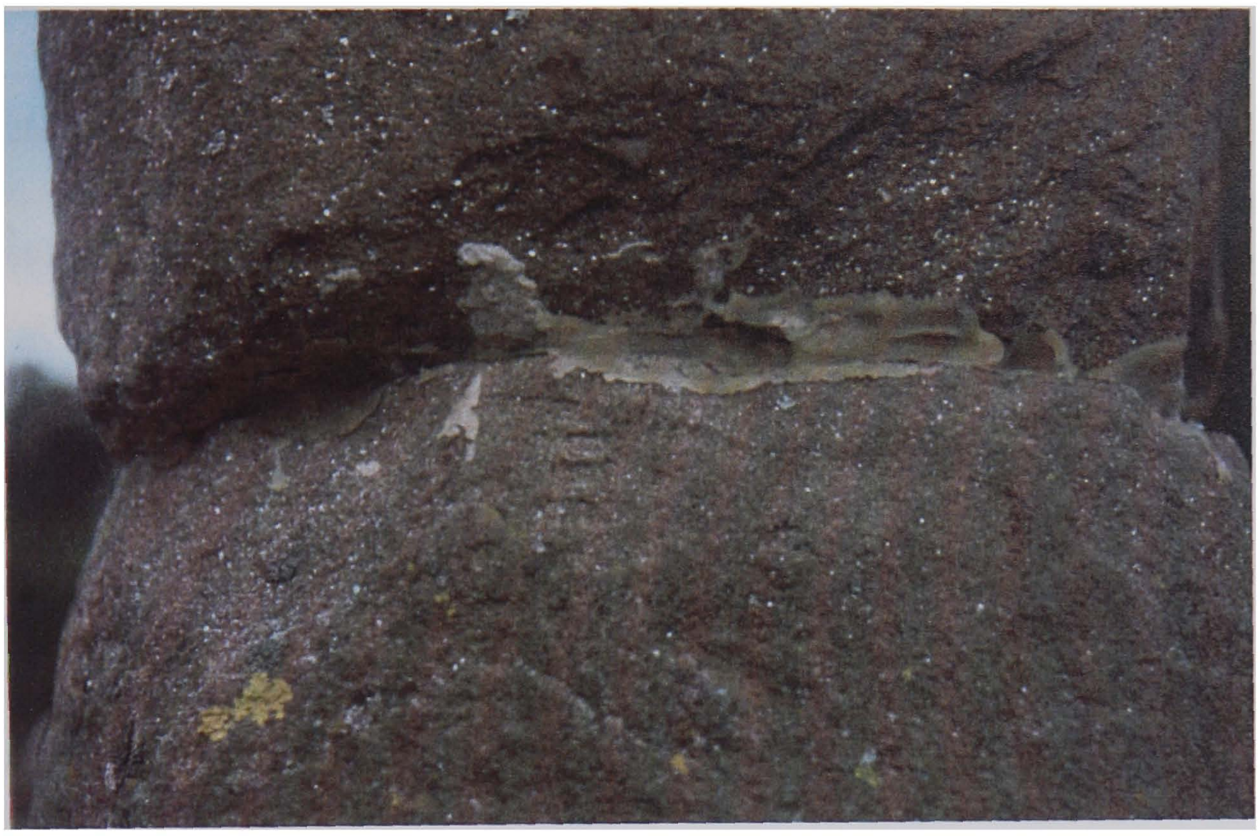


Plate 4.2 Cromarty market cross: inappropriate conservation materials.

unchecked at the shaft base, although this part of the shaft may not have been subject to resin repair in 1969.

On the **Dundee** cross the capital, shaft and base were secured together with epoxy resin joints. Further resin repairs were also made to the lower parts of the shaft. The resin may have been applied during the removal and re-erection of the cross in 1993. Some spalling is evident at the top and bottom of the shaft next to the joints, and also around the joints of the pedestal base. There are also fissures at the shaft base and around the shaft centre. While it is possible that the use of epoxy resin may have caused or aggravated the spalling and fissures, there is a lack of photographic evidence to confirm whether this decay was present to the same extent prior to the resin application in 1993.

In conclusion, there is no definite evidence that the use of resin on these monuments has caused any of the visible decay types in the surrounding masonry. However, all recorded applications of the resin within the sample have been within the last 30 years, a relatively short time period within the overall timescale of stone decay and it is possible that the effects are not yet being seen. Additionally, the condition of the stone prior to the repair cannot be investigated due to the lack of close-range photographic evidence.

4.5.2.2 Mortar repairs

Aside from its use for repointing, a porous mortar mixture has been applied in some cases for joining broken fragments, infilling holes and remodelling in the case of at least 10 crosses in the sample. It has been used for substantial remodelling of the shafts at Beauly, Dallas, Dunbar, Inverkeithing and Ochiltree, and to remodel smaller areas upon Ormiston shaft, Rossie steps, and the lower finial pieces of Turriff cross. Sometimes there are multiple phases of mortar repairs on each monument (eg Dunbar and Inverkeithing shafts). Mortar has also been used to rejoin the broken shaft sections at Ochiltree and Pencaitland, and to repair a fissure on the Dunbar shaft. Additionally it was used to secure delaminating areas on Inverbervie steps and Ormiston shaft. There was no evidence of associated decay in any case in the sample where a porous mortar mixture had been used for repair. However, the erosion of the remodelling mixture has been very rapid in the case of Beauly cross. A mixture of mortar and crushed stone of a matching colour was used to fill out the profile of the shaft around the joint areas during conservation work in 1987; however, the remodelled parts had all completely eroded away by 1998.

4.5.2.3 Hard cement repairs

Hard cement was formerly used for repairing some monuments, but it is now known to be harmful to adjacent masonry and is no longer used for the conservation of historical monuments. The most visible use in the sample is at Cromarty.

Cromarty shaft had been broken into pieces and was rejoined in 1772 with the aid of iron dowels, iron straps, wire and non-porous, Portland cement (see Plate 4.2). Such cement can trap water and thus accelerate the decay of underlying masonry. At Cromarty cross, the iron supports are increasing the damaging potential of the cement. The iron cramps and wire are expanding outward on the side and rear of the upper shaft section, causing the cement beneath them to become cracked and displaced from the stone surface. This may in turn be pulling fragments of the stone away from the surface. The profile of the rear side of the shaft is actually buckled due to this. Additionally, this displacement of the cement is creating pockets in which moisture can be harboured which could lead to further decay. The exposed sandstone on other parts of the shaft shows very severe and extensive delamination, scaling and crumbling. However, the actual condition of the stone beneath the Portland cement is obscured. The repair materials would need to be carefully removed in order to examine this.

At **Beauly** cross much stone had already been lost around the joints of the shaft sections prior to repairs in 1987, as described above in Section 4.5.2.1. The records consulted attribute this damage to the past use of a hard cement mortar, which caused water to become trapped around the joints and for flakes to delaminate in these areas. This hard mortar has since been replaced.

4.5.2.4 Render

Three of the sampled crosses have components that have been subject to the application of a cement render coat. The render itself is vulnerable to soiling and cracking. However, it is porous and thus does not tend to trap water like a hard cement. In the past, a render coat has usually been applied when the existing masonry has become degraded, in an attempt to preserve the monument and neaten its appearance. It is impossible to see the condition of the underlying stonework where render covers it. However one solution would be to use ultrasound, which detects differences in density and could allow the surface profile of stone beneath the render to be mapped. No records exist of the condition of the masonry on the three sampled crosses prior to the render application. Therefore it is difficult to establish whether the decay seen beneath the detached patches of render existed prior to the render application, or whether the decay has been aggravated or even caused by the render. There may be nothing to gain by removing the render coats from the stone. Indeed the act of its removal could be damaging, particularly if the sandstone has degraded further since the render application.

Prior to the Portland cement application described above, **Cromarty** shaft, capital and finial were totally covered with render at around 1772. The render covering is now patchy, since it has cracked and broken away in places. The exposed stonework is in very poor condition, exhibiting very severe, large-scale delamination, scaling and crumbling. Much of the render on the finial has also now broken away, and some cracks can be seen in the stone beneath the detached parts. It is possible that some of the delaminating surface layers on the cross may have been pulled away with the render, but this cannot be confirmed. Photographs consulted between 1957 and the present show very little change regarding the extent of the scales and delamination on the shaft, although the progressive detachment of some render is visible over this period.

Inverbervie shaft was totally covered with render at some point between 1901-75. The render coat is now degraded and various cracks run down it on every side of the shaft, allowing increased water ingress. A section of render has detached at the base of the shaft exposing the underlying stone, where there is a small, scaled patch, a severe fissure and a small patch of weeds. The render on the finial appears partly cracked and flaked. Old photographs indicate that the shaft and finial had delaminated substantially by the 1880's prior to the render application. Therefore, significant former damage is currently concealed by the render cover, and it is unclear whether the render has aggravated this.

Tain shaft was covered with render at some time around the 1960's. The render shows some hairline cracks at the top and base sections of the shaft. On the E side the render has been eroded away from a small area at the top corner of the shaft. Here the stone has eroded inward to a depth of a few centimetres and appears crumbly. Otherwise the render forms a smooth and uninterrupted covering, with a little particulate soiling and some light patches of algae. The photographic evidence is limited, and those of adequate quality post-date the render application. Therefore it is again unclear whether the render has caused any decay problems to the stone.

In summary, there is currently no definite evidence of decay problems caused by cement render in the sample.

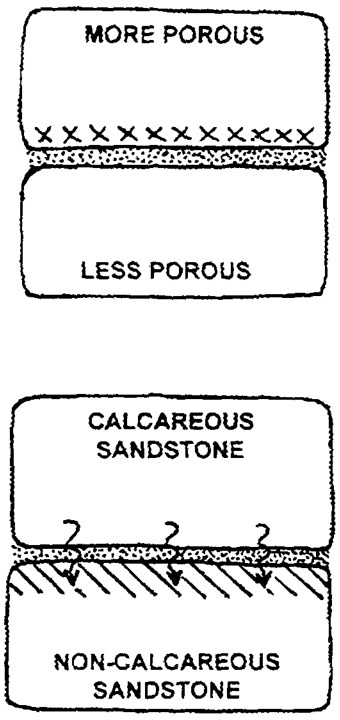
4.5.2.5 Chemical cleaning

Edinburgh High Street cross is the only monument in the sample that has been chemically cleaned. It is also the only cross in the sample exhibiting efflorescence and blistering. It is located in Scotland's capital city and thereby exposed to a relatively high level of atmospheric pollutants. However, as the other market cross in Edinburgh (in nearby Canongate) does not exhibit any efflorescence or blistering, its incidence does not seem to be due to the polluted air. It is therefore likely that the cleaning episode has had a major role in the occurrence of efflorescence and blistering on Edinburgh High Street cross. Laboratory tests upon an efflorescence sample during the research indicated that the salts on the monument could be the residues of chemical cleaning. There are no records relating to this cleaning episode, although it is referred to in a document that records subsequent conservation (Historic Scotland Restoration Records). The *Conservators' Report* indicated that the monument was chemically cleaned with the aid of high-pressure water. The report recorded significant damage seen in 1989 and attributed it to the effects of the cleaning agent along with poor cleaning methods. The decay effects identified from this cleaning were scouring and a loss of definition on carvings, bed and joint arises rounded off and wasted, erosion of softer beds to varying depths, the washing out of the mortar to leave vacant joints, salt crystallisation, efflorescence and blistering, as well as drip and run marks from the cleaning process. It is also possible that the phosphates produced by the cleaning chemicals may have encouraged the heavy algal growth on the parapet. Some joints exhibited voids of up to 4cm in depth during field visits made for the present research in 1998. The damaging effect of the salts may be further increased if water is penetrating through the cross roof, increasing the erosion in the joints. However, not all of the stone decay on the cross was caused by the recent cleaning. Old photographs show that the extensive granulation along weaker beds in the sandstone was visible as early as 1910 (just 25 years after the cross construction in 1885), when the granulation actually appeared to be as advanced as it is today. Note that it is unlikely that permission will be granted again for the chemical cleaning of historical monuments, since the damaging consequences of this are now known.

4.5.2.6 Stone replacement

The replacement of components or individual masonry pieces in the monuments could generate decay if the new stone has widely different properties from the existing stone. This is particularly the case if a different stone *type* is added, eg if a limestone block is added to a sandstone monument. However, the replacement masonry and their stone contexts in the sample are all sandstone. Nevertheless, the possible effects when both masonry pieces are sandstone are that a significant difference in porosity could cause a build-up of water at the junction between the old and new stones. If the replacement stone has a lower porosity than its context, the downward passage of moisture through this stone is stalled with the effect that the older masonry directly above could experience a build-up of moisture just next to the joint. By the same process, the moisture could build up in base of the replacement stone itself, if it has a higher porosity than that of the course of masonry beneath. Other damage could also result on a non-calcareous stone if a calcareous-cemented stone was set above it. Calcium can be transferred downwards resulting in a gypsum crust upon the non-calcareous stone. This effect could occur on either the replacement stone or the older stone, depending on which one has which cement type (see diagrams in Figure 4.8 below).

Figure 4.8 The effects of juxtaposing incompatible stone types.



Stones with different porosity:
Water becomes trapped around the base of the more porous stone, since the downward passage of moisture is stalled by the less porous stone beneath. This could lead to greater decay in the zone of greater moisture.

Sandstones with different cement types:
Calcium is displaced downwards into the non-calcareous sandstone, resulting in the development of a gypsum crust and subsequently potential stone loss.

In the sample there are 15 crosses which could be at risk from decay due to stone replacement. However, upon examination of these there is little evidence for decay that can be attributed to such differences in the stone properties. Decay evident on certain crosses (eg Dunbar) can be discounted from this analysis where old photographic evidence indicates that it already existed prior to the addition of the new stone parts. In some cases the apparent lack of any effect might be due to the very recent dates of some replacements (eg replacements were made at Turriff in 1997, Banff in 1994 and Cupar in 1987). As such, the time elapsed since the intervention may be insufficient to produce visible decay effects. However, in the case of stone replacements made at Beauly (1987) and Inverkeithing (1974), the time required for the development of the decay now visible on the *new* masonry seems relatively short. The lowest shaft section of Beauly cross was replaced just 11 years prior to the present field survey and is already showing a little granulation around the top on one side next to the joint. At Inverkeithing a new shaft section was inserted into the middle of the shaft in 1974. It now shows a patch of moderate scaling towards its top on one side. This salt damage could potentially be due to incompatibility of cement types, but this cannot be confirmed without testing. If the decay in the two latter cases at Beauly and Inverkeithing is indeed due to differences in adjacent stone properties, then it seems the effect of this can be relatively rapid. It is unclear whether decay observed on the older stone parts of Bowden cross and on Dundee cross is related to differing properties of adjacent stones. It is incidentally also noticeable from a few of the other monuments that soiling (particulate, algae and even certain lichen species) can rapidly appear upon recently carved masonry.

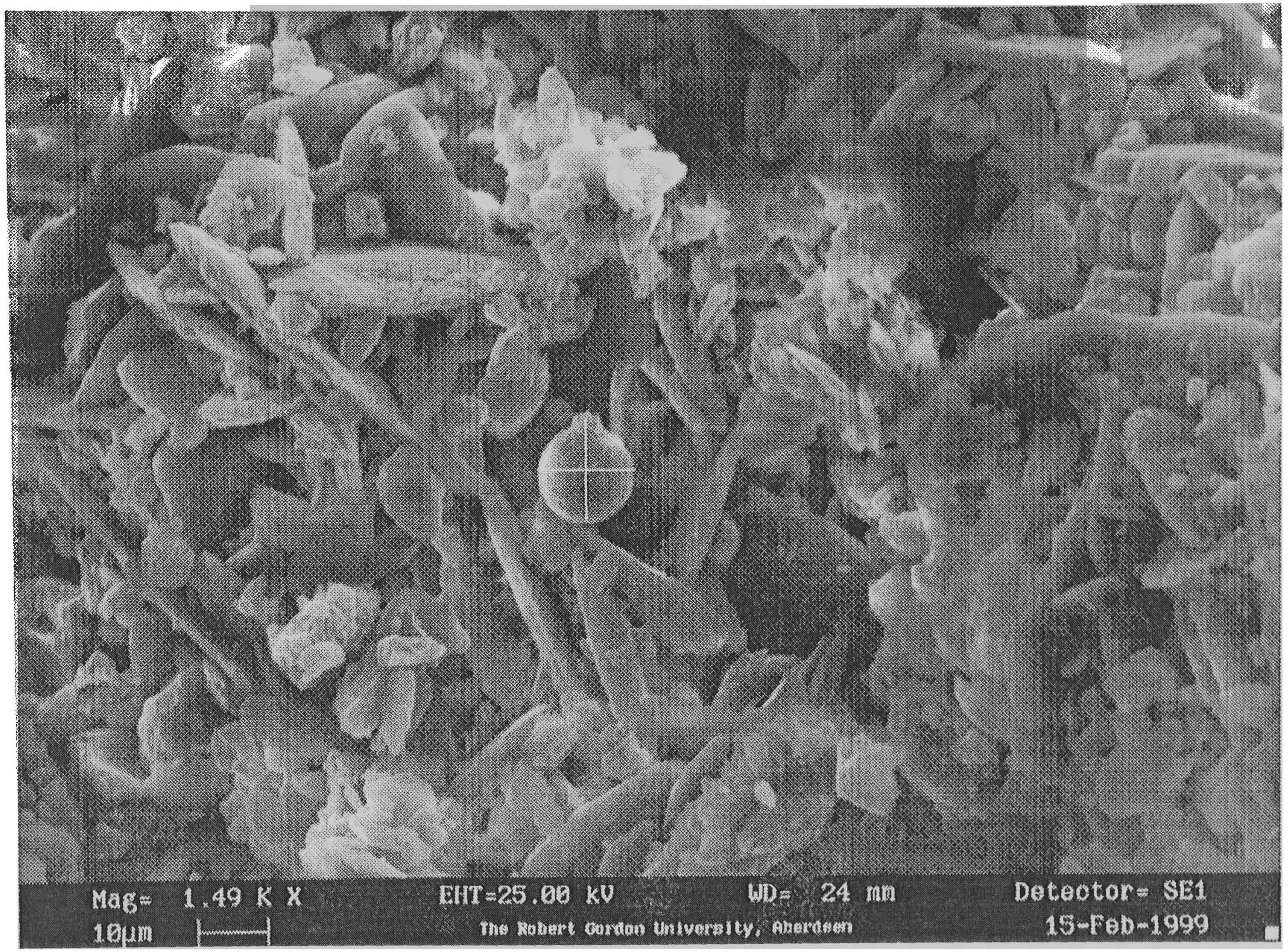
4.6 Laboratory testing of samples

In most cases, it was not possible to obtain samples of stone from the visited crosses. However, at Inverkeithing a few small, already detached, stone scales were collected, and at Edinburgh High Street cross samples of gypsum crust and efflorescence were taken from the stone surface. For the purposes of the present research, these fragments were subject to analysis using Scanning Electron Microscopy (SEM) and X-ray diffraction. SEM was used to magnify the surface of the collected fragments for a detailed visual examination, and X-ray diffraction tests were then used to examine the composition of selected surface features spotted during the SEM. The height and abundance of peaks produced in the X-ray diffraction results provide a raw indication of the dominant elements in a sample. In addition to the fragments collected from Edinburgh and Inverkeithing, the finial of Turriff cross was removed in 1997 and replaced, allowing samples to be taken from this former part. Thus, a core was taken from the arm of the former cross finial and chemically analysed, and a piece of soiled mortar from this finial was also subject to SEM and X-ray analysis. The results are summarised below.

Edinburgh High Street cross: A sample of soiled crust thought to be gypsum was removed from a joint area on the W face of the tower-base. Examination by SEM showed linear and crystalline forms suggesting that the crust was indeed composed of gypsum. X-ray diffraction analysis showed calcium and sulphur peaks, also suggesting gypsum. Some spherical soot particles were also seen on the surface of the crust sample (see Plate 4.3). Sulphate from pollution may be a major factor at this site in the city, causing the heavy crust formation. A sample of efflorescence was also taken from the surface of the tower-base in order to examine its composition. X-ray diffraction showed that gypsum and hexahydrite were the dominant components in the efflorescence. Hexahydrite is a salt that gains an extra water molecule when wetted and changes to epsomite. The crystallisation pressure produced during this cycle could pose a risk of decay to the stone. The test results cannot confirm whether or not this efflorescence has arisen due to the previous chemical cleaning of this monument, although it is a possibility.

Inverkeithing cross: A stone scale from the surface of the steps was examined using SEM. This revealed a filamentous biological growth in one spot, which could be algae or cyanobacteria (ie 'blue-green algae'), as well as soot particles. X-ray analysis of one such particle showed it to be soot which was rich in iron, with titanium, aluminium and silicon. These metals are left behind in the soot when the hydrocarbons have been burnt.

Plate 4.3 SEM image of gypsum crust sample from Edinburgh High Street market cross. A soot particle is marked by a cross in centre.



Turriff cross: A drilled core was taken from the arm of the former cross finial (dating from 1865), and powders produced from different depths of this core up to 40mm were chemically analysed. These revealed the presence of chloride and sodium (both coming mainly from sea salt), nitrate (produced largely by motor vehicles) and sulphate (from air pollutants including traffic exhaust emissions and smoke from the burning of other fossil fuels). The sulphate level was highest at the stone surface; however, the nitrate was dispersed throughout the depth of stone examined since it is more soluble. As expected, no phosphate or fluoride was present as there were no recorded instances of stone cleaning of this monument. The salts identified do not appear to have resulted in salt decay of the stone and may be considered to be insignificant in this case. These salts are likely to be the same as those found on most sandstone structures in Scotland. A piece of soiled mortar from the former finial was also examined using SEM. Some fungi were found in one patch, with long strands of fibres (although of insufficient size to be algae). The fungi would require nourishment from organic material, which implies that there must also be some soot or dead algae present on the mortar, not seen during the examination. X-ray analysis of another area of the mortar surface revealed only elements that were natural components of the mortar.

Therefore, providing that samples can be obtained, SEM and X-ray tests are useful for investigating the composition of crusts, efflorescences and particulate soiling, and for detecting surface micro-organisms. The opportunity to obtain drilled cores of historic stonework for chemical analysis is rare; however, this type of stone sample can yield detailed information about the salt types and their depth of penetration within the stonework.

4.7 Summary

The statistical tests applied to the sample data showed that the patterns of decay, and particularly soiling, are greatly influenced by the characteristics of the monuments. This would appear to be due to the degree to which the stonework is dealt, and retains, moisture. In particular the type of components, their position within the monument and their built or carved nature are important with regard to this. Stone properties, such as the presence of inclusions and the grain size were of limited significance. Only a limited range of stone properties could be estimated, since the stonework could not generally be tested in a laboratory. Additionally, not all components in the sample could be examined at a close enough range to determine the grain size and cement type. The other unmeasured stone properties may be exerting an influence on the decay patterns. Environmental factors frequently showed significant correlations to decay and soiling patterns. Land-use type was important, particularly with regard to whether the site was urban and whether the ground was surfaced. However, the effect of actual traffic levels was of less importance than expected. The role of annual average climate data was not always clear and may even be misleading. Geographic differences in the climate within Scotland may be insufficient to cause much variation in the decay and soiling patterns. This issue is further discussed in the Risk Assessment Model chapter (see Section 5.2.7). There was little evidence to relate intervention episodes to decay in the sample. Exceptions were high re-siting frequency, which introduces increased opportunity for damage during dismantling and from impacts during removal. Although only one monument in the sample had been chemically cleaned, this intervention type was found to have produced damaging consequences. The age of the stonework was found to have no relationship to the patterns of most of the decay and soiling types in the sample.

The main limitation experienced during the data analysis was the low incidence of certain decay and soiling types as well as certain factors of influence. In some cases no statistical tests could be applied due to this. The division of the crosses into their individual architectural components as a unit of analysis was designed partly to deal with this problem by increasing the frequencies, as well as to allow increased precision and investigation into the effect of architectural features and age of carving. Nevertheless the problem of low frequencies still prevailed, albeit to a lesser extent. This was particularly the case when the decay and soiling incidences were subdivided according to the degree of severity/density and surface distribution that they exhibited. Indeed, some decay and soiling types showed no variation at all in the sample with regard to this. The method of classifying surface distribution in the database could be more precise and this issue is dealt with in the design of the practitioners' risk assessment in Chapter 5. The lack of variation and the low frequencies account for the lack of significant correlations for certain of the decay/soiling types tested.

In conclusion, not many of the formulated hypotheses were supported at a level of statistical significance. In some cases the trends for incidence, severity/density and surface distribution even seemed contradictory. In other cases the trends opposed the formulated hypotheses and, due to the extensive testing programme, further unhypothesised correlations were found. With regard to the hypotheses set out in the Introduction Chapter (see Section 1.4), the following conclusions can be made:

- Against expectations, motor vehicle emissions show little observable influence upon the salt weathering and particulate soiling on the market crosses. However, the growth of lichen and moss is discouraged in contexts of heavy vehicular traffic flow in the sample.
- Coastal proximity was expected to influence the salt weathering patterns on the monuments. However, coastal proximity has little bearing upon the patterns of salt decay, and upon weathering and soiling generally, on the market crosses.
- It had been hypothesised that geographic climatic variations, derived from the Meteorological Office, could cause some variations in the decay and soiling of the monuments. However, there is no clear relationship between climatic variations and the observed decay and soiling patterns. Variations in

micro-climate at different monuments, and even at different points across a single stone structure, may be more relevant with regard to the temperature and moisture experienced on stonework.

- The orientation of monument facades is known to affect biological soiling patterns. However, the incidence of biological growths in the sample did not generally demonstrate this. Instead, architectural characteristics and land-use type were observed to be more important determining factors.
- The hypothesis that stone carved at earlier dates should exhibit greater decay was only significantly supported in the case of pitting, delamination and mechanical damage. This indicates that there are other more influential factors that affect the patterns of the other decay types. Pitting and delamination may have a relatively slow rate of advance compared with other decay types. The greater mechanical damage exhibited by older stonework may reflect the fact that it has been exposed to more numerous opportunities for breakage, particularly with regard to the greater re-siting frequencies undergone by older monuments.
- With regard to damage expected due to the use of certain conservation materials, there is some evidence to support this hypothesis. Chemical stone cleaning residues, Portland cement and rusting iron components are considered to be causing some damage to the stonework in the sample. However, the effects of epoxy resin, cement render and stone replacement on the market crosses are currently not clear. The frequency of most of the conservation materials in the sample is rather low to provide results that could be extrapolated.
- It was expected that market crosses would be particularly vulnerable to vandalism and graffiti due to their frequently urban and accessible locations. The sampled crosses with rural locations exhibited no incidences of this at all. Those with urban settings showed a little of this type of damage; however, generally it has a low frequency on the sampled monuments. Therefore market crosses on the whole are only a little vulnerable to this damage type.

The implications of all of the statistically significant trends are systematically discussed in the next chapter and have been used to form the basis of the risk assessment.

5 THE DEVELOPMENT OF A RISK ASSESSMENT MODEL

5.1 Risk assessment model introduction and aims

Two risk assessment models have been constructed. The first model has been used to quantify the risks to the sampled monuments as a whole, while the second is designed for use by practitioners to assess the risks to other individual monuments. It is aimed that the calculated risk values presented in the sample model can be used to infer the risks that can be expected amongst the whole market cross population. The first 'sample model' identifies which agents of decay and soiling pose a risk to the sampled monuments and quantifies the associated risk of stone loss. Arising from the sample model, a formula has been developed for use by practitioners, in order to apply the results of the sample risk calculations to unsampled crosses or even to other small monument types of similar morphology (Section 5.3). It is aimed that the practitioners' formula will allow a risk assessment to be made of individual, surveyed monuments, such that appropriate and timely intervention can be undertaken. A database has also been designed for the practitioner to help with the risk calculation, to standardise recording and to provide a means of storing the data from successive surveys. An associated set of intervention criteria and guidelines (Section 5.4) has been produced to help the practitioner to make informed judgements about the care of the monuments. Additionally, some recommendations for the interpretation and promotion of Scottish market crosses to the public provide suggestions for a management strategy which extends beyond the field of conservation, into that of the promotion and enhancement of this heritage resource for the public (see Appendix E). If adopted, this comprehensive management framework could ensure the optimum condition of these monuments and enhance their perceived value in the future.

5.2 Sample risk assessment model

5.2.1 Sample model objectives

Based upon the results of the data analysis, the objectives of the sample model are to:

- Show the correlations found to be statistically significant between the decay/soiling types and various factors of influence

- Calculate the rate of occurrence (probability) of these relationships
- Estimate the possible consequences of the various decay/soiling types by quantifying the corresponding stone loss observed in the sample
- Show the calculated risk of stone loss, based upon both these factors of the observed rate of occurrence of decay/soiling and the corresponding potential stone loss

5.2.2 Method of risk calculation in the sample

The conventional method of risk calculation described in the literature review is:

Risk = hazard frequency x consequence

(Ballard 1992; Spjotvall 1987). Accordingly, the present risk assessment is based upon a formula incorporating these. In terms of the degradation of historical stone monuments, the hazards are the various factors of influence which can cause or contribute to stone weathering. The consequence is the eventual deterioration or loss of stone from the monument surface through various decay types. The consequences could be considered to be greater if the architectural components affected are of some antiquity, or if the decay has occurred on surfaces of historical importance (eg carved detail or inscription). A risk level has been calculated for each correlated pair of variables (ie factor of influence and associated decay/soiling type) that were found to be statistically significant, or nearly significant, during analysis of the sample data.

Calculation of hazard consequence, ie degree of consequent stone loss

Based upon findings from the literature review and visual observations, the 'consequence' with regard to the risk assessment was classified in terms of the resulting degree of stone loss. The maximum degree of severity/density and surface extent of each decay/soiling type observed in the sample was used to establish the degree of stone loss that could be caused by each. For example, spalling can cause a very high degree of stone loss, particularly if the distribution is extensive. Algae, on the other hand, will always result in little or no stone loss, regardless of its density and distribution. The stone loss classifications are based upon considerations of both direct and indirect stone loss. For example, moisture is a prime factor in stone decay and since this can be retained by moss, and in the soil from which higher plants grow, these biological soiling types could be considered to contribute to causing some stone loss. Table 5.1 below shows the categories for the degree of stone loss, assigned for the various levels of severity/density and surface distribution of every decay and soiling type observed in the sample. Shaded table cells represent combinations of decay or soiling severity and distribution that were *not* seen in the sample, nevertheless the corresponding amount of stone loss that could be expected at these levels has been classified. Note that the stone loss ratings should not be confused with the *risk* level - the overall risk of stone loss involves a further calculation of probability. The highest observed level of stone loss for each decay/soiling type in the sample was used to quantify the *Consequence* in the risk assessment for each decay and soiling type. The criteria used for classification of degree of stone loss was:

Low Little or no stone loss

Moderate Slight, superficial stone loss

High Significant surface stone loss

Very High Substantial surface stone loss or severe structural damage

Table 5.1 Classification of the degree of stone loss for the sample risk assessment.

Decay/soiling type	**Localised surface distribution**			**General surface distribution**		
	Low severity	**Moderate severity**	**High severity**	**Low severity**	**Moderate severity**	**High severity**
Algae	*low*	*low*	*low*	*low*	*low*	*low*
Lichen	*low*	*low*	*low*	*low*	*low*	*mod*
Moss	*low*	*low*	*mod*	*mod*	*mod*	*high*
Plants	*low*	*low*	*mod*	*mod*	*mod*	*high*
Fungi	*low*	*low*	*low*	*low*	*low*	*low*
Particulate soiling	*low*	*low*	*low*	*low*	*low*	*low*
Black crust	*low*	*mod*	*mod*	*mod*	*high*	*high*
Staining	*low*	*low*	*low*	*low*	*low*	*low*
Efflorescence	*mod*	*mod*	*mod*	*high*	*very high*	*very high*
Painted graffiti	*low*	*low*	*low*	*low*	*low*	*low*
Bird excrement	*low*	*low*	*mod*	*low*	*mod*	*mod*
Mechanical damage	*low*	*mod*	*high*	*mod*	*high*	*very high*
Flaking (<5mm)	*low*	*mod*	*high*	*mod*	*high*	*very high*
Scaling (>5mm)	*mod*	*mod*	*high*	*high*	*very high*	*very high*
Spalling	*mod*	*high*	*very high*	*high*	*very high*	*very high*
Delamination	*low*	*mod*	*high*	*mod*	*high*	*very high*
Blistering	*low*	*mod*	*high*	*mod*	*high*	*high*
Fissures	*low*	*mod*	*mod*	*very high*	*very high*	*very high*
Granulation	*low*	*mod*	*high*	*mod*	*high*	*very high*
Crumbling	*mod*	*high*	*very high*	*very high*	*very high*	*very high*
Differential weathering	*low*	*mod*	*high*	*mod*	*high*	*very high*
Pitting	*low*	*low*	*mod*	*low*	*mod*	*high*
Honeycombs	*mod*	*mod*	*high*	*mod*	*high*	*very high*
Dissolution	*low*	*mod*	*high*	*mod*	*high*	*very high*

It is acknowledged here that monument parts that are highly carved or those that are of greater antiquity could be considered to incur more damaging consequences due to their perceived greater value. A method has been devised to incorporate this consideration into the practitioners' risk assessment and is described later in this chapter (Sections 5.3.2.1 and 5.3.3).

Calculation of hazard frequency rate, ie probability

The other element of the risk equation in addition to stone loss is the decay/soiling type probability. This is the frequency rate in the sample of each decay/soiling type in conjunction with a tested factor of influence, and is calculated as a percentage. For example, the incidence rate of spalling upon sandstone components with inclusions in the sample was found to be 56%. To generate the overall risk value represented by this within the sample, this probability figure would then be multiplied by the estimated amount of consequent stone loss (an example of the calculation is shown in the diagram below). Probability values naturally decrease when there are a greater number of categories or possibilities. However, for simplicity and consistency, in most of the statistical tests the data for each factor of influence was divided into two opposite, exclusive groups. For example, the occurrence and severity of decay/soiling types were tested in conjunction with sandstone with or without inclusions, on components that were older or younger, and in locations with higher or lower rainfall level, etc. Thus the decay/soiling patterns evident in these opposing groups were statistically compared. The risk assessment calculation was applied only to correlations that were shown to be significant by the statistical tests. That is, the risk values refer only to strong, proven correlations, which take account of the overall frequency levels in the sample.

5.2.3 Method of model design

The diagram below shows how the conventional risk equation has been adapted in the Sample Model:

Conventional risk formula:

Hazard frequency rate	X	**Hazard consequence**	=	**Risk**

⬇

Sample risk assessment formula:

(Frequency of components with decay/soiling type *d* which occur in conjunction with factor of influence *i*) ÷ Total frequency of components occurring in conjunction with factor *i* in the sample	X	Maximum observed level of stone loss from decay/soiling type *d* in the sample	=	Risk level

Example data:

91 cross components in the sample were identified as being composed of sandstone. Of these:

16 sandstone components have inclusions, and 9 of these exhibit spalling = 56% occurrence rate;

75 sandstone components have *no* inclusions, and 22 of these show spalling = 29% occurrence rate.

These occurrence rates of spalling on components with and without inclusions were compared by applying the Fisher's Exact Test. The result showed that there is a significant association between sandstone components with inclusions and spalling. Therefore, the formula could then be applied in order to calculate the risk of stone loss due to spalling on components with inclusions in the sample:

Spalling rate upon sandstone with inclusions: 56% (6)	X	Maximum observed stone loss from spalling: Very high (8)	=	48	=	Very High Risk

The system of substituting values for the purposes of the risk calculation can be explained as follows. Percentage occurrence rates for probability have been assigned a value on a scale of 1 to 10 for simplicity of calculation in the model, ie

% Occurrence rate	Probability value
0-9%	1
10-19%	2
20-29%	3
30-39%	4
40-49%	5
50-59%	6
60-69%	7
70-79%	8
80-89%	9
90-100%	10

The degree of stone loss that can be caused by various levels of decay and soiling has been assigned a classification value according to a four-point scale. In order to produce a suitable spread of calculated risk values, the classification value for each degree of stone loss is double that of the previous ie:

1	*Low*	Little or no stone loss
2	*Moderate*	Slight, superficial stone loss
4	*High*	Significant surface stone loss
8	*Very High*	Substantial surface stone loss or severe structural damage

The resulting spread of risk values that could potentially be produced by multiplying the *probability* by the *degree of stone loss* value are shown in Table 5.2 below:

Table 5.2 Range of calculated risk values from sample.

	Degree of stone loss			
Probability	1 Low	2 Mod	4 High	8 Very high
1 (0-9%)	*1*	*2*	*4*	*8*
2 (10-19%)	*2*	*4*	*8*	*16*
3 (20-29%)	*3*	*6*	*12*	*24*
4 (30-39%)	*4*	*8*	*16*	*32*
5 (40-49%)	*5*	*10*	*20*	*40*
6 (50-59%)	*6*	*12*	*24*	*48*
7 (60-69%)	*7*	*14*	*28*	*56*
8 (70-79%)	*8*	*16*	*32*	*64*
9 (80-89%)	*9*	*18*	*36*	*72*
10 (90-100%)	*10*	*20*	*40*	*80*

The spread of risk values has been interpreted as corresponding to five classifications of risk *level*, shown in Table 5.3 below. The degree of shading for each risk value in the table above refers to the corresponding risk level below.

Table 5.3 Risk categories for sample risk assessment.

Risk level category	Risk values
Low	1-5
Low-to-moderate	6-10
Moderate	12-20
High	24-40
Very high	48-80

5.2.4 Sample risk assessment results

Table 5.4 below contains the risk assessment results calculated for the sample. The results are tabulated according to five broad classes of decay and soiling types: *Biological soiling*, *Non-biological soiling*, *Granular disaggregation*, *Planar disaggregation* and *Fractures*. The meaning of each data field is described after the table.

Table 5.4 Sample risk assessment results.

SAMPLE RISK ASSESSMENT: BIOLOGICAL SOILING				
Soiling type	**Class of factor**	**Type of factor**	**Soiling aspect**	**Risk level**
ALGAE	Monument part	Less exposed parts	Incidence	(9) Low-Moderate
		Sculpted parts	Density	(6) Low-Moderate
		Elevated parts	Density	(4) Low
		Washed parts	Density	(4) Low
		Washed parts	Surface extent	(4) Low
	Environment	Surfaced ground	Incidence	(9) Low-Moderate
		Sheltered facades	Density	(4) Low
	Stone properties	Coarse-grained sandstone	Density	(5) Low
HIGHER PLANTS	Monument part	Base components	Incidence	(8) Low-Moderate
		Built components	Incidence	(8) Low-Moderate
LICHEN	Environment	Non-surfaced ground	Incidence	(18) Moderate
		Non-surfaced ground	Surface extent	(12) Moderate
		Non-surfaced ground	Density	(8) Low-Moderate
		Grassy land-use	Incidence	(16) Moderate
		Grassy land-use	Surface extent	(8) Low-Moderate
		Lower traffic levels	Incidence	(14) Moderate
		Lower traffic levels	Density	(6) Low-Moderate
		Non-roads land-use	Density	(4) Low
		Lower traffic levels	Surface extent	(8) Low-Moderate
		Inland sites	Incidence	(14) Moderate
		Inland sites	Surface extent	(12) Moderate
	Monument part	Built components	Incidence	(16) Moderate
		Base components	Incidence	(14) Moderate
		Less exposed parts	Incidence	(12) Moderate
		Non-relief carved parts	Incidence	(12) Moderate
		Non-sculpted parts	Incidence	(12) Moderate
		Sculpted parts	Density	(4) Low
		Exposed parts	Density	(6) Low-Moderate
		Elevated parts	Density	(4) Low
	Climate	Higher relative humidity	Incidence	(12) Moderate
		Higher relative humidity	Surface extent	(6) Low-Moderate
		Lower temperatures	Incidence	(12) Moderate
		Lower temperatures	Surface extent	(6) Low-Moderate
		Greater frost frequency	Surface extent	(6) Low-Moderate
		Greater frost frequency	Density	(4) Low
		Greater fog frequency	Surface extent	(6) Low-Moderate
	Monument properties	Older components	Incidence	(14) Moderate
		Older components	Density	(4) Low
MOSS	Monument part	Base components	Incidence	(36) High
		Built components	Incidence	(32) High
		Less-exposed parts	Incidence	(24) High
		Non-relief carved parts	Incidence	(16) Moderate
		Non-sculpted parts	Incidence	(16) Moderate
		Washed parts	Incidence	(20) Moderate

Table 5.4 Sample risk assessment results *(continued)*.

SAMPLE RISK ASSESSMENT: BIOLOGICAL SOILING				
Soiling type	**Class of factor**	**Type of factor**	**Aspect of soiling**	**Risk level**
MOSS	Environment	Rural land-use type	Density	(16) Moderate
		Unsurfaced ground	Density	(12) Moderate
		Lower traffic levels	Density	(8) Low-Moderate
	Monument properties	Older components	Density	(4) Low

SAMPLE RISK ASSESSMENT: NON-BIOLOGICAL SOILING				
Soiling type	**Class of factor**	**Type of factor**	**Aspect of soiling**	**Risk level**
BLACK CRUST	Monument part	Relief-carved parts	Incidence	(6) Low-Moderate
		Parts carved with cornices	Incidence	(6) Low-Moderate
	Environment	Coastal locations	Incidence	(2) Low
PARTICULATE SOILING	Monument part	Base components	Incidence	(8) Low-Moderate
		Built components	Incidence	(8) Low-Moderate
		Less exposed parts	Incidence	(7) Low-Moderate
		Non-relief-carved parts	Incidence	(6) Low-Moderate
	Environment	Roads land-use	Incidence	(9) Low-Moderate
		Surfaced ground	Incidence	(7) Low-Moderate
STAINING	Monument part	Base components	Incidence	(3) Low
		Built components	Incidence	(2) Low
		Less exposed parts	Incidence	(2) Low

SAMPLE RISK ASSESSMENT: GRANULAR DISAGGREGATION TYPES				
Decay type	**Class of factor**	**Type of factor**	**Aspect of decay**	**Risk level**
CRUMBLING	Monument part	Less exposed parts	Incidence	(16) Moderate
		Unwashed parts	Incidence	(16) Moderate
DIFFERENTIAL WEATHERING	Monument part	Less exposed parts	Incidence	(32) High
		Non-sculpted parts	Incidence	(24) High
		Elevated parts	Depth	(8) Low-Moderate
		Non-built components	Depth	(8) Low-Moderate
		Cross shafts	Depth	(16) Moderate
	Stone properties	Sandstone with inclusions	Incidence	(48) Very High
	Intervention	Repointed components	Incidence	(48) Very High
	Climate	Higher wind speeds	Incidence	(24) High
PITTING	Monument properties	Older components	Incidence	(20) Moderate
		Older components	Surface extent	(12) Moderate
		Older components	Density	(8) Low-Moderate
	Environment	Low traffic level	Incidence	(24) High
		Non-surfaced ground	Incidence	(24) High
		Inland locations	Incidence	(20) Moderate
		Inland locations	Surface extent	(32) High
	Monument part	Non-relief-carved parts	Incidence	(20) Moderate
		Non-sculpted parts	Incidence	(20) Moderate

Table 5.4 Sample risk assessment results *(continued)*.

SAMPLE RISK ASSESSMENT: PLANAR DISAGGREGATION TYPES				
Decay type	**Class of factor**	**Type of factor**	**Aspect of decay**	**Risk level**
DELAMINATION	Monument properties	Older components	Incidence	(24) High
		Older components	Surface extent	(8) Low-Moderate
		Sandstone with inclusions	Incidence	(32) High
SCALING	Environment	Coastal locations	Incidence	(8) Low-Moderate
SPALLING	Monument properties	Sandstone with inclusions	Incidence	(48) Very High

SAMPLE RISK ASSESSMENT: FRACTURE TYPES				
Decay type	**Class of factor**	**Type of factor**	**Aspect of decay**	**Risk level**
FISSURES	Monument part	Base components	Incidence	(12) Moderate
		Built components	Incidence	(12) Moderate
		Less exposed parts	Incidence	(10) Low-Moderate
		Non-relief-carved parts	Incidence	(10) Low-Moderate
		Non-sculpted parts	Incidence	(10) Low-Moderate
MECHANICAL DAMAGE	Intervention	High re-siting frequency	Severity	(3) Low
		Repointed components	Incidence	(9) Low-Moderate
	Monument part	Non-sculpted parts	Incidence	(5) Low
	Monument properties	Older components	Severity	(3) Low

5.2.5 Description of sample model data fields

Decay/soiling type

This data field lists each decay or soiling type in the sample that showed a statistically significant relationship to some factor(s) of influence.

Class of factor

The factors influencing decay and soiling are grouped according to their general type/source, ie *monument properties, stone properties, monument part, climate, environment* and *intervention.*

Type of factor

All factor types which yielded a statistical significance value of ≤0.1 in the calculations when tested in relation to the decay/soiling types are listed (see Sections 4.3.2-3 in previous chapter for an explanation of the significance levels). A full list of all the factor types tested during the data analysis can also be found in Table 4.14 in the previous chapter, along with the criteria for their classification. The factor types can be considered as the hazards or the sources of the risks assessed in the model. The decay/soiling types under which these are listed in the table, and the stone loss ultimately engendered, are the consequences.

Aspect of decay/soiling

During the data analysis, three aspects of decay and soiling on the cross components were tested in relation to all of the factors of influence:

- The incidence (ie presence) of the decay/soiling types
- The decay severity or soiling density
- The extent of surface distribution of the decay/soiling types

Thus, the decay/soiling *Aspect* in Table 5.4 indicates to which of these the correlation applies. For example, sheltered facades of crosses do not show a greater *incidence* of algal occurrence; however, they do show algal growth that has a significantly greater *density*. In the sample there are a greater number of significant relationships for incidence than there are for severity/density and distribution, since certain of the decay and soiling types in the sample do not show much variation with regard to the degree of severity/density and distribution.

Risk level

The risk calculation method described above was applied to each significant variable pairing (ie decay/soiling type and factor of influence) to generate a risk value.

5.2.6 Discussion of significant relationships shown in the Sample Model

All of the relationships in the sample with a statistical significance value of ≤0.1 are discussed below. The results are compared to the original hypotheses and possible reasons for significant trends are discussed. Of the 123 significant relationships listed in the previous chapter, 27% were found to support the hypotheses, while 20% were actually found to oppose them. The other 53% of the relationships had not been anticipated, in the sense that no specific hypotheses had been formulated about them prior to the testing. However, some possible reasons for the unexpected trends are discussed in this section. Relationships judged to be less valid due to bias or coincidence are discussed, while certain others are identified as indirect relationships that seem to have arisen due to some other common factor or due to secondary mechanisms. Due to the testing of a high number of variables, it is statistically likely that a number of apparent correlations will be flagged-up as significant in the tests where no true cause-and-effect relationship exists. After all, it is statistically valid to accept as 'proved' relationships with a 95% probability of being real, and this in itself would imply that 1 in 20 (5%) of the apparently true relationships could be invalid. Of the original pool of 123 significant trends, 89 (72%) were finally selected to appear in the sample model table. The reasons for rejecting the other 34 relationships from the model are discussed below (22 of the rejected relationships involved climatic variables, discussed in Section 5.2.7).

BIOLOGICAL SOILING

ALGAE

Although algae had a very high incidence rate on the sampled crosses, they generally cause little or no stone loss, therefore the risk levels generated were *Low* and *Low-to-Moderate*. The worst consequence of heavy algal growth is that it may be considered an eyesore, or could be a safety hazard to the public if it creates a danger of slipping on the steps of a monument. It was observed growing in various densities upon the crosses and the surface distribution also varied from localised to a general cover. The prime factors influencing the patterns of algal growth in the sample were mostly the architectural characteristics of the crosses and their environment. These factors are significant primarily due to their role in determining the amount and distribution of water upon the crosses. Certain of the monument parts were found to exhibit algae more frequently, or with greater density or greater surface extent. Algal *incidence* was found to be more frequent upon less exposed components and on crosses sited on surfaced ground. The 'splash-back' action of rainwater from surfaced ground onto the monument can be considered responsible for greater algal incidence on components on surfaced ground. The *density* of growth was found to be greater upon sculpted, elevated and washed components, as expected, since all of these monument parts are more exposed to direct rainfall and run-off. The surface distribution of algae also tended to be more extensive upon washed components. Monument facades subject to the shelter of a nearby wall also exhibited denser algal growth than non-sheltered facades, since they stay wetter for longer. Additionally a correlation was found between dense algal growth and coarse-grained sandstone. The rougher surface and the increased pore spaces on such stone may be the reason why algae thrive on such surfaces. In conclusion, all of the significant correlations found between algae and the cited factors support the general hypothesis that algal growth is largely determined by the presence and amount of moisture on the stonework. A further correlation had been expected between algae and facades orientated towards the N and E due to decreased solar incidence and therefore increased periods of wetness on these surfaces. However, the tests did not indicate a significant relationship.

FUNGI

Observations regarding a fungi-like soiling have been rejected from the Sample Model. Small patches of tiny black speckles were observed in the case of 4 crosses and recorded as fungi. In another case, a furry, fungal growth was observed growing across a large surface area of the cross-slab situated inside Fowlis Wester church, perhaps encouraged by the warm, humid atmosphere. The fibres of this growth were only just visible to the naked eye. Usually the presence of fungi on stone cannot be reliably established without tests, therefore it would be imprudent to include the unconfirmed fungi in the sample model. In any case, only one significant correlation was found for fungi, ie that the fungal incidence was greater on crosses sited on non-surfaced ground (ie on grass or soil). It may be that fungal colonisation is more likely to occur on this ground type; however, positive identification of these growths as fungi would be needed in the sample.

HIGHER PLANTS

Factors hypothesised to influence patterns of growth of higher plants in the sample were architectural properties and the level of maintenance of the monuments. Like moss, higher plants need pockets of soil and are therefore most likely grow in monument parts that incorporate crevices or enclaves. The incidence of plants in the sample was low (observed on just 6 components), and their distribution on monuments was usually localised. If the growths are left unchecked they could eventually result in structural damage to a monument, since woody stems can force stones apart and there is also increased opportunity for moisture ingress in such cases, which can aggravate other decay types. However, due to the low occurrence rate in the sample, the calculated risk levels in relation to the influencing factors are *Low-to-Moderate*. The observed growths usually consisted of small weeds growing in the masonry joints. As expected, they exhibit a significantly greater incidence on built and base component types of the sampled crosses, due to the higher frequency of masonry joints. However, there was no significant correlation between higher plants and the level and nature of previous intervention, perhaps because weeds can grow fairly quickly in small crevices even if monuments are regularly maintained.

LICHEN

Lichen incidence was high upon the sampled monuments. However, it causes little or no stone loss, thus the calculated risk levels range from *Low* to *Moderate.* Lichen growth exhibits various densities in the sample and its distribution on monuments ranged from localised to extensive. The occurrence of lichens is generally very dependent upon the location and substrate. Some species prefer uplands, some favour coastal locations, some species are attracted to sandstone, and some prefer limestone. However, the species of lichen were not recorded in the sample, since their identification is a specialised and time-consuming discipline, outwith the resources of the research. Lichens are generally not very tolerant of polluted air and this is reflected in some of the correlations. Lichen incidence, density and distribution were all greater in the context of lower traffic levels. Perhaps for similar reasons, the land-use type around the crosses was also found to be a significant factor. Lichen grows less densely upon crosses sited on roads. Correspondingly, it has a higher incidence, greater density and more extensive surface distribution upon crosses sited on grassy land-uses, as opposed to crosses sited on roads and pavements. Certain monument parts were also found to be significant. Built components, commonly forming the base of the monuments, tended to have a greater lichen incidence. This trend could be due partly to the tendency for certain species to favour the alkali in lime mortars (eg yellow-coloured lichens of the genus Caloplaca).

However, in the less frequent cases in which lichen was observed growing upon the more elevated. sculpted and exposed monument parts, it tended to grow with greater *density* than on other component types. A possible explanation is that pollution from car exhausts declines very rapidly with increasing height. The other monument characteristic affecting lichen growth in the sample was the age of the cross components. Older components have a significantly higher incidence of lichen as expected, since the colonisation and growth rate of lichen on stone tends to be slow. However observations made during the fieldwork suggest that this depends somewhat on the species and the degree of lichen growth in the surroundings of a monument. The cross in Dallas churchyard has very dense and extensive, foliated lichen growth. However, a nearby graveslab erected as recently as the 1953 also exhibited dense, foliated lichen growth along its top, suggesting that foliose species can grow relatively quickly. With regard to location, lichen shows a higher incidence and a more extensive surface distribution on crosses sited further from the coast, perhaps due to the preferences of a certain species abundant in the sample. The lower levels of atmospheric sea-salt or lower traffic emissions away from the coastal roads and towns/cities are possible reasons for this. Certain climatic factors showed a correlation with lichen growth. Crosses in areas of higher relative humidity, as well as those located in areas of lower temperature, exhibited a greater incidence and more extensive surface distribution of lichen. Crosses sited in areas with more frequent days of fog exhibited more extensive lichen growth across their surface, and lichen growth density and surface distribution were greater upon crosses in areas with more frequent days of frost. A possible explanation for these patterns is that there is greater moisture on stone surfaces in locations of higher frost/fog/relative humidity, due to increased dew formation on the stone surface created by the temperature differential. Therefore, apart from the preference of particular lichen species, the statistical tests indicate that environment factors and monument properties have the most influence upon patterns of lichen growth. The main hypotheses are supported by the data; however, the role of climatic factors is less clear. No significant correlations were found between lichen growth and intervention types to which the monuments have been subject.

MOSS

The requirements of moss on stonework are moisture and a small amount of soil. Moss tends to grow in crevices, enclaves and on horizontal surfaces. Crosses that have received less maintenance should exhibit greater moss growth, since it can be removed with relative ease. Incidence levels in the sample were relatively high, although growth density was usually low and the surface distribution was usually very localised. Although moss does not usually cause a loss of stone directly, the moisture that it harbours can be damaging to the stone due to its role in various decay mechanisms. Therefore the calculated risk levels range from *Low* to *High*. Factors of the monument design were found to be the predominant influence upon patterns of moss growth in the sample. Built components, forming the base of the monuments, exhibited a greater incidence of moss, due to the increased existence of crevices in the masonry joints of such components. Correspondingly, moss has a lower incidence on the more elevated, sculpted and relief-carved components, presumably due to their lack of joint space and the fact that deposition rates for wind-borne soil particles decline rapidly with increasing height. Washed components exhibited a high incidence of moss. The increased moisture encourages moss growth and the washing action of rainwater across a surface also helps to move soil and dust into the crevices. Older components were found to exhibit denser moss growth, as might be expected. Environment was revealed to be another significant factor. Crosses situated in rural areas and on grassy land-types had denser moss growth. In contexts of lower traffic levels, moss also grew more densely on crosses, perhaps because moss is not very tolerant of direct exposure to motor vehicle emissions. There was no significant correlation between moss growth and the level and nature of previous maintenance, perhaps because moss grows back relatively quickly. In conclusion, the findings therefore lend some support to the hypotheses.

NON-BIOLOGICAL SOILING

BLACK GYPSUM CRUST

Gypsum crust is known to occur on unwashed stonework, and particulates in the air from sources of pollution cause it to become blackened. The presence of gypsum in a crust can be confirmed by X-ray diffraction, and such a test applied to Edinburgh High Street cross allowed positive identification. Black crust generally had a low incidence in the sample (observed on just 5 components). The decay consequences are moderate in that the detachment of a black crust can occasionally cause the loss of some surface stone, therefore the risk levels generated were *Low* and *Low-to-Moderate*. Black crust had a very localised surface distribution in all observed cases in the sample. The findings support the hypothesis with regard to the monument parts affected. Incidence was greater on components carved with relief and components carved with cornices (mainly on the undersides of capitals and also on the unwashed parts of the tower-base of Edinburgh High Street cross). This is due to the existence on such components of unwashed areas beneath the carvings. However, no significant correlation was found with regard to nearby traffic levels. All 5 instances of black crust occur upon the crosses with a more coastal location. The crust cannot be caused by atmospheric sea-salt; however, the increased atmospheric moisture in these areas may be encouraging the crust formation.

EFFLORESCENCE

Efflorescence was observed at only one cross in the sample (Edinburgh High Street), distributed around the masonry joints. It would not be valid to draw any statistical conclusions from one case, and this soiling type has therefore been excluded from the sample model; however, the characteristics of the observed case can be discussed. It is significant that the only case of efflorescence occurs on the only monument in the sample that has been subject to stone-cleaning by chemical methods. Efflorescence is known to be one potential effect of chemical treatment. In the observed case, the chemical residues have allowed salt crystallisation in the stone, particularly around the masonry joints where there has been greater absorption of the chemical cleaner. Laboratory tests of a sample of efflorescence taken from this monument indicated that the cause could indeed be residues from chemical cleaning.

PARTICULATE SOILING

It was hypothesised that particulate soiling would be greater upon crosses in the context of higher traffic levels. The incidence of particulate soiling is high in the sample; however, it causes little or no material loss thus the calculated risks do not exceed *Low-to-Moderate*. The density of soiling varies from low to high and surface distribution ranges from localised to extensive. It is generally found that particulate soiling on sandstone is often most dense upon washed areas; however, the tests revealed no such statistically significant relationship in the sample. Land-use type was found to have some influence. The incidence of particulate soiling was significantly greater on crosses sited on roads and pavements. This would support the hypothesis with regard to direct exposure to motor vehicle emissions; however, there was no significant relationship with regard to the nearby traffic *level*. Certain monument parts were also found to be more vulnerable to particulate soiling. Built components at the base of the monuments had a greater incidence, as they tend to trap wind-blown dirt from passing motor vehicles and they are more directly exposed to exhaust emissions at this lower level of the monument. Presumably for the same reasons, the soiling incidence was lower on the more exposed, relief-carved components which normally occupy elevated positions in the crosses and usually lack masonry joints.

An unexpected finding, rejected from the risk assessment, was that particulate soiling incidence was lower on older components. This trend may have arisen due to a bias, because components located at a greater distance from roads in the sample (which have a lower soiling incidence), also have a slightly greater tendency to be older. It was expected that there might be a correlation between particulate soiling and the frequency of fog. Fog is a medium for carrying smaller particulates, which can be deposited on unwashed areas of a monument; however, there was no evidence in the sample to support such a hypothesis.

STAINING

The definition for this in the sample was staining on stonework due to metal attachments and did not include discolouration due to iron traces occurring naturally in the sandstone. Thus there is an obvious correlation between staining and monument parts incorporating rusting iron attachments such as railings and brackets. The incidence of staining in the sample was very low (identified on just 7 components) and the observed cases were all very localised stains. The stains themselves are benign, thus the calculated risk values are all *Low* (however, it should be noted that there is an associated danger that the rusting iron pieces could expand through oxidation and cause the stone to fracture). The significant relationships found for iron staining simply reflect the most common position of iron attachments on the crosses. The base, built components, which also occupy less exposed positions in the monuments, had a higher incidence of staining. No staining due to copper wash was observed in the sample, although there were a number of copper and copper alloy pieces attached to the stones, such as information plaques.

GRANULAR DISAGGREGATION

CRUMBLING

Crumbling did not have a very high frequency in the sample. It was observed on only 8 components, with various degrees of severity, and the effect was very localised in all cases. Nevertheless the consequence of material loss from crumbling can be very high. The calculated risk values are therefore of *Moderate* level. Monument parts and climatic factors were found be significant. Crumbling incidence is lower upon more exposed and washed components, perhaps because evidence of the disintegrated stone is washed away by rainwater on such monument parts.

DIFFERENTIAL WEATHERING

Differential weathering was quite a common decay feature in the sample. It was observed in various degrees of severity, although usually localised in extent. A very large amount of stone can be eroded away due to this decay type, therefore the calculated risk values range up to *Very High*. The presence of differential weathering is related to the stone type characteristics. Some sandstones are particularly vulnerable to this type of decay, and will exhibit this decay regardless of the climate, environment or other agents of decay. In the sample, monument parts are the source of the most influential factors in differential weathering. This decay type generally has a higher frequency on the less exposed and non-sculpted components in lower positions on the monuments. This could be due to the selection of more durable stone for sculpting, since the vulnerability of stone types to differential weathering is a factor likely to be known to the masons. On the other hand, in cases where differential weathering *does* occur on the elevated and carved components, as well as on shafts, it tends to be more severe (ie the stones have been eroded to a greater depth). In the case of shafts, this pattern could be due to the vertical alignment of bedding layers, which encourage the channelling of water down the weathered furrows. Crosses in locations with higher windspeed were found to have a higher incidence of differential weathering. A potential explanation for this is the scouring effect of the wind, especially where vortices are generated. This is quite a common mechanism and could be a factor in the patterns of differential weathering. There is a highly significant trend linking a higher incidence of differential weathering to sandstone with inclusions. However, confusingly, sandstone *without* inclusions tends to exhibit a greater depth of surface stone loss due to differential weathering. The incongruity here suggests a spurious correlation. The latter trend regarding depth of stone loss is very weak, therefore it has been rejected from the risk model. There was a significantly higher incidence of differential weathering upon components that had been repointed. The differential weathering may in certain cases have been aggravated by the repointing material, or alternatively by increased former moisture ingress through the vacant joints. The surface distribution of the observed cases did not tend to suggest a cause-and-effect relationship between repointing and differential weathering, thus despite the trend it might be largely independent of the repointing, or may have occurred prior to the repointing. In conclusion, most of the relationships revealed as statistically significant with regard to differential weathering were not anticipated, although explanations can be offered in some cases.

GRANULATION

Granulation can cause a large amount of stone loss. The rate of stone loss can be gradual or, in cases where the sandstone grains detach when touched, it can be more rapid. This decay type was fairly frequent in the sample, exhibited by 27 components. The severity of the observed granulation was varied, although its surface distribution was mostly localised. No statistically significant relationships were found during testing.

HONEYCOMB WEATHERING

The cause and mechanisms of honeycomb weathering are not fully understood, but the literature review suggested that salts, wind and sunlight might exert an influence. Thus it was hypothesised that significant factors in the sample should be coastal proximity, exposure to wind, windspeed, and exposure to direct sunlight. However, honeycombs were only identified upon one component in the sample and it would not be valid to extrapolate from one case. This decay type has thus been excluded from the sample model. In the observed case at Ormiston, the honeycombs were distributed extensively across the surface of this cross with moderate severity. Ormiston cross is situated inland, 7km from the nearest stretch of coast and the wind speed is fairly average at this site. The honeycombs occur on much of the NW, N, E and SE sides of the cross, eating into the two opposing, edge-bedded sides. Therefore, in conclusion there are no specific factors present at this cross to support the hypotheses.

PITTING

Pitting was quite frequent in the sample, and was observed in various degrees of severity with a surface distribution ranging from localised to extensive. It can cause a significant amount of material loss, thus the calculated risk levels range up to *High*. Various factor types influence pitting in the sample. Land-use type was found to be a significant factor. Pitting was found to have a higher incidence on crosses sited on non-surfaced ground (ie those not sited on roads and pedestrian thoroughfares) and in contexts of lower traffic levels. A possible explanation is that some crosses associated with roads, pavements and higher traffic levels may have experienced erosion such that the effect of any pitting has been rendered less obvious. Pitting was additionally found to have a significantly higher incidence and surface distribution on crosses situated at more inland sites; however, it is doubtful that this represents a direct cause-and-effect relationship. Inland sites tend to have lower traffic levels in the sample, thus this trend may have arisen for the same reason that pitting has a lower incidence on crosses in contexts of lower traffic levels. Certain monument properties were found to have some influence. As might be expected, older components exhibit a higher incidence, greater intensity and more extensive surface distribution of pitting. This is presumably due to relatively slow rate of progress of this type of erosion. Pitting had a lower incidence upon sculpted and relief-carved components, perhaps because better quality stone was selected for the carving of such monument parts. Pitting incidence was greater upon repointed components, although this is not likely to represent a direct relationship. Thus while reasons can be offered for the role of environment, monument parts and age, the relationship of pitting to repointing does not correspond with any of the hypotheses and this latter finding has been excluded from the sample model.

PLANAR DISAGGREGATION

Flaking, scaling, spalling and blistering are all effects of salt decay. It was therefore expected that these decay types would be correlated with high air pollution from traffic emissions, climatic factors associated with frequent wetting and drying cycles and coastal proximity.

BLISTERING

Blistering had a very low frequency in the sample (identified on just 1 component). It would not be valid to draw statistical conclusions from one case, therefore this decay type has been excluded from the sample model. However the characteristics of the observed case (Edinburgh High Street cross) can be discussed. This cross is located 3 km from the nearest stretch of coastline, thus sea-salt may be prevalent in the atmosphere. However, more interestingly, the only case of blistering in the sample was recorded upon the only monument subject to chemical stone cleaning. Like the efflorescence on this cross, the blistering is localised around the masonry joints and is very likely to be caused by the salts from the chemical cleaning.

DELAMINATION

Delamination is the separation of bedding layers and the subsequent detachment of planes of stone. It commonly occurs on face-bedded sandstone, thus it was expected to occur more frequently upon shafts and slabs in the sample. Moisture introduced from the ground through capillary processes is a factor in delamination, therefore it was hypothesised that crosses sited on non-surfaced ground would exhibit greater delamination. Delamination incidence is fairly low in the sample; however, since it can result in a considerable amount of stone loss the generated risk levels range up to *High*. The observed level of severity varied, although the surface extent was usually *Localised.* The findings did not lend support to the hypotheses; however, an explanation can be offered for some of the relationships. Monument properties were found to be the prime factors influencing delamination in the sample. Delamination had a higher incidence and greater surface extent upon older components, perhaps because this decay type advances at a relatively slow rate, or alternatively that it takes a long time to become established. Delaminating components for which the age of carving was known ranged between 228-1250 years old, relatively old with regard to the rest of the components in the sample. Sandstone with inclusions was found to have a higher incidence of delamination, perhaps because the detaching inclusions or their expansion encourage the detachment of delaminating planes.

FLAKING

Flakes are smaller versions of scales and the criterion for their identification in the sample was a diameter of <5mm. Flaking incidence was very low in the sample (identified on just 5 components). Therefore, although it can cause a moderate amount of material loss, the calculated risk level was *Low*. The lack of significant relationships is due to the low occurrence and also because the surface distribution was '*Localised*' in all cases in the sample, and the severity level did not exceed '*Moderate*'. Only one significant relationship was found, where flaking had a greater incidence on crosses located in areas of lower relative humidity. This trend corresponds with none of the formulated hypotheses, and it is unclear whether it might be due to a bias or coincidence. This relationship has been excluded from the risk assessment.

SCALING

Scaling was differentiated from flaking in the sample on the basis of the size of the detaching planes (scales >5mm diameter). Scaling was more common than flaking in the sample and was observed on 13 components. In all cases the scales had a localised distribution. Scaling can cause considerable stone loss; however, due to the low rate of occurrence in the sample the calculated risk values are all *Low-to-Moderate*. Scaling has a greater occurrence rate upon crosses with a more coastal location. This may be somewhat due to atmospheric sea-salt; however, flaking and spalling show no such correlation with coastal proximity. There is also significance with regard to land-use type. Scaling shows a greater incidence on crosses sited on surfaced ground, and in particular on crosses sited on pedestrian thoroughfares. A possible reason for this is that scaling can be caused by de-icing salts. However, there is no significant relationship in the sample between scaling and the base components of the monuments to support this. While the scaling on crosses in such locations might be aggravated by nearby motor vehicle emissions, there is no supporting relationship between the scaling and the nearby traffic level. A further significant relationship that cannot be explained by the hypotheses is a lower scaling incidence on sculpted components. Since all the relationships with regard to scaling are judged to be spurious, they have not been included in the risk assessment.

SPALLING

Spalling is a relatively extensive form of scaling, manifested by the detachment of large planes of stone following the contours of the stonework. It can be caused by the accumulation of salts at a constant depth beneath the stone surface. Spalling exhibited a moderate level of incidence in the sample and, as it can cause a large amount of stone loss, the risk levels generated range up to *Very High*. Monument properties were found to have some influence. Sandstone with inclusions exhibited a higher incidence of spalling. An explanation is that the erosion of inclusions from the sandstone - particularly in the case of clay inclusions that expand when wetted - could encourage the detachment of spalling planes. The other significant relationships generated by the tests cannot easily be explained as they do not correspond with any of the hypotheses. They have been excluded from the risk assessment, but will be mentioned here. Spalling distribution is more extensive but tends to be of lower severity upon relief-carved components. Another unexpected relationship was revealed between older components and a lower spalling incidence. One explanation for this, noted earlier, is the slight bias in that crosses sited further from roads tend to have a higher mean age.

FRACTURES

FISSURES

Fissures were a frequent feature in the sample. Their surface extent was localised in all cases; however, the degree of severity varied. Fissures can lead to a moderate amount of stone loss due to their capacity to retain water as well as soil which can encourage moss and weed growth. Additionally, fragments of masonry could potentially become detached due to fissuring. The risk levels generated are *Low-to-Moderate* and *Moderate*. The type of monument part was found to be a significant source of influence on the occurrence of fissures in the sample. Built, base components had a higher incidence of fissures, as opposed to the sculpted and relief-carved components in more exposed positions. One explanation is that fissures due to impacts are more likely to occur at lower levels. However, there is perhaps a slight bias here, since the built components tend to comprise a much greater volume and a greater number of stone pieces, thus the incidence of fissures is statistically more likely. A further reason is that fissures in stone at lower levels may be caused or aggravated by increased pressure from stone above.

MECHANICAL DAMAGE

Mechanical damage was hypothesised to be greater on crosses with a high re-siting frequency, since this allows increased opportunity for breakage and impacts during removal operations. Additionally, greater mechanical damage could be expected on older components since the increased age allows increased opportunity for various impacts leading to mechanical damage. Mechanical damage was common in the sample, usually in the form of small chips off the edges of the stonework. In a few cases the shafts had broken into separate pieces and were rejoined. The degree of severity of mechanical damage in the sample is varied, although the surface distribution is usually localised. While mechanical damage can cause the loss of large pieces of stone, the damage is episodic. Its treatment in the risk assessment therefore ought to be different from that of the other decay and soiling types that advance gradually. The calculated risk values of decay due to mechanical damage are *Low* and *Low-to-Moderate*. Various factors influence patterns of mechanical damage in the sample. Mechanical damage incidence is lower upon sculpted components, perhaps since impacts are less likely to occur at the more elevated positions occupied by such components. Incidence is higher upon repointed components. While this trend could be due to the greater likelihood of impact at the lower positions normally occupied by the repointed components (usually steps), there was no corresponding correlation with base or built component types. A possible explanation is that damage can occur by workmen during the removal of old pointing by chipping it out. In support of the hypothesis, older components were found to have more severe mechanical damage. Additionally, as expected, crosses that had a high re-siting frequency exhibited more severe mechanical damage.

5.2.7 Summary of the effects of the significant factors

Based upon the statistical tests, many of the relationships can be interpreted as supporting the hypotheses; however, there are also many hypotheses that cannot be supported. A considerable number of the relationships calculated as being statistically significant cannot be explained by any known processes. This is particularly the case with regard to the climatic factors.

The effect of geographical climatic annual average values

There is no clear relationship between most of the climatic factors and the decay/soiling patterns. Most of the significant climatic correlations have therefore been rejected from the sample model, but are listed for reference in Table 5.5 below. The relationships between lichen and some climatic factors could be explained by moisture levels produced on the stone surface, and it was suggested that a true relationship could exist between differential weathering and windspeed. However, other climatic trends cannot be easily explained and the presence and direction of these correlations are presented in the table below.

Table 5.5 Significant relationships involving annual average climatic data.

Climatic factor	Decay/soiling type	Direction of correlation	Decay/soiling aspect
Relative humidity	Mechanical damage	+	Incidence
	Pitting	+	Incidence
	Crumbling	-	Incidence
	Flaking	-	Incidence
	Moss	-	Distribution
More frequent days of fog	Crumbling	+	Incidence
	Pitting	-	Incidence; distribution
	Mechanical damage	-	Incidence
More frequent days of frost	Crumbling	-	Incidence
	Particulate soiling	-	Incidence
Higher temperature	Particulate soiling	+	Incidence
	Pitting	+	Incidence: distribution
	Delamination	-	Incidence
	Lichen	-	Incidence; distribution
Higher wind speed	Mechanical damage	+	Incidence
	Spalling	-	Incidence
Higher precipitation	Mechanical damage	+	Incidence
	Fissures	-	Incidence
	Particulate soiling	-	Density

Some of these relationships have obviously arisen due to coincidence, in particular mechanical damage is unlikely to be caused or increased by climatic factors. It may be the case that the geographic data for climatic averages, derived from selected climate stations across Scotland, is not strongly related to decay and soiling patterns and that more localised conditions of sunlight, temperature, wind patterns and moisture upon the monument are more decisive. The availability of climate data was limited by the existing distribution of climate stations in Scotland. In acknowledgement of this, map evidence was used during the data analysis to investigate the presence of any local topographic features likely to affect the prevailing climate in each town in the sample (see Section 4.4.1.3 previous chapter). Fog and frost can exhibit quite localised patterns depending upon the local topography. For example, they are more likely to form on valley floors, and haars are a common feature of the eastern seaboard of Scotland. However, very few topographic features considered to be of influence were found in the sample. Annual average daily temperatures also have the potential to be misleading. The actual stone temperature is likely to be more significant for decay and soiling. Stone retains the cold or warmth for longer periods than the surrounding air. The resulting temperature differential at the stone surface can create increased moisture due to condensation, and moisture is known to be a major factor in decay and soiling. Therefore the daily difference between the maximum and minimum local temperature may be of greater relevance. For the same reason, the level of atmospheric relative humidity recorded at climate stations may be irrelevant. The frequency of the wetting-drying cycle was hypothesised as being an important factor in salt decay since it is the recurring crystallisation of salts which can place damaging stress on the pores. The annual average values for relative humidity, fog, precipitation, windspeed and temperature may be obscuring the local variations that control the wetting and drying frequency of the stone. Additionally the built environment can shade a monument, thus locally affecting the wind patterns, solar incidence, direct rainfall and thus the moisture experienced at the stone surface. However, shade was in fact observed to have little effect upon the observed decay and soiling in the sample (see previous chapter, Section 4.4.1.1). It was only found to be significant in relation to the density of algal growth. Additionally, the orientation of the cross facades and the cross aspect were also found to have little effect upon decay and soiling patterns (see Section 4.4.1.2). In the sample, there were few local features found regarding aspect and the built environment that could influence the micro-climate experienced at the stone surface of the crosses. Many of the crosses have no aspect as they tend to be sited on flat ground, and only three crosses were in the shade of a nearby wall. In conclusion, the inexplicable nature of many of the climatic relationships would imply that there is no straightforward cause-and-effect relationship between them and the degree of the various decay/soiling types. It would be more relevant for future research projects to concentrate on measuring the micro-climate at each monument, where possible. Accordingly, it is not recommended that practitioners include consideration of geographic climatic data in their risk assessment. Furthermore, climatic factors are not open to alteration - the only way to modify their influence on a monument would be to remove it indoors. On the other hand environmental factors could be altered, albeit not easily (eg changing the land-use or reducing nearby traffic levels, see discussion at the end of this chapter, Section 5.4.2)

Age of components

One might expect a general tendency for older stonework to exhibit more advanced and extensive decay and soiling than younger components. Pitting, delamination, mechanical damage, lichen and moss do indeed show greater levels upon older components in the sample. In particular, the trends suggest that delamination, lichen and pitting all tend to take a longer time to establish themselves upon stone (since their incidence is lower upon less old components). Furthermore the rate of their advancement is also slow compared with other decay/soiling types, since their intensity and/or surface distribution also tends to be lower on less old components. Moss density increases with the age of stonework, but the data in this case is no doubt distorted due to numerous instances of its removal on various monuments since their construction. The severity of mechanical damage generally increases with the age of the monument, due to the increased opportunity for various impacts. However, in the case of most decay and soiling types, no such relationship with component age exists.

Monument parts

Monument parts were frequently found to be a factor of influence in the decay and soiling patterns. Their significance is principally due to the role of their morphology and position in dictating the amount of moisture dealt to the stone. The types of monument part to which statistical tests were applied were exposed, sculpted, washed, built, base and relief-carved components and components carved with cornices. These classes were defined for various reasons in order in investigate specific hypotheses. The classes of monument parts overlap, and in some cases two or three similar classes appear as significant for the same decay or soiling type for the same reason. For example, built components show a higher incidence of lichen in comparison to non-built components, and base components also show a higher incidence of lichen in comparison to the more elevated components. Since both component classes comprise largely the same components, the trend regarding lichen on the base components in this case can be explained by the fact that some lichens are particularly attracted to the alkali in mortared masonry joints, as found in the built components. There is also overlap between sculpted and elevated components. The effect of such overlap has been considered in the interpretation of the relationships in the preceding section. The monument parts were classified in expectation of the following: the architectural features affect the run-off patterns, the distribution of sheltered zones, and the general surface-to-volume ratio. Elevated components have a greater exposure to the elements, while base components are less exposed to the elements and are open to sources of decay and soiling coming from lower levels, eg more direct exposure to traffic emissions, capillary moisture transfer, de-icing salts. The built components incorporate mortar and can include crevices that harbour moisture, dirt and biological soiling types. As expected, the type of monument part featured significantly in the results.

Stone properties

Although some crust and soiling samples were gathered from a few of the crosses, it was not possible to remove samples of stone for laboratory analysis. Therefore, many of the stone properties have not been measured. It is possible that some of the decay patterns may be explained by these unquantified factors. The existence or otherwise of inclusions in the sandstones was a visually obvious factor which could be classified for all components. A small proportion had inclusions, and this was found to be significant in relation to three decay types. Sandstone grain size could only be estimated when a component could be examined at close-range. The grain size data is therefore incomplete and is biased towards the components positioned at lower levels in the monuments. It was only found to be significant with regard to the density of algal growth. The sorting of the grains was usually uniform and there were no significant relationships with regard to this. In conclusion, it is considered that the recorded data of stone properties paints only a small part of the picture regarding their effect upon decay and soiling patterns in the sample.

Intervention

The intervention factors analysed were the effects of repointing, cleaning, re-siting frequency, conservation materials (epoxy resins, hard Portland cement, cement render and iron dowels), and stone replacement. Many of the built components had recorded instances of repointing. These components showed higher instances of four decay types; however, the reason for these relationships was unclear most cases. A problem in analysing this is the lack of information regarding the date of repointing episodes and also regarding the condition of the crosses prior to this, even despite the consultation of archived photographs. This is another instance that demonstrates the importance of record keeping. However, as the position of these decay types was generally not at the joints, it is presumed that these relationships have arisen due to other reasons. Only one cross was subject to chemical cleaning and the influence of this was confirmed as being very damaging, particularly around the joint areas. Re-siting frequency was found to have produced a greater severity of mechanical damage, as expected. The frequency of applied conservation treatments in the sample was too low to allow statistical analysis and their effects have instead been discussed (see previous chapter for full discussion, Section 4.4.2). Although epoxy resin can cause problems if used extensively due to its propensity to trap water, no damaging after-effects were observed from this in the sample. Cement render coats had been applied to components on 3 crosses and, although the render had cracked in some cases, there was no evidence to suggest that it had caused damage. However, the analysis for render was not conclusive, since the underlying stone could not be adequately examined. Portland cement was used as a repair material in 3 cases in the sample. Damage to stonework around the joints of Beauly cross was attributed to the former application of hard cement for pointing (Historic Scotland restoration records). In the case of Cromarty cross, visual observation established that the cement repair is likely to have been damaging. Aggravated by the expansion of rusty iron components, the cement had become displaced from the stone surface, although the degree to which this has affected the underlying stone is again obscured. There were several instances in which the interaction between replaced stone and older, surrounding stone could be investigated. No statistical tests were run for this analysis, since the database design was not suited to this particular query. Instead, visual examination showed that there was little evidence of damaging effects from this in the sample, perhaps because the stone types chosen for the replacements had been suitable matches. In some cases local stone might still be available; however, it may be more difficult to match stone in the future as many quarries have closed.

Land-use

Land-use type was found to be significant with regard to several decay and soiling types. In many instances this was interpreted as being due to the degree of direct exposure to motor vehicle emissions, and a number of decay and soiling types were found to have been affected by this (eg particulate soiling, lichen). The nature of the surrounding ground surface was also significant. Paved and metalled surfaces in the sample (roads and pedestrian thoroughfares) were again associated with greater levels of pollutants from nearby traffic and also with the splashback of rainwater which increases the incidence of algae and particulate soiling. The risk from de-icing salts associated with this land-use may have contributed to scaling incidence. Grassy and rural land-use types seem to be factors that have encouraged lichen and moss growth.

Nearby traffic levels

Against all expectations, crosses in the context of greater traffic levels did not show a greater degree of any decay or soiling type. Instead, these crosses were associated with lower levels of lichen, moss and pitting.

The proximity of the crosses to roads also had an influence upon biological soiling. Crosses sited closer to roads exhibited lower frequencies of biological soiling.

Coastal proximity

Coastal proximity and the associated salty atmosphere were found to have little role in salt decay in the sample. Scaling incidence and black crust formation were greater on crosses at more coastal locations; however, these trends could be due to greater moisture levels from haars rather than atmospheric sea-salt. Lichen also exhibited greater levels at more inland sites, which could perhaps be explained by the preference of certain species that were abundant in the sample, or possibly due to lower pollution levels at inland sites away from the coastal roads and towns/cities. Pitting has a greater occurrence and surface extent upon crosses sited at greater distances from the coast. This trend may have arisen for the same reason as pitting incidence is greater on crosses associated with lower traffic levels, since inland locations tend to have lower traffic levels in the sample.

5.3 Practitioners' risk assessment

5.3.1 Objectives of practitioners' risk assessment

Arising from the sample risk assessment, the practitioners' risk assessment objectives are to:

- Identify the environmental factors of influence present
- Identify the current decay and soiling types and evaluate their severity and extent
- Predict the future risk of stone loss from each decay/soiling type
- Prescribe intervention to reduce the decay/soiling and/or its causes
- Maintain a record of any intervention

It is aimed that regular records are kept of the monument condition and intervention. Previously this type of data has not been recorded; however, it is invaluable for informing future intervention, and research into decay rates and the effectiveness of applied conservation materials. It is recommended that the crosses should be surveyed every 10 years if possible (every 5 years if degradation is generally very advanced or if intervention prescribes that the decay or soiling should be monitored). Thus the record could be updated at regular intervals with documentation of any change which has occurred with regard to decay, soiling, weathering agents, and intervention.

5.3.2 Additional considerations for the practitioner

The practitioners' risk assessment is necessarily different from the method applied to the sample. The sample model risk formula is a baseline calculation from which the generated risk levels posed by various factors of influence are applicable to the broader population of crosses. However, certain additional factors should be considered by practitioners to augment the magnitude of hazard at other individual crosses, and thereby the risk from various decay and soiling types. The perceived 'value' of the monument part and the decay rate are such factors.

Value judgements

The perceived 'value' of the monument parts should be an additional consideration in the practitioners' assessment. Monuments parts judged to be of greater historical value due to their greater antiquity and/or various carved features, or parts which play a key functional role in the cross, could be considered to suffer greater consequences if damaged. The risk to these would therefore be greater than to other masonry of less historical and architectural significance. The scheme for this evaluation is described below in Section 5.3.3.

Decay rate

The sample risk assessment presented in the previous Section 5.2 indicated the risks to the sampled crosses, based upon the maximum observed stone loss per decay/soiling type. The extent to which these observed findings could be applied to *individual,* unsampled crosses to predict the risk of increased damage depends partly upon the *rate* of advance of the decay/soiling types. However, little information is available on the timespan of decay cycles and of the rate at which stone loss proceeds. Analysis of the sample data showed that the incidence, severity and surface extent of many of the decay and soiling types exhibited no significant relationship to the age of the stonework. Decay rate was not included in the sample risk assessment because the risk levels were being calculated based upon the maximum observed stone loss to date, in which the preceding decay *rate* was a latent factor. Instead the occurrence levels across the whole sample were used as probability values in the risk formula. The practitioner, faced with estimating the risk for an individual monument, is interested in the degree to which the decay/soiling will *increase,* rather than the likelihood of decay and soiling types occurring, since the mere fact of incidence has often already been exceeded. Therefore, in attempting to apply the sample risk assessment to other individual monuments, the decay/soiling rate of advance now becomes an issue. One method of calculating rate of advance where no previous data exists could be to divide the value for the surface area covered by the decay/soiling type by the component age. However, this method would not be valid since it assumes that the decay/soiling has been advancing since the date the stone was carved and that the rate of advance has been constant. Furthermore, analysis of the collected sample data indicated that there was no correlation between the age of the carving and the decay and soiling patterns in most cases. A method of predicting the advance of decay/soiling on individual monuments has been developed, which can make use of data from previous observations where this is available (see full description in Section 5.3.3). There is additionally a need to consider which point has been reached in the cycle of various decay/soiling types, and the length of time needed to reach the maximum decay, based upon the existing stone loss and the estimated decay rate. Another important point to consider is at what stage the stone loss or future risk projections necessitate some intervention. These issues are dealt with in the intervention criteria presented in Section 5.4.1.

5.3.3 Method of risk calculation

The conventional formula for calculating risk (see review in Section 2.6) is:

Risk = hazard frequency x consequence

Based upon this concept a formula has been designed for use by practitioners to assess the risk of stone loss at individual monuments. However, the conventional formula has had to be adapted since the hazards *already* exist at the monuments in many cases. Therefore the task of the practitioners' risk assessment is to assess the extent to which the existing decay/soiling types will advance and cause future damage through stone loss. Thus the hazard 'consequence' in the practitioners' risk assessment is represented by the existing degree of damage. The hazard frequency or probability element of the formula is represented by a quantification of the expected degree of *advance* of this decay/soiling, based upon the previous rate of advance, as well as the presence of any factors thought to influence the rate of decay/soiling. Thus the formula developed for the practitioner to assess the risk of stone loss from a certain decay/soiling type on a market cross over ten years can be expressed as:

$$\mathbf{R = VDFA}$$

Where:

R = Risk value per decay or soiling type

V = Perceived '*value*' of the affected stonework

D = *Depth* of stone loss

F = Degree to which *factors* of influence are present

A = Surface *area* of the stonework which the decay/soiling is predicted to cover

In effect, **V** and **D** together represent an evaluation of the current stone loss. **A** represents the extent to which this is predicted to increase, based upon surface area measurements, while **F** can further augment the total value according to the degree to which factors of influence are present at the cross (eg environmental factors or monuments characteristics). It is recommended that market crosses should be regularly surveyed and assessed using this system (ideally at ten-year intervals). The monument should be divided into two parts for this assessment, if appropriate, according to the historical/architectural 'value' **V** of the components. The formula should be applied to each individual decay and soiling type observed. Another important use for the method is to assess the effectiveness of applied conservation materials. For example, a patch of delamination repaired with epoxy resin will be stabilised for a while, and during this time the decay should exhibit a constant surface area thus proving the success of the treatment over a period of time. If the conservation treatment failed, successive area measurements taken over a period of time for the purpose of the risk calculation would show whether the treatment had slowed or accelerated the decay. Therefore, future records over a long time span could give useful information about the success or failure of different interventions. Each element of the formula and the criteria for its quantification are described in detail below.

V: 'Value' of the affected stonework

For each decay and soiling type, **V** should be quantified simply as *1* or *2*, in reference to the position of the observed decay or soiling pattern. A value of 2 should be assigned if the distribution of the decay/soiling type occurs on a part or feature of the monument which is of relatively greater value in terms of its antiquity, carved historical features or due to its role as a key functional or structural feature within the monument. The features on a monument that could be regarded as functional, and therefore key to the physical integrity of the crosses, are those which act to divert rainwater away from the stone surfaces, eg cornices or water spouts. On the other hand, **V** can be assigned the lower value of *1* if the decay/soiling is only distributed upon relatively plain and/or less old masonry. There is inevitably a little subjectivity involved in this evaluation, since each monument is a unique subject in terms of its design and historical features. Effectively, the role of **V** in the formula is to augment the hazard consequence, ie the resulting degree of stone loss, in the case of more 'valuable' parts.

D: Depth of stone loss caused by the decay/soiling

D is a value assigned to indicate the degree to which the decay or soiling type is causing a loss of stone from the monument surface. This is dictated to some extent by the decay or soiling type, eg algal growth causes no direct stone loss, thus the value in its case will never exceed 0 in the classification. Any soiling type that can be assigned a D value of 0 will generate a total value of 0 in the risk assessment, since **D** is a multiplier. The criteria for classification of **D** is as follows:

0 *Little or no stone loss*, ie the consequences are primarily aesthetic (most biological soiling)

1 *Moderate*, ie superficial stone loss from the surface up to 1mm (eg light granulation; pitting should also be classified as this, to take account of the fact that it is less dense across the surface than other decay types).

2 *High*, ie a significant amount of stone loss, to a depth of between 1-5mm (eg planar detachments, severe granulation, differential weathering and crumbling mostly exceed 1mm in depth)

3 *Very High*, ie very considerable stone loss, to a depth of over 5mm

F: Factors of influence present

The statistical tests applied during the data analysis showed which factors had an influence upon each decay and soiling type. The criteria used for defining these factors of influence were shown in Table 4.14 in the previous chapter. The factors of influence which yielded statistically significant relationships in the sample with regard to soiling density, decay severity, or the extent of their surface distribution, are listed in Table 5.6 below. The *high* or *moderate* probability levels indicated by the tests are shown in brackets after the significant relationships. A number of hypotheses, which had been formulated as a result of the literature review, were *not* supported in the sample by the statistical tests. These other factors of influence are nevertheless also included here for the practitioner, since evidence from other research has shown them to be generally important in affecting decay and soiling patterns. The lack of significance shown by these additional factors in the sample may be partly explained by insufficient frequencies and unavoidable confounding factors in the sample, or may be partly due to factors of the stone properties that could not be measured during the research.

For the purpose of the risk assessment, the **F** value can be selected for each decay and soiling type observed on a monument by referring to Table 5.6 below, which lists the corresponding factors of influence that are likely to increase the rate of decay or soiling. Where any of these factors are present or are applicable to the cross being assessed, a greater severity or surface extent of the corresponding decay/soiling type could be expected. Note that the listed factors apply to the *increase* of existing decay/soiling, not simply to its occurrence. The decay and soiling types are generally already visible upon the stonework. As explained earlier, the task of the practitioners' risk assessment is to predict the degree to which the existing decay and soiling will *increase*. There is little point is assessing the risk from a decay or soiling type that does not occur on a monument. Even if such a decay or soiling type were to manifest itself at a future date it would not initially represent an immediate risk, and could be incorporated in future risk assessments given that the recommended interval of assessment is ten years. For example, testing of the sample data indicated a significant relationship in which algae grow with greater density upon course-grained sandstone. Therefore, if the component or cross being assessed by the practitioner is made from course-grained sandstone then this factor would count towards the total **F** value to be assigned to algae on that cross. Although most algae represent no risk in terms of stone loss, the related factors of influence are nevertheless listed in the table since heavy algae can be an eyesore. Those charged with the care of such monuments might wish to reduce this in order to enhance the aesthetic value of the monument (see the intervention guidelines for suggestion of possible methods of removal, Section 5.4.1). By observing which of the relevant factors of influence are present at the cross being assessed, a total value can be established for **F**, per decay and soiling type. The factors of influence are grouped according to four main spheres of influence:

- Environmental factors
- Vulnerable monument parts
- Stone properties
- Inappropriate interventions

The calculation method is potentially complicated by the fact that there are varying numbers of factors influencing each decay and soiling type, arising from varying numbers of spheres of influence. However, environmental factors and vulnerable monument parts are in most cases the predominant source of factors associated with the increased severity or extent of decay/soiling. Indeed, environmental factors are thought to be key to influencing the rate of decay and soiling (Yates et al 1999). The position of the component within the monument was found to be relevant, particularly with regard to the extent to which it is exposed to sources of moisture. Thus the level of elevation and exposure of the component within the monument, and whether or not the component type includes masonry joints, are significant factors. Stone properties were found to have a limited influence; however, it was mentioned earlier that few of these variables could be measured during the research. There were few damaging effects due to previous intervention episodes that could be identified as causing increased decay/soiling on the sampled monuments, although Section 2.4.5 of the literature review indicated that Portland cement and rusting iron parts could be damaging. It is not yet clear whether modern conservation materials (epoxy resin and consolidants) will have an adverse effect where they have been applied to the crosses. However, successive risk assessments will allow this to be monitored. The **F** value is calculated for each observed decay or soiling type by use of the following simple formula:

$$\mathbf{F = 1 + f/n}$$

n is the total number of spheres of influence which could exert a damaging effect upon a particular type of decay or soiling (with a value ranging from 1 to 4), and **f** is the number of these which are present at, or which apply to, the cross being assessed. To deal with the varying numbers of factors and spheres of influence per decay and soiling type, this element of the formula must be a score or fraction. The maximum value must be kept low in order that it is not too weighted in relation to the other elements of the formula. A basic value of *1* must be allocated for **F** in situations where no factors of influence are present at crosses being assessed. This is necessary in order to accommodate some advance of the decay or soiling in the formula. Therefore the F value will fall within the narrow range of 1.00-2.00 as follows:

F value	Corresponding degree of factors of influence present
1.00	*No relevant factors of influence are present at or are applicable to the cross, ie $f = 0$*
1.00-2.00	*One or some of the relevant spheres of influence are present at/applicable to the cross*
2.00	*At least one factor from every relevant sphere of influence is present at/applicable to the cross, ie $f/n = 1$*

For example, a hypothetical cross exhibits black crust on an unwashed area on the underside of the capital, which is carved from calcareous sandstone. These characteristics can be matched with factors of influence arising from two spheres, ie *vulnerable cross parts* and *stone properties*, as shown in Table 5.6 on the next page. However, it is not the case that the cross is located on a road or in close proximity to heavy traffic.

Therefore 2 out of the 3 possible spheres of influence exist at this cross, thus **F** = 1 + 2/3 = 1.67. The reason that the *spheres* of influence are counted, rather than the individual factors of influence, is because some individual factors which arise from the same sphere of influence have qualities which overlap. For example, *Roads* or *Pedestrian thoroughfare land-use* or proximity to *Higher traffic levels* in the sphere of *Environmental factor*s could all give rise to an equivalent effect upon a monument. There is therefore some duplication of qualities in each table cell. Note that largely the same set of environmental factors have been listed for all of the salt decay types (blistering, crumbling, efflorescence, flaking, granulation, scaling, spalling), in order to show all of the possible salt sources. The specific factor of influence that is causing the damage will depend upon the salt source, and therefore the type of the salt, which may not be evident from visual observation.

Note that it is impossible to accurately quantify the effect of the individual factors in terms of consequent stone loss. This is due not only to the lack of existing knowledge, but also to the large number of variables involved in the decay and soiling processes, the characteristics of which vary from monument to monument. Instead, it is only possible to indicate which factors are likely to strongly or weakly, and positively or negatively, influence the amount of certain decay/soiling types.

Table 5.6 Factors of influence contributing to increased decay or soiling.

Decay or soiling class	Decay or soiling type	SPHERES OF INFLUENCE (f)				Total no. of relevant spheres of influence (n)
		Environmental factors	Vulnerable cross parts	Stone properties	Inappropriate intervention	
Biological soiling	**Algae**	Sheltering wall (moderate);	Horizontal and sloping surfaces (eg steps); Sculpted & elevated parts (high); N & E facades;	Course-grained sandstone (high);	Phosphate residuces from chemical cleaning;	4
	Lichen	Unsurfaced ground (very high); Inland site (high); Lower traffic levels (very high); Rural land type	Exposed, elevated, sculpted or non-built components (high);	-	Phosphate residuces from chemical cleaning;	3
	Higher plants	Unsurfaced ground	Built components; Ledges and crevices;	-	-	2
	Moss	Rural land type (high); Unsurfaced ground (high); Lower traffic levels (high);	Built components; Ledges and crevices;	-	-	2
Non-biological soiling	**Bird excrement**	Coastal site;	Horizontal or sloping surfaces;	-	-	2
	Black crust	Higher traffic levels; Roads land-use;	Sheltered, unwashed parts; Masonry joint areas;	Calcareous stone type;		3
	Efflorescence	Pedestrian thoroughfare land-use; Roads land-use; Coastal location;	Built components; Low-level components;	Stone with high proportion of microporosity;	Residues from chemical cleaning;	3
	Painted graffiti	Urban sites; Unfenced site;	Low-level components;	-	-	2
	Particulate soiling	Higher traffic levels; Roads land-use;	Washed components; Low-level components;	-	-	2
	Staining	-	-	-	Rusting iron parts formerly used for repairs; Aggressive chemical cleaning;	1

Table 5.6 Factors of influence contributing to increased decay or soiling *(continued).*

Decay or soiling class	Decay or soiling type	SPHERES OF INFLUENCE (f)				Total no. of relevant spheres of influence (n)
		Environmental factors	Vulnerable cross parts	Stone properties	Inappropriate conservation	
Granular disaggregation	**Crumbling**	Higher traffic levels; Roads land-use; Pedestrian thoroughfare land-use; Coastal location;	Low-level components (moderate);	-	Use of hard, impermeable mortar or cement;	2
	Differential weathering	-	Vertically bedded components, eg shafts (high); Elevated and/or non-built components (high);	Sandstone incorporating softer beds	Abrasive cleaning of sandstone with softer beds;	2
	Dissolution	High local levels of sulphur emissions (industrial);	-	Calcareous-cemented stone;	Use of stone cleaning acids on calcareous sandstone;	2
	Granulation	Higher traffic levels; Roads land-use; Pedestrian thoroughfare land-use; Coastal location;	Built components; Low-level components;	Weakly-cemented sandstone;	Use of hard, impermeable mortar or cement;	3
	Honeycomb weathering	Coastal location; Greater exposure to wind; Direct solar incidence;	-	Calcareous-cemented stone;	-	1
	Pitting	-	-	Stone with softer inclusions	Use of cleaning acids on calcareous stone; Abrasive cleaning of stone with softer inclusions;	1

Table 5.6 Factors of influence contributing to increased decay or soiling *(continued)*.

Decay or soiling class	Decay or soiling type	SPHERES OF INFLUENCE (f)				Total no. of relevant spheres of influence (n)
		Environmental factors	Vulnerable cross parts	Stone properties	Inappropriate conservation	
Planar disaggregation	**Blistering**	Higher traffic levels; Roads land-use; Pedestrian thoroughfare land-use; Coastal location;	Built components; Low-level components;	Porous stone overlies an impermeable stone (eg sandstone over granite);	Residues from chemical cleaning;	3
	Delamination	Unsurfaced ground;	Face-bedded stones, eg shafts;	Stone with clay inclusions;	-	3
	Flakes	Higher traffic levels; Roads land-use; Pedestrian thoroughfare land-use; Coastal location;	Built components; Low-level components;	-	-	2
Planar disaggregation *(continued)*	**Scaling**	Higher traffic levels; Roads land-use; Pedestrian thoroughfare land-use; Coastal location;	Built components; Low-level components;	-	Residues from chemical cleaning;	2
	Spalling	Higher traffic levels; Roads land-use; Pedestrian thoroughfare land-use; Coastal location;	Built components; Low-level components;	-	Residues from chemical cleaning;	2
Fracture types	**Fissures**	Ground subsidence;	-	-	Removal operations; Rusting iron parts formerly used for repairs;	1
	Mechanical damage	Roads land-use; Urban land-use; Unfenced site;	-	-	Removal operations;	2

Calculation of A

A is the area which it is predicted will be covered by the decay or soiling type in ten years time. If:

Ac = Area covered by the decay/soiling type *currently*
Ap = Area covered by the decay/soiling type during *previous* survey
T = Time which has elapsed since the previous survey, in number of years

Then:
A = Ac + 10/T(Ac - Ap)

Deciding what units to use for measuring the value of **A** is problematic due to the variation in the size and the architectural characteristics of the crosses. As most of the decay and soiling patterns showed no correlation with the date of carvings in the sample, the varying age of cross parts now seems less important in the analysis. Due to the practical difficulties represented by the architecture, it is recommended that built components (eg tower bases, pedestals and stepped bases) are treated differently from single, monolithic elements (eg shafts) for the purposes of the area measurement in the calculation. The area of decay and soiling types on monoliths could be measured fairly easily, eg in square centimetres. However, for quantifying decay and soiling on larger, built elements it would be easier to count the number of individual stones affected. In order to quantify risk, the magnitude of damage (ie amount of stone loss) must relate to a maximum amount, the point at which the stonework is totally destroyed. For cross elements, the maximum amount is the widely varying total size or surface area, therefore the **A** value must make reference to this whole. For example, 2 square metres of severe spalling represents damage more holistically devastating to a cross shaft than it would to a large built component such as a tower base. Therefore, the absolute area value of affected stone upon these two types of components should not be viewed upon the same scale, since a large, built component could sustain a greater surface area of stone loss than a smaller element could. Area **A** must therefore be a fraction or percentage of the total area of the component being assessed. Thus, 2 square metres of spalling upon a shaft could represent 90% surface area damage to that component (which may also be of relatively high architectural or historical 'value'). On the other hand, a similar area of damage on a built pedestal could affect 5 out of 20 stones, representing 25% of the pedestal surface area.

The formula for **A** aims to project the recent rate of surface advance recorded since the last survey into the future, to predict the amount of damage in ten years time (with alteration, it could alternatively be used to predict damage over a longer timescale). Therefore, severe predictions could be considered to warrant preventative intervention in the present. However, it is acknowledged that the initial application by practitioners of the designed risk assessment will not have the benefit of decay/soiling area data from previous surveys. Thus no values will exist with which to calculate the rate of advance of the decay/soiling. Experience during the research has shown that this is unlikely to be quantified adequately from old photographs and from the existing archived records. The initial risk assessment for each cross can therefore only quantify the *immediate* risk.

It is recommended that the risk assessment is undertaken every ten years; however, if surveys to gather data were undertaken at shorter or at varying intervals, then a value for **A** can still be calculated. Note that the rate of advance of some decay types is very gradual and it is possible that no difference in the affected surface area could be detected over short time-spans. However, wherever previous data is used the calculated **A** value will always represent the predicted advance over the next ten years due to the flexibility allowed by the inclusion of **T** in the formula. If the interval is ten years, as recommended, then 10/T = 1; if 5 years have elapsed between two surveys, then 10/T = 2; if 15 years have passed then 10/T = 2/3; if the interval is 20 years then 10/T = ½, and so on. This ensures that **A** always refers to advance during a ten-year period.

Different decay/soiling types tend to vary in their extent with some exhibiting relatively extensive surface distributions (eg algae, lichen, pitting, efflorescence, particulate soiling and sometimes granulation), while others are often limited in scale (eg flaking and crumbling). This effect is balanced by the inclusion of **D** in the formula, which quantifies the depth of resulting stone loss. Thus while soiling and light granulation tend to cause little or no surface stone loss, more localised and destructive decay forms will be classified with a higher depth value to augment the overall risk value accordingly. The risk formula is flexible in allowing practitioners to use either the number of affected masonry blocks or the percentage surface area in calculating **A**. One approach may be more suitable than the other in certain cases. For example, in recording spalling, practitioners might find it most effective to measure the percentage area affected. However, for pitting it would be best to record the extent by counting the number of masonry blocks affected. Although the absolute area does not appear in the risk formula, in the case of smaller scale components where this has actually been measured to calculate **A** it will be useful for future research into decay/soiling dynamics. It could allow future comparisons to be made between the advance of a decay/soiling type upon different monuments.

The range of possible values for **VD**, representing the present magnitude of damage, is 0 to 6. In order to predict the advancement of this damage, **VD** is then multiplied by **F** (the degree to which relevant factors of influence are present) and by **A** (the expected area of advance). As **F** has a range of 1.00-2.00 and **A** is a percentage, expressed as a decimal with a range of 0.01 to 1.00 (ie 1-100%), the total calculated risk value will fall within the range of 0-12.00. A total value of 12.00 represents a predicted devastating stone loss of maximum depth and surface area to a highly valuable cross component where all relevant factors of influence are in operation. Table 5.7 below interprets the final calculated risk values and classifies them according to the level of risk they are judged to represent, in terms of the degree of stone loss.

Table 5.7 Classification of risk level from total **VDFA** value.

Degree of stone loss R	Risk level	Guide to level of intervention required
0	None	No intervention required
0.01-0.50	Low	No intervention required
0.51-1.00	Moderate	Monitor
1.01-1.50	High	Intervention advised
1.51-2.00	Very High	Intervene immediately
>2.00	Extreme	Intervention essential

For example, a *Low* risk from granulation could be calculated for lower value components predicted as having up to 50% surface area covered with light granulation, causing superficial surface loss (to about 1mm deep). The same type of damage would also represent a *Low* risk if it was predicted to advance onto up to 25% of a higher value component. Decay to a depth of 1-5mm (eg spalling) upon a low value component would also represent a *Low* risk if it covered less than approximately 25% of the surface area. Generally, no intervention would be necessary for decay in this risk category.

A *Moderate* risk would be incurred if light granulation (up to 1mm deep) covered >50% area of a low value component, and the practitioner would be advised to monitor the cross more regularly. A higher value component would similarly incur a *Moderate* risk if the same type of damage was predicted to spread onto between 26-50% of its area. Or, a lower value component could be assigned a *Moderate* risk if decay 1-5mm deep (eg spalling) covered an area of between approximately 26-50%.

A *High* risk would be incurred if a low value component was predicted to have 51-75% surface area of decay 1-5mm deep (eg spalling) or if it was to have between about 34-50% area of decay >5mm deep (eg severe crumbling). A higher value component would have a *High* risk from light granulation (about 1mm deep) if it was predicted to cover between about 51-75% surface area, or if it were to experience spalling (1-5mm depth) over a surface area of between about 26-37%. Decay >5mm deep (eg severe crumbling) on a high value component would also constitute a *High* risk if it covered 17-25% of the surface area. It is advised that intervention should be dealt to decay in this risk category if circumstances permit.

Very High risk would be incurred if a lower value component was predicted to have decay up to 1-5mm deep (eg spalling) covering over 75% surface area, or if 51-66% of its surface area was to develop decay >5mm deep (eg severe crumbling). A high value component would incur a *Very High* risk if spalling between 1-5mm deep was to spread onto between 38-50% of its surface area, or if it were to develop severe decay >5mm (eg severe crumbling) over an area of between 26-33%. These situations should never be allowed to arise and intervention should take place immediately if appropriate to the circumstances.

Extreme risk is unacceptable and should be a rare occurrence. However, the classification would arise if a low value component was predicted to develop >67% surface area of severe crumbling (>5mm deep). Higher value components expected to develop severe spalling (1-5mm) on >50% of their surface area, or predicted to have >34% surface area of severe crumbling (>5mm) would also incur *Extreme* risk.

Note that **VDA** would also be subject to multiplication by the **F** value, ie the degree to which the relevant damaging factors of influence are present. **F** varies between 1.00-2.00 and could thus as much as double the resulting risk value.

Example risk calculation

To illustrate the use of the formula, a hypothetical cross situated on a road is being assessed for the risk of stone loss from crumbling. The crumbling is evident upon the steps, which occupy a low position in the monument, a factor found to be moderately significant in the data testing (eg perhaps due to damage caused by de-icing salts). The crumbling is evident upon 5 of the 20 total masonry blocks that make up the steps. In the previous survey undertaken 15 years before, the crumbling was recorded on just 3 of the blocks. Consultation of the tabulated factors of influence (**f**) indicates that 2/3 of the relevant damaging sources of influence *(environmental factors and vulnerable monument parts)* exist at this cross.

V = 1, since the crumbling affects a lower 'value', plain part of the monument, the steps.
D = 2, since the crumbled depth is currently between 1-5mm deep.
F = **1 + f/n** = 1+2/3 = 1.67
A = **Ac + 10/T(Ac - Ap)** = 5/20 + 10/15(5/20 - 3/20) = 0.318 = 31.8%, ie 6.33 masonry blocks out of 20.
R = **VDFA** = 1 x 2 x 1.67 x 0.318 = 1.062

Therefore a *High* risk of stone loss from crumbling is estimated, based upon its predicted advance over the next ten years. Note that if no known relevant factors (**f**) were present at the site of the cross to increase the rate of the crumbling, then the overall risk value would be halved and would be *Moderate*.

One could plot the successive advance of a type of decay/soiling on a monument (using the **Ac** values) to show changes in the rate of advancement over a period of time. The plotted values would give a straight line if the advance was at a constant rate every decade and a curve would be produced if the rate were accelerating or decelerating. Successive recording in future decades could add considerably to our knowledge of decay and soiling dynamics. This would be particularly valuable coupled with the recorded data regarding the influencing factors at each monument.

5.3.4 Application procedure and case study

The sequence of the practitioners' assessment can be summarised as follows:

1. Visit the monument.
2. Record the environmental factors present (**f**).
3. Record the visible decay and soiling types, along with their severity (**D**) and extent (**Ac**). If time permits a drafted mapping should be prepared to record the distribution of this data across the facades.
4. Input relevant data into the digitised pro-forma.
5. Divide the monument into components for analysis, based upon the perceived 'value' (**V**).
6. Calculate a value for the future advance (**A**) of each decay/soiling type on these components by applying the designed formula. Note that where no previous data on decay extent is available, only the immediate risks at the cross can be calculated, by use of the current area value.
7. Establish a value for **F** based on the total potential spheres of influence (**n**) for each decay and soiling type.
8. Calculate the risk level represented by each decay/soiling type, using the formula **R=VDAF.**
9. Based upon the risk levels, consult the intervention guidelines (see Section 5.4) to see whether any course of action is appropriate with regard to each decay/soiling type.
10. Undertake the recommended intervention, if circumstances are appropriate.
11. Record the intervention in the pro-forma and/or database

For greater efficiency and standardised recording, a relational database has been designed for use by the practitioner in order to hold the recorded data and simplify the risk assessment process. The fields for data entry include lists of classification options to assist with standardising the recording. Sample data from a trial risk assessment at Turriff cross is included in this database, and is shown in the printout included in Figure 5.1 below. It is recommended that practitioners' surveys include photographic recording, and even elevation sketches showing the position and extent of the decay/soiling forms and conservation materials if time permits. Such mappings, as prepared during the survey of the sampled market crosses, can also allow easier quantification of the affected surface area of the monument since the edges of the decay/soiling or conservation features are clearly defined.

Figure 5.1 Practitioners' pro-forma for survey and risk assessment, printed from the designed database, with data from a trial risk assessment assessment at Turriff market cross.

MARKET CROSS RISK ASSESSMENT PRO-FORMA

Press "Page Down" key to get to other data fields or use navigation buttons below

MONUMENT NAME AND DESIGNATIONS

Key monument number	1
Monument name	Turriff market cross
LB designation	Category B
SAM status	☐
Architectural and historical description	The cross is built in the Gothic Revival style of architecture. It consists of a sandstone pedestal, which is octagonal in plan and adorned with many finials, and a shaft surmounted by a finial in the form of a Celtic cross. The whole structure sits upon two octagonal granite steps in the middle of a road junction at the edge of Turriff. The preceding cross was built sometime before 1557 and stood a short distance to the east in the High Street. However, this cross was removed in 1865 and no longer survives. The current market cross was built in 1865 but contains no part of the former one (although the Listed Building data claims that the present shaft originates from the former cross).

LOCATIONAL DETAILS

+ Add new set of location data for this cross | Go to Stone Components data >> | Go to Intervention Details >> | Go to Decay/Soiling data and Risk Assessment >>

Monument no. 1

Street name Castle Street

Site number 1

Coastal proximity Inland; North Sea located 15km N and 39km E of Turriff.

NGR NJ 7232 4979

Scroll back up to top for Monument Details

ENVIRONMENT DETAILS

Key n	Monument site	Land-use type	Ground surface	Road class	Traffic level	Traffic orientation	Presence of shelter	Shelter orientation
1	1	Roads	Surfaced	A	Busy	/ALL/	☐	

<< Go back to previous

Go to Decay/Soiling details and Risk Assessment >>

+ Add new component record

STONE COMPONENTS

Mon no.	Monument part	Date	Stone type	Source	Grain size	Inclusions?	Degree of carving	'V' value'
1	Pedestal base	1865	Sandstone		Coarse	Yes, pebbles and clay clasts.	2	1
1	Shaft	1865	Sandstone			No	2	1
1	Upper finial	1997	Sandstone	Turriff Red or		No	4	1
1	Steps	0	Granite			No	1	1
1	Lower finials	1865	Sandstone			No	4	2

<< Go back to previous | Go to Stone Components details >> | Go to Location and Environment details >> | Go to Intervention details >>

DECAY/SOILING TYPE

Key decay no. 1 | Key monument no. 1

Decay or soiling type: Scaling (>5mm pieces)

Ac: current area
Ap: previous area
A: predicted area

Risk R = VDF

$A = Ac + 10/T(Ac-Ap)$

RISK ASSESSMENT

Key	Survey date	Monument parts	Orientation of affected faces	'V'	'D'	'F' factors	Current area	Recent advance.	'A' Predicted	Risk value	Risk level
1	03/09/98	Pedestal	/N/NW/SW/S/E/NE/	1	2	1.67	0.05			0.17	Low

DECAY/SOILING TYPE

Key decay no.	2	Key monument no.	1
Decay or soiling type	Pitting		

Ac: current area
Ap: previous area
A: predicted area

Risk R = VDF

A = Ac + 10/T(Ac-Ap)

RISK ASSESSMENT

Key	Survey date	Monument parts	Orientation of affected faces	'V'	'D'	'F' factors	Current area	Recent advance,	'A' Predicted	Risk value	Risk level
1	03/09/98	Pedestal	/ALL/	1	1	1.5	0.62			0.93	Moderate
1	03/09/98	Shaft	/SW/	1	1	1.5	0.08			0.12	Low
1	03/09/98	Finials	/W/	2	1	1.5	0.06			0.18	Low

DECAY/SOILING TYPE

Key decay no.	3	Key monument no.	1
Decay or soiling type	Differential weathering		

Ac: current area
Ap: previous area
A: predicted area

Risk R = VDF

A = Ac + 10/T(Ac-Ap)

RISK ASSESSMENT

Key	Survey date	Monument parts	Orientation of affected faces	'V'	'D'	'F' factors	Current area	Recent advance.	'A' Predicted	Risk value	Risk level
1	03/09/98	Pedestal	/NNW/W/WSW/SSW/S/SSE/S	1	2	1.33	0.07			0.19	Low
1	03/09/98	Shaft	/S/SW/NE/	1	3	1.67	0.06			0.3	Low

DECAY/SOILING TYPE

Key decay no. 4 Key monument no. 1

Decay or soiling type: Granulation

Ac: current area
Ap: previous area
A: predicted area

Risk R = VDF

A = Ac + 10/T(Ac-Ap)

RISK ASSESSMENT

Key	Survey date	Monument parts	Orientation of affected faces	'V'	'D'	'F' factors	Current area	Recent advance.	'A' Predicted	Risk value	Risk level
1	03/09/98	Pedestal	/NW/S/SE/E/NE/W/SW/SSW/	1	2	1.5	0.013			0.04	Low
1	03/09/98	Shaft	/NW/N/NE/E/SE	1	2	1.25	0.17			0.43	low

DECAY/SOILING TYPE

Key decay no.	5	Key monument no.	1
Decay or soiling type	Crumbling	Gr	

Ac: current area
Ap: previous area
A: predicted area

Risk R = VDF

A = Ac + 10/T(Ac-Ap)

RISK ASSESSMENT

Key	Survey date	Monument parts	Orientation of affected faces	'V'	'D'	'F' factors	Current area	Recent advance.	'A' Predicted	Risk value	Risk level
1	03/09/98	Pedestal	/SW/NE/	1	2	1.67	0.01			0.03	Low

DECAY/SOILING TYPE

Key decay no. 6 | Key monument no. 1

Decay or soiling type: Dissolution

Ac: current area
Ap: previous area
A: predicted area

RISK ASSESSMENT

Risk R = VDF

A = Ac + 10/T(Ac-Ap)

Key	Survey date	Monument parts	Orientation of affected faces	'V'	'D'	'F' factors	Current area	Recent advance,	'A' Predicted	Risk value	Risk level
1	03/09/98	Pedestal	/SE/E/NNW/NW/WNW/WSW/	1	2	1.3	0.11			0.29	Low

<< Go back to previous | Go to Decay/Soiling Details and Risk Assessment >>

INTERVENTION DETAILS

Mon no.	Year	Type of work		Aim of work	Monument parts affected	Conservation product name	Conservation method and details	Cross-reference
	0							
	0							
1	1980	Resited		Road alterations necessitated the removal of the cross by a few yards.	All of the cross.	n/a	Around 1980 a metal plate was inserted underneath the whole market cross to move it a few yards during roadworks.	
1		Stone replaced	S	Vandalism had caused the fragmentation of some carved stones. These were removed and replaced with recarved replicas.	Certain of the lower finials.	n/a	A few of the lower finials were damaged due to vandalism. They were replaced with recarved replicas. The date of this is uncertain (1980's or early 1990's).	
1	1997	Stone replaced	S	Some stone parts were fragmented due to vandalism. These were removed and replaced.	The uppermost finial and one lower finial piece.	n/a	The upper finial and one lower finial piece were recarved.	
1	1997	Plastic repair	P	An incident of vandalism in 1997 had damaged a few of the cross pieces. The plastic repair was intended to restore the profile of one damaged stone.	One of the lower cross finials on top of the pedestal.	n/a	Small patch of plastic repair to infill a chip to one of the lower cross finials. Undertaken at the same time as two other pieces were recarved.	

The cross shown in the example data is fairly typical and incorporates a large built element and numerous sculpted pieces. The results of the trial risk assessment are presented in the form of a printout from the database which has been designed for the practitioners (Figure 5.1 above). The first page contains details of the monument name and designations, with space to record details of the general architecture and history. The second page records the location and environmental details for the cross site. The following page contains data fields to list each component of the monument. In this example the monument has been divided according to the constituent pedestal, shaft, finials and steps. This allows for the fact that components can be replaced and can have different characteristics. Note that the upper finial of a market cross would normally be classed as being stonework of 'value' 2. In this case it has been judged to be of 'value' 1, since it was only very recently replaced (1997) and currently has no historical value. The next section of the printout contains details of the decay/soiling and the corresponding risk assessment. Each page or record lists data associated with a different decay type, and contains data from the trial risk assessment, based upon field visits made to the cross during 1998. The current area values for most of the decay types are not very large. An exception is pitting, which covers 0.62 (62%) of the pedestal stones; however, its low 'D' value still keeps the risk value fairly low. The risk levels generated were all *Low* or *Moderate* and no intervention is currently necessary. All of the 'V' values in the risk assessment are low, with the exception of the lower finials, of which one exhibits some pitting. There is no previous data on the extent of decay from any previous surveys. Therefore, the calculated risk levels are based upon the current area only, and thus refer to the immediate risk rather than the future risk predicted. Future risk assessments of this cross can incorporate the present data in order to predict the advance of the decay and plan intervention more effectively. Future survey data can be added into these data-entry forms, and the database could also be queried. The final printout in Figure 5.1 provides a record of intervention. The example lists some previous incidents of intervention. Any future interventions (eg guided by the risk assessment and intervention guidelines produced in this research) should be input into this form in the same way. Cross-reference should be made to any other associated documents, photography or mappings. In the example provided, no documents were known, and the information was obtained from a personal communication with Moray Stone Cutters in Elgin, who undertook the work.

In conclusion, the risk assessment method worked adequately in the case of the example. Further trial applications of the method would be useful; however, time and budget restrictions do not allow for this in the present research. The fact that the calculated risk levels are mostly low reflects the fact that intervention to the monument cannot be justified currently, since the severe decay forms are relatively small-scale and mostly affect the plainer, built element of the monument which is of less architectural 'value'. The results also highlight the fact that conservation is not always strictly necessary, and indeed it can even engender further decay if applied inappropriately and extensively.

5.4 Intervention criteria and recommendations

The intervention guidelines are twofold. The first set in table format are conservation guidelines with options for the direct, remedial treatment of the stonework. The discussion following this recommends preventative ways in which the factors of influence (eg environmental) could be modified in order to reduce the risk of damage. The conservation guidelines are aimed to provide the practitioner with an indication of at what stage in the decay/soiling cycle the intervention should proceed. They identify which monument parts should have priority for treatment, prescribe suitable intervention strategies and classify the urgency of intervention. The conservation guidelines are ordered first by decay/soiling class, and then alphabetically by the *type* of decay/soiling. Using these, the practitioner should follow any recommendations regarding the direct treatment of the observed decay/soiling, and then consider whether it is feasible and appropriate to modify any of the factors of influence to reduce the future risk of damage. Any intervention undertaken should be recorded in the pro-forma and/or database. The intervention guidelines are purposefully brief, since conservation should only proceed with further specialist advice. Since most of the crosses are Listed Buildings, any conservation proposal must be submitted to Historic Scotland and advice can thus be obtained from this source. Historic Scotland now encourage conservation proposals to be drawn up within the framework of a *'Conservation Plan'* (Historic Scotland 2000b). The designed intervention guidelines are presented in Table 5.8 and in the discussion that follows this.

5.4.1 Treatment of decay and soiling

Table 5.8 Guidelines to treating decay and soiling.

INTERVENTION GUIDELINES: BIOLOGICAL SOILING TYPES					
Soiling type	**Need for intervention**	**Conditions for intervention**			**Recommended action**
		Density and distribution	**Monument part**	**Description of soiling**	
Algae	Consider intervention	*High* density, *General* distribution	Steps	The growth is considered to be a hazard due to the risk of people slipping	Remove with water and a brush. A biocide can be used as a last resort, although retreatment would be required about every two years.
Fungi	No intervention required	*High* density, *General* distribution	All parts	Fungal growth is heavy and extensive	Test to establish the presence of fungi and monitor. Fungi in itself are not a cause of material loss, but treatment could be applied for cosmetic purposes.
Higher plants	Consider intervention	*High* density growth, *General* distribution	Joints and enclaves	General weed growth	Weed when the opportunity arises. Complete the treatment by repointing the vacant joints. For re-pointing use a lime-based mortar no harder than the surrounding stone. The pointing should be left slightly recessed so that the rainwater can run off the edge of each stone.
	Intervention advised	*High* density growth, *Localised* distribution	Any monument part	Plants have woody stems	Such weeds should be removed at the earliest opportunity since they pose a risk to the structural stability of the monument.

Table 5.8 Guidelines to treating decay and soiling *(continued)*.

INTERVENTION GUIDELINES: BIOLOGICAL SOILING TYPES *(continued)*					
Soiling type	**Need for intervention**	**Conditions for intervention**			**Recommended action**
		Density and distribution	**Monument part**	**Description of soiling**	
Lichen	Consider intervention	*High* density, *Localised* distribution	Carved ornament and historical features	The lichen is causing patches of granulation, where grains detach when touched	Try to remove some of the lichen from a small test patch. If its removal is pulling off surface sandstone grains then a biocide could be used. See guidelines published by Historic Scotland in TAN 10 (Cameron et al 1997) for information on the use of biocides.
				Dense growth of a foliate lichen type is obscuring carved detail	
	Intervention advised	*High* density, *Localised* distribution	Any	The lichen is of a species which causes large pits in the stone	A biocide could be applied, and re-applied as necessary to prevent further loss of stone. See guidelines published by Historic Scotland in TAN 10 (Cameron et al 1997) for information on the use of biocides.
Moss	Consider intervention	*High* density, *General* distribution	Masonry joints and enclaves	Moss growth is dense and extensive, and it is harbouring much moisture	Remove the moss and repoint any vacant joints when the opportunity arises.

Table 5.8 Guidelines to treating decay and soiling *(continued).*

INTERVENTION GUIDELINES: NON - BIOLOGICAL SOILING TYPES					
Soiling type	**Need for intervention**	**Conditions for intervention**			**Recommended action**
		Density and distribution	**Monument part**	**Description of soiling**	
Black gypsum crust	Consider intervention	*High* intensity, *Localised* distribution	Unwashed cross parts, ie below overhanging features	The gypsum crust is visibly thick and blackened	A small sample can be removed and analysed to identify the deposit as gypsum. The crust could possibly be removed with water accompanied by gentle brushing; however, removal is generally difficult. Other methods are dependent upon the stone type.
Staining	No intervention required	-	-	-	-
Efflorescence	Consider intervention	*Moderate* or *High* intensity, *General* distribution	Areas around joints on plain masonry or simple architectural detail	Extensive and heavy distribution of efflorescing salts	Monitor the appearance and distribution of the efflorescence at different times of the year. Take a small sample to test the composition. Sodium sulphate is damaging, but sodium chloride is less of a risk. If the salts are of a damaging type, a clay poultice could be applied.
	Intervention advised	*Moderate* or *High* intensity, *General* distribution	Areas around joints on plain masonry or simple architectural detail	The monument has previously been subject to chemical cleaning	Salts deposited in the stone from stone cleaning can be very damaging and an attempt should be made to remove them immediately.

Table 5.8 Guidelines to treating decay and soiling *(continued).*

INTERVENTION GUIDELINES: NON - BIOLOGICAL SOILING TYPES *(continued)*					
Soiling type	**Need for intervention**	**Conditions for intervention**			**Recommended action**
		Density and distribution	**Monument part**	**Description of soiling**	
Particulate soiling	Consider intervention	*High* density	Unornamented facades	Where the soiling is heavy and considered to be an eyesore	Gentle water washing could help to reduce the soiling. No other cleaning method should be attempted unless the soiling poses a risk of decay (eg detaching gypsum).
			Base areas, enclaves	Soiling consists of loose particles of dirt	Remove loose particles by gently brushing.
Painted graffiti	Consider intervention	*High* density graffiti with extensive distribution	Any	Cases in which the graffiti is particularly disfiguring, or where it is encouraging further attacks, and particularly if it obscures carved detail.	Removal method depends upon stone type and condition, and the nature of the graffiti pigment. See guidelines published by Historic Scotland in TAN 18 (Urquhart 1999) for information on the treatment of graffiti. Where problems persist, consider the use of prevention strategies, eg fences or town centre surveillance systems.

Table 5.8 Guidelines to treating decay and soiling *(continued)*.

INTERVENTION GUIDELINES: GRANULAR DISAGGREGATION TYPES					
Decay type	**Need for intervention**	**Conditions for intervention**			**Recommended action**
		Severity and distribution	**Monument part**	**Description of decay**	
Crumbling	Intervention advised	*Moderate* or *High* severity, *Localised* distribution	Carved ornament and historical features	These monument parts are showing a rapid rate of material loss, ie crumbs detach when touched	Consolidant can be used as a last resort. The long-term effects of consolidants are not yet known, so a full record of the masonry should be made prior to the treatment. Alternatively, replace the original part with a carved replica, or provide the monument with a shelter, or remove it indoors.
Differential weathering	Intervention advised	*High* severity, *Localised* distribution	Carved ornament and historical features	Carved details in these areas are becoming obliterated by deep differential erosion of sandstone beds. The erosion is rapid and grains detach when touched.	Consolidant can be used as a last resort. The long-term effects of consolidants are not yet known, so a full record of the masonry should be made prior to the treatment. Alternatively, replace the stone part with a carved replica, or provide the monument with a shelter or remove it indoors.
	Consider intervention	*High* severity, *Localised* distribution	Plainer masonry	Erosion is causing deep weathered furrows which has profoundly altered the profile of the stonework.	The stone part could be replaced with an indent.

Table 5.8 Guidelines to treating decay and soiling *(continued)*.

INTERVENTION GUIDELINES: GRANULAR DISAGGREGATION TYPES *(continued)*					
Decay type	**Need for intervention**	**Conditions for intervention**			**Recommended action**
		Severity and distribution	**Monument part**	**Description of decay**	
Granulation	Intervention advised	*Moderate* and *High* severity, *Localised* distribution	Carved ornament and historical features	These monument parts are showing a rapid rate of material loss (eg material detaches when touched)	Consolidant can be used as a last resort. The long-term effects of consolidants are not yet known, so a full record of the masonry should be made prior to the treatment. Alternatively, replace the stone part with a carved replica, or provide the monument with a shelter or remove it indoors.
			Joint areas	Stone around the joint areas is severely eroded inward (to a depth of at least a few mm), particularly if the erosion inward is such that it poses a risk to the structural stability	Repoint with a lime-based mortar mix.
	Monitor	*Moderate* and *High* severity, *General* distribution	Other monument parts	Surface material is gradually being lost from the surface	Monitor regularly

Table 5.8 Guidelines to treating decay and soiling *(continued).*

INTERVENTION GUIDELINES: GRANULAR DISAGGREGATION TYPES *(continued)*					
Decay type	**Need for intervention**	**Conditions for intervention**			**Recommended action**
		Severity and distribution	**Monument part**	**Description of decay**	
Honeycombs	Intervention advised	*Moderate* and *High* severity, *Localised* distribution	Carved ornament and historical features	Honeycomb caverns are developing as a series of small pits (eg 1-2cm diameter) with dense distribution across the stone surface	Remove the affected carved masonry piece indoors. Replace the damaged stone with a recarved copy of similar stone properties.
	Monitor	*Moderate* intensity, *General* distribution	Plainer areas of masonry	Honeycomb caverns are developing as a series of small pits across the stone surface	The cause of honeycomb weathering is not known and no specific treatment has been developed. Conduct a detailed survey to record the affected parts. Regularly monitor the evolving spread and growth of the caverns, for the volume of continuing material loss may require the affected stone parts to be removed indoors in the future.
	Consider intervention	*High* intensity, *General* distribution	Plainer areas of masonry	Honeycomb caverns have matured and are numerous and extensive	When the honeycomb caverns become large (by merging) and extensively distributed, stone replacement can be considered. Remove the affected stone indoors. Replace the damaged stone with a recarved copy of similar stone properties.
Pitting	No intervention required	*High* severity	Carved ornament and historical features	Carved details in these zones have become obliterated by erosion through pitting	No intervention is recommended. Pits are not normally infilled since they are usually small and shallow, and infilling could create spots instead of pits. Usually the erosion virtually stops once the weaker spots of material have been eroded out.

Table 5.8 Guidelines to treating decay and soiling *(continued).*

INTERVENTION GUIDELINES: PLANAR DISAGGREGATION TYPES					
Decay type	**Need for intervention**	**Conditions for intervention**			**Recommended action**
		Severity and distribution	**Monument part**	**Description of decay**	
Blistering	Intervention advised	*Moderate* or *High* severity	Stone around joint areas	Blistered flakes and grains detach to the touch	If caused by hard mortar, the mortar could be replaced with a softer one.
				The monument was previously subject to chemical cleaning	Treatment with a poultice might help to remove some of the salts that are causing the blistering.
			Junction between two different stone types (eg sandstone and granite)	Blistered flakes and grains detach to the touch	Replace the problem stone with a more compatible stone type.
Delamination	Intervention advised	*High* severity, *Localised* distribution	Carved ornament and historical features	Substantial delaminating flakes are about to detach (a hollow sound exudes from the delaminating area when lightly tapped)	Apply epoxy resin to 'glue' detaching flakes. The use of epoxy resin on stonework should be minimal and localised, since moisture can become trapped behind it and the long-term effects are not known.
Flaking	Consider intervention	*High* severity, *Localised* distribution	Carved ornament and historical features	Flakes (ie <5mm length pieces) detach when touched	Consolidant could be applied to the stonework as a last resort, to stall further material loss. The long-term effects of consolidants are not well understood, thus a full record should be made of the masonry prior to treatment.

Table 5.8 Guidelines to treating decay and soiling *(continued).*

INTERVENTION GUIDELINES: PLANAR DISAGGREGATION TYPES *(continued)*					
Decay type	**Need for intervention**	**Conditions for intervention**			**Recommended action**
		Severity and distribution	**Monument part**	**Description of decay**	
Scaling	Intervention advised	*High* severity, *Localised* distribution	Carved ornament and historical features	Scales (ie >5mm length pieces) detach when touched	Consolidant could be applied to the stonework as a last resort, to stall further material loss. The long-term effects of consolidants are not well understood, thus a full record should be made of the masonry prior to treatment.
Spalling	Intervention advised	*High* severity, *Localised* distribution	Carved ornament and historical features	Rapid loss of surface material through spalling exhibiting fresh edges	Consolidant could be applied to prevent further material loss. Alternatively epoxy resin could be used to 'glue' scales about to detach. The use of either type of treatment should be minimal and localised, since their long-term effects are not known and also because epoxy resin can cause moisture to become trapped.
		High severity, *General* distribution	Any	Rapid, severe and extensive spalling across a *large* area of the monument	Such spalling cannot be treated effectively. Epoxy resin should not be used over a large surface area. Consider removing the monument indoors to stall the spalling if it is beyond repair and if valuable stonework is being lost.

Table 5.8 Guidelines to treating decay and soiling *(continued)*.

INTERVENTION GUIDELINES: FRACTURE TYPES					
Decay type	**Need for intervention**	**Conditions for intervention**			**Recommended action**
		Severity and distribution	**Monument part**	**Description of decay**	
Fissures	Intervention advised	*High* severity, *Localised* distribution	Carved ornament and historical features	Stone fragment is about to detach	Use a minimal amount of epoxy resin to 'glue' the detaching part in place.
				Fissure(s) bisect the feature	Fill with lime-based mortar immediately.
			Other monument parts	Stone fragment is about to detach	Fill with epoxy resin immediately.
	Consider intervention	*High* severity, *Localised* distribution	Other monument parts	Fissure(s) bisect the masonry	Fill with lime-based mortar when the opportunity arises.
Mechanical damage	Consider intervention	*High* severity, *Localised* distribution	Carved stone parts	Component broken into at two or more large pieces due to a recent impact	Piece together surviving large fragments with stainless steel or phosphor bronze doweling, fixed in place with epoxy resin. Fill the joins with a lime-based mortar.
				Stone broken due to a recent impact has some small fragments missing	Could consider remodelling the former profile with a lime-based mortar mixed with crushed stone to obtain a suitable colour match with the surrounding stone.
				Stone piece broken into numerous fragments due to a recent impact, in a condition beyond repair	Stone replacement. Analyse the stone properties of the broken pieces in order to find a suitable stone type for the replacement.

Table 5.8 Guidelines to treating decay and soiling *(continued)*.

INTERVENTION GUIDELINES: FRACTURE TYPES *(continued)*					
Decay type	**Need for intervention**	**Conditions for intervention**			**Recommended action**
		Severity and distribution	**Monument part**	**Description of decay**	
Mechanical damage *(continued)*	Intervention advised	*High* severity, *Localised* distribution	Carved stone parts	A stone fragment is about to detach due to a recent impact	If the detaching fragment is small, use epoxy resin to 'glue' the components together. A larger component may need to be doweled to the monument along with some epoxy resin in order to secure it in place sufficiently
			Key structural masonry	The broken piece plays a key structural role in the monument	Replace the stone with a recarved replica of matching stone type.
	Consider intervention	*High* severity, *Localised* distribution	Un-ornamented masonry, eg steps	Masonry blocks have been chipped due to a recent impact and are a safety hazard	The steps have an obvious functional role, thus re-attached chips of broken stone may not produce a sufficiently stable platform for public use. If the stone is badly fragmented it should be replaced. Alternatively, the broken pieces could be re-mortared together if they are large enough.

The data fields in the above intervention Table 5.8 can be interpreted as follows:

Decay/soiling type

All types of decay and soiling identified in the sample are listed here, grouped according to their general class.

Need for intervention

A classification of the need for intervention has been assigned based upon consideration of the specific decay/soiling type, the potential amount and rate of stone loss, the monument part affected and the available forms of treatment. The classification indicates whether or not intervention could deal with the problem, and the urgency of the intervention. Decay types that are liable to cause catastrophic episodes of material loss should be treated by immediate intervention. Other types proceed very slowly and gradually, and the intervention is thus less urgent and may be postponed until the next available opportunity. The classifications are defined as follows:

No intervention required	No treatment is necessary. In some cases options are available if the practitioner wishes to improve the appearance of the monument (eg for algae or particulate soiling).
Monitor	Monitor every 5 years if possible, in order to closely gauge the rate of the decay/soiling.
Consider intervention	Undertake treatment when the opportunity arises (eg repointing is an example of a less urgent intervention requirement).
Intervention advised	Implement appropriate intervention immediately (eg epoxy resin repair, removal of monument indoors).

Density/severity and distribution

Shows the degree of soiling density or decay severity, and the extent of surface distribution at which this intervention is appropriate.

Monument part

The practitioner will already have recorded specific monument parts as exhibiting decay/soiling and as being at risk in the pro-forma. The intervention table identifies the monument parts to which the recommended intervention pertains. Generally the carved ornament and historical features are the monument parts identified as being most 'valuable' and thus having a greater need for conservation.

Description of decay/soiling

These criteria provide the practitioner with a detailed description of at what stage in the decay/soiling cycle intervention should proceed.

Recommended action

Appropriate conservation materials and methods are described here, as researched during the literature review. Conservation should be minimal and, due to a lack of knowledge about the long-term effects of treatments, many are recommended only as a last resort. This information is intended to provide only a very brief guide. During the planning and implementation of such treatment, the services of professional stone conservators must be sought.

5.4.2 Intervention guidelines for reducing the effect of influencing factors

While conservation treatments allow reactive, remedial measures, we can also take preventative measures by focusing upon reducing the cause of the damage, ie the factors of influence. However, the options for altering such factors are few and in many cases would be considered unfeasible or too costly to implement. However, situations in which alteration of the factors of influence could be considered particularly important are if:

- The degree of stone loss is advanced and continuous.
- Severe decay has such an extensive surface distribution that it cannot be effectively treated by conservation. The blanket application of conservation materials such as epoxy resin and consolidants is not recommended due to their water-trapping properties and also because their long-term effects are not known.
- There is a high level of projected risk of stone loss from the existing factors of influence.
- The risk assessment shows the stone loss to be very strongly linked to a *particular* factor of influence.

Reducing environmental effects

Options for reducing the effects of environmental variables are limited, and are most likely to arise due to the broader aims of other development projects such as the redevelopment or enhancement of town centres. It is possible that the land-use type around the base of a cross could be changed, for example a road could be changed to a pedestrian precinct (as at Aberdeen Castlegate in the 1980's). Another method to counter high emission levels from motor vehicles would be to change the adjacent road scheme in order to reduce the flow of traffic. Particular mention must be made here of the risk of massive mechanical damage to which crosses sited in the middle of road junctions are exposed. The sample data yielded no statistically significant relationship regarding this, although the cross at Cupar was recently knocked over and parts were broken due to an impact by a heavy goods vehicle. It is only a matter of time before similar incidents occur elsewhere, especially with road traffic constantly increasing. In the sample, Cupar, Ochiltree and, to a lesser extent, Turriff cross are all currently at risk from this. For such crosses which are sited in the middle of a road junction with heavy goods vehicles and busy traffic passing directly on more than one side, re-siting to a location with a more favourable environment could be considered if they do not stand upon their original site. Turriff cross indeed does not occupy its original site; Cupar cross is located a few yards from its original position at a junction which is uncomfortably narrow for the large vehicles which pass through; Ochiltree cross *does* stand upon its original site although the present construction dates from only 1836. However, note that even if a cross is not upon the original site of its construction, its removal could raise local objections, since its existence throughout living memory upon a particular site may have come to be regarded as integral to the townscape and local heritage. As such, the removal of a monument always has the potential to incite emotional responses. Removal indoors should only be a last resort, if the monument is in an advanced and increasing state of decay beyond repair. Recent cases in which crosses have been removed indoors or into museums since the 1950's are at Thurso, Kirkwall and Fowlis Wester. Note that these crosses had already been re-sited during their history, all were suitably small-scale structures that could be easily moved to an indoor location, and in all cases a replica was erected upon the site from which they had been removed.

Reducing the effects of climatic factors

The only way of reducing the effects of climatic factors is to provide an enclosed shelter or to remove the monument indoors to allow humidity and temperature to be controlled. Shelters have been erected over certain Pictish carved stones in Scotland (eg Sueno's stone in Moray and Eassie in Angus). However, this method of preservation would be less applicable to market crosses since they tend to be much less old, and they are composite monuments which have a tradition of having their component parts replaced piecemeal when the old parts have deteriorated. The provision of glass shelters can also introduce a new set of problems as their interiors tend to generate 'greenhouse' conditions. Additionally, shelters can be visually intrusive, and the presentation of a monument as if it were an antiquity in a museum case could alienate the viewer and the local inhabitants, particularly if public access were denied (see discussion in Fry 1995). For these reasons, the complete enclosure of market crosses using these methods is not recommended. For reasons of preserving townscape and historical continuity, as well as the expense, the removal of a monument should generally be presumed against and, as described above, should be a last resort.

Reducing the adverse effects generated by monument properties

The data analysis showed that monument properties themselves had a significant effect upon several aspects of decay and soiling patterns. It would not be ethical to alter the architectural characteristics of monuments, since these are elements fundamental to the perceived value. Stone properties such as grain size and the presence of inclusions are factors that cannot be altered unless the deterioration is such that the stone must be replaced. However, since replacement stone should match the properties (especially porosity) of the surviving context, there may be little opportunity for the selection of a stone with more durable properties.

Reducing adverse effects from previous intervention

Section 4.4.2 discussed the effects due to conservation materials observed in the sample. There was generally little evidence in the sample of actual damage incurred due to the application of unsuitable conservation materials. However, the dangers are widely acknowledged and it is therefore recommended that such materials should be removed from the crosses and replaced with suitable alternatives. Thus mismatched stone replacements could be removed and replaced again with a more suitable type. Repointing and plastic repairs made with Portland cement or hard mortar ought to be replaced with a soft, lime-based mortar. Where iron dowels have been used to rejoin cross components, these should be replaced with stainless steel or phosphor bronze dowels which will not rust. As the long-term effects of modern consolidants and epoxy resins are not yet known, their performance on crosses ought to be regularly monitored. The surface profile of existing resin repairs should exhibit minimal propensity for trapping water, ie they should not form a 'lip' in which water can collect. One cross in the sample has been subject to chemical cleaning which has left an unsightly and damaging salt residue. Should any further such problems be encountered in the future, poulticing could help to remove some of the salts. Fenced crosses occasionally have the railings bedded in the steps. This situation proved detrimental to the cross at Inveraray in 1964, when a vehicle reversing next to the cross backed into the railings causing them to tear up part of the steps. It is recommended that railings should be repositioned when the opportunity arises such that they are not bedded in the fabric of the monument. Finally, a significant amount of mechanical damage has occurred to crosses that have been subject to removal in the past. Stringent measures should be exercised to safeguard the stonework during any future removal operations. For the recent, successful removal indoors of the Fowlis Wester cross-slab (1991), the base area was first subjected to a small-scale archaeological excavation, then the slab was wrapped with padding in situ, enclosed in a wooden box and lifted by crane out of its setting. However, a recent incident of damage occurred during the dismantling of Dundee cross for the purpose of its removal (1998). When attempts were made to detach the Dundee shaft from the pedestal, the shaft began to split due to existing decay at an angle of 70 degrees to the bedding alignment. In order to avoid further damage the shaft had to be sawn at the top of the fault. To make up for this, a new lower, short stone section will be inserted when this cross is re-erected (Duthie, Dundee City Council Planning and Transportation Dept 1999, pers comm). This incident demonstrates that even careful removal methods can place stress upon existing weaknesses in the stone, and this is an additional reason why proposals to re-site monuments ought to be carefully considered.

5.5 Summary of the developed risk assessment

For the purposes of the present research, risk was defined as the expected degree of stone loss. The sample risk assessment identified many factors that significantly influence decay and soiling from sources including the environment, climate, architectural characteristics, stone properties and intervention. All significant relationships found between decay/soiling types and various factors of influence were systematically discussed. Data for geographic climatic averages was judged to have a limited influence upon variations in the stone decay/soiling patterns within Scotland. These climatic factors were therefore excluded from the factors of influence listed for use in the practitioners' risk assessment. It was necessary to add in further hypothesised factors of influence for the practitioners' use that had not been proved as significant in the statistical testing. The literature review had indicated a number of important factors in stone decay/soiling, which were not shown as significant in the sample due perhaps to low frequencies, unavoidable confounding factors and stone properties which could not be measured during the research. Most of the resulting factors of influence that are relevant to the practitioner refer to the environment or monument characteristics.

The risk assessment methods applied to the sample involved adaptation of the conventional risk formula. The practitioners' risk assessment had to be further adapted from this to include considerations pertaining to individual monuments, ie the decay rate and the perceived 'value' of the stonework. A potential practical difficulty with the practitioners' risk assessment is that the calculation of the extent of surface area covered by each decay/soiling type is likely to be quite time-consuming. Resources may not always enable this type of detailed survey and risk assessment. However, if predictions are to be accurate they must be based upon accurate existing data. The designed risk assessment is a model, a system for prediction, and time will reveal the extent to which the design is valid. In particular, it was discussed that the effect of the influencing factors is complex and difficult to quantify absolutely in terms of the consequent degree of stone loss.

A major problem in predicting future decay/soiling patterns is that there is simply not enough known about the trajectories to enable prediction of the variation of rates within a cycle of decay or soiling, or even to estimate the overall timescale required for the cycles. At present, we can only talk in very general terms about whether or not decay/soiling tends to increase and whether or not it is self-limiting. The extent to which the rates of some decay/soiling types accelerate or decelerate is unclear. However, where previous survey data exists, the method of calculating the future surface extent of decay/soiling allows the rate to be incorporated. An existing hypothesis is that the decay types to which masonry is susceptible are controlled by the stone type and the way in which it is used, while the decay *rate* is determined by the environment (eg Yates et al 1999). This is likely to be true for certain decay types, eg pitting and differential weathering. However, most of the *significant* relationships found between the environment and decay/soiling in the sample refer to the degree of biological soiling types rather than to decay types. This could be partly explained by the low frequencies of certain decay types in the sample and a lack of variation in the intensity or distribution patterns exhibited by some. Further research into decay/soiling rates is required in the future, and should be enabled once serial data is accumulated through regular surveys and risk assessments. Such knowledge, in relation to on-site factors of influence, requires systematic, long-term programmes of monitoring and recording. The designed risk assessment method provides a tool that can enable this.

The effect of modern conservation materials showed no adverse impact upon the stonework in the sample (eg epoxy resin repairs, consolidants and the effects of juxtapositioning incompatible stone types). This could be partly due to the low frequency of these types of conservation or the delayed nature of the side effects, or it could be because the conservation treatments have after all been suitable and compatible with the stone context. However, that it not to say that these materials will not cause problems in the future, and their performance will be reflected in future risk assessment calculations.

In conclusion, a larger sample size, the means to measure a greater variety of stone properties and the collection of micro-climate data at the site of each cross are all ways in which an improved data set might have been obtained for the statistical testing and subsequent risk assessment design. However, these options were not feasible within the framework and resources of the current research. The results of the developed risk assessment are encouraging and suggest that there is scope for wider application of risk assessment methods within the field of study of monument degradation.

Recommendations for the interpretation and promotion of Scottish market cross to visitors are presented in Appendix E. These recommendations take the research into the realms of heritage interpretation and presentation, thereby helping to justify the preservation and conservation of this monument type, and contributing to a more comprehensive management framework. Market crosses have value historically, culturally, architecturally, socially and as a heritage asset. Their survival today enhances the townscape of historic burghs and, wherever possible, their preservation on these sites should be favoured. Smaller towns in Scotland have undergone significant change in recent decades, and tourism and recreation is a growth area which can offer new opportunities to historic burghs. The historical assets of the Scottish burgh, including the market cross, could be further promoted, and methods for this can be found in Appendix E.

6. CONCLUSION

6.1 Discussion of the research aims and objectives

In accordance with the research aims, the data collection and analysis have improved the level of existing knowledge about the scale and rate of weathering and soiling patterns on market crosses, and the effects of previously applied intervention. Increased knowledge has been imparted regarding the relationships between the condition of market crosses and various causal factors. The value of applying risk assessment techniques to predict the degradation of monuments has been explored and offers potential for their future care. An improved management framework has been presented through the design of methods for the recording, assessment, care and promotion of market crosses. The achievement of specific objectives in the research is discussed below.

6.1.1 Development of a mapping methodology

A system for classifying decay and soiling types and their severity was developed from the technique pioneered by the NORMAL system (1988) and Fitzner et al (1989; 1992; 1995). A pro-forma and relational database were also created in order to record and analyse the mapped data. The mapping and recording methods were applied during field visits to 27 sampled crosses. The recording method was comprehensive and rigorous, and included consideration of historical intervention factors not incorporated in analyses by other researchers. The intervention data recorded in the database consisted of all information that could be gathered from archives regarding the resiting of the crosses, replacement of component parts, conservation attempts, and changes in land-use type and environment to which each cross had been subject in the past. With the aid of the classification criteria (Tables 3.2 and 4.14) and illustrations of decay and soiling types (Plates 3.1-3.28), the methodology could be replicated by another practitioner with limited geological expertise and without any 'high-tech' measuring equipment. However, due to the high level of detail recorded, the mapping phase of the exercise was necessarily lengthy, requiring up to a day to complete for each cross, or even two days for large, tower-based crosses. The practitioner may well not have this time available to complete a survey. If available, the use of a hand-held computer could speed up the recording process, or digital-mapping methods could even be used on-site. Drafted mappings provide an effective means of recording the exact distribution and extent of observed decay/soiling and can allow changes in condition to be monitored and studied in the future. Therefore, whenever time is available practitioners should seek to convey the stone condition data in a mapping.

6.1.2 Current condition of Scottish market crosses

A basic level of data was collected from national archives and publications, and recorded for all of the surviving crosses. A representative sample of 27 crosses was selected with regard to certain factors of environment, climate, monument properties and intervention. An increased and exhaustive level of data was collected and recorded for the sampled crosses from the archived and published sources consulted. This second-hand data relates mainly to the architectural characteristics, history and intervention of these crosses. In order to complete the record of the sampled crosses and to allow the data analysis and risk model development, the sampled crosses were then each subject to a detailed field survey. The condition of each facade of the monuments was drafted in detail, and decay and soiling were classified and described in detail in the pro-forma and database. Photographic surveys undertaken also contribute towards the creation of a complete record of the current condition of the sampled crosses. This level of detail is generally not found in any existing archived records. The collected data was subject to a systematic programme of analysis by interrogating the relational database. Descriptions were provided of the frequencies, central tendencies and spread of a variety of market cross characteristics. Analyses were then performed for each decay and soiling type to establish where statistically significant relationships existed between these and a variety of weathering agents (ie factors of environment, climate, monument properties and intervention). These relationships were systematically discussed in relation to the formulated hypotheses, and the factors that were considered relevant were incorporated in the subsequent risk assessment of the sampled crosses. Generally the condition of the crosses can be linked to various factors arising due to their environment, architectural characteristics, stone properties and previous interventions. Some of the crosses are decaying rapidly and currently require conservation (see Table 4.9 and fieldwork reports in Appendix D).

6.1.3 Risk assessment of the decay and soiling of market crosses

The probability of occurrence and consequent loss of stone material were quantified for each variable pair which had generated a statistically significant relationship in the data analysis (ie each decay/soiling type and corresponding potential factor of influence). These quantified values were multiplied to give a value for risk, which could then be classified according to a five-point scale. This indicated the level of risk of stone loss amongst the sample due to various contributing factors. The sample model inferred the risks that could be expected within the population of market crosses as a whole. In order to enable a risk assessment to be undertaken by practitioners upon *individual* crosses in the population, it was then necessary to further modify the calculation method. A formula and digitised pro-forma were created to allow a means of calculating risk based upon the current characteristics of any visited cross and its environment. The pro-forma also provides an effective means for storing the field data and risk assessment data. The conventional formula for risk calculation had to be adapted for the practitioner, to include additional factors. These were the perceived 'value' of the stonework, the existence of any weathering agents previously shown in the sample model to be significant, the depth of the decay and the predicted surface extent of the decay/soiling in ten years time. A difficult factor to quantify for the risk equation is the expected advance of decay/soiling. This is because the rate of decay and soiling on a stone surface has previously been largely unresearched and unrecorded. Archived photographs of market crosses dating from the 1800's onwards were found to be of very limited value in attempting to establish this in comparison to the present stone condition. This was due to their frequent poor clarity and a lack of close-range photography of the subject in general. However, in cases where no previous data exists on the extent of decay and soiling, the formula could still be used to calculate the immediate risk. The designed practitioners' method therefore allows the prediction of risk of increasing stone loss from various decay/soiling types, based upon the characteristics observed at each monument in conjunction with some of the risk data from the sample model. It is a potentially powerful tool which could improve and standardise systems of monument management. Its regular application would also incur the monitoring and measurement of the advance of decay types across stone surfaces. As such, it could additionally allow a means for investigating decay rates.

6.1.4 Intervention criteria, methods and materials

Intervention guidelines were provided, based upon information obtained from the literature review and upon the observed effectiveness of conservation treatments in the sample. The criteria were designed to correspond with classifications assigned during the risk assessment. It is intended that practitioners should refer to the intervention guidelines following the risk assessment of a monument, undertake the prescribed course of action where appropriate and record the intervention in the risk assessment pro-forma. The *Conservation* guidelines (Table 5.8) lists each decay and soiling type with corresponding directions for its direct treatment. The table includes criteria to advise the practitioner about stages in the decay or soiling advancement at which conservation is appropriate. These criteria are based upon the severity and extent of the decay or soiling, and the type of monument parts affected. The criteria have additionally been classified according to the urgency or need for intervention. A second set of guidelines was presented for reducing the effect of damaging factors of influence. The options for this are rather more limited and in many cases may be considered to involve too much expense. However, they suggest measures that could have a greater preventative effect, since they allow the perceived sources of the damage to be modified, as opposed to the *Conservation* guidelines which offer suggestions for the remedial treatment of decay and soiling types on the stonework. In addition to these guidelines, a further section (Appendix E) offers suggestions for how market crosses might be interpreted and integrated within broader schemes to enhance historic burgh centres for the public.

6.2 Summary of significant findings

In accordance with the general hypothesis that underpinned the research, the data analysis generated a large body of evidence to suggest that stone condition is related to material and architectural properties, factors of environment, and intervention. Specific, significant findings from the data collection and analysis of the sampled market crosses can be summarised as follows:

- Market crosses have undergone an extremely high level of previous intervention in relation to other monument types. This intervention has consisted of frequent episodes of resiting and the replacement of component parts, more so than attempts to conserve the existing stone. The act of re-siting monuments introduces opportunities for mechanical damage. The insertion of replacement parts into some monuments could not be confirmed as causing any damaging effects in the study, but the effects are widely appreciated.
- The character and quality of archived historical images (photographs and drawings) are very limited for the purposes of gauging decay and soiling rates. However, they are useful for providing evidence of interventions (eg resiting and replacement of component parts) and for the dating of these.
- No relationship was apparent between coastal proximity and salt weathering of the stone. Indeed, salt decay patterns in the sample often did not support the hypotheses with regard to the exposure of the monuments to the expected salt sources (ie motor vehicle emissions, atmospheric sea-salt and de-icing salts). Existing knowledge of salt decay is dependent upon the particular stones previously researched with regard to this. Salt decay patterns are influenced by some stone properties (eg porous characteristics). It follows that salt decay patterns are therefore dependent upon the particular properties of the stone selected for building and carving. It is likely that better quality stone has previously been selected for monuments, as opposed to less significant buildings (eg poorer quality stone might be more used for building some dwellings). Therefore, the salt weathering of monuments might show different patterns from those more widely appreciated. Another important point is that sandstones have very variable qualities, therefore the specific weathering patterns vary and are difficult to predict exactly.
- Crosses located on pavements and roads generally exhibit altered weathering and soiling patterns, in contrast to those sited on grassed areas and in more rural locations. This is presumed to be reflective of their proximity to motor vehicle emissions. However, the *amount* of motor traffic passing on nearby roads shows no significant relationship to stone decay in the sample.

- Climatic variations within Scotland show no clear relationship to the observed weathering and soiling patterns. The differences may be too slight to exhibit an influence, and microclimate variations may be more relevant to stone condition particularly with regard to the amount of moisture created on the monuments.
- Factors of architectural design and the position of stone components within monuments are significant in influencing the patterns of weathering and soiling upon individual monuments. This is often due to the degree to which the different monument parts are dealt, and retain, moisture. For example, zones exposed to greater rainwash, and shaded parts from which evaporation is lower, experience greater algal growth. Built components with vacant masonry joints collect more soil and moisture, and exhibit greater moss, higher plants and particulate soiling. Additionally, better-quality stone may often have been selected for the more highly carved monument parts, which generally exhibit less pitting and fractures. Other trends regarding weathering patterns on particular monument parts were discussed in Sections 5.2.6 and 5.2.7.
- The orientation of monument facades shows no significant relationship to the occurrence of biological soiling. Particular facades sheltered by nearby walls did show denser algal growth. However, the direction towards which the facades are pointing, and the corresponding differences which therefore prevail with regard to the exposure of different facades to factors of temperature and moisture, do not appear to have had much effect upon the biological soiling patterns observed across individual monuments in the sample. Instead, architectural characteristics and land-use were found to have more influence upon the patterns of biological soiling.
- In most cases the date of carving of stone components is not directly proportional to the type, extent and severity of weathering and soiling exhibited. With the exception of pitting, delamination and mechanical damage, decay rates and patterns are influenced to a greater extent by the other factors at play in the sample.
- The use of previous intervention materials (eg stone cleaning chemicals, Portland cement, epoxy resin and iron cramps) has caused some damage to the stonework; however, these materials exhibited very low frequencies in the sample. The use of more recent types of conservation treatments on market crosses (ie consolidants, water repellents and biocides) has been infrequent, or at least recorded instances are very low.
- Despite their central, urban location, market crosses exhibit fairly low levels of vandalism and graffiti. The crosses located in rural settings showed no vandalism or graffiti at all, which could be explained by their less readily accessible sites.

6.3 Originality and benefits of the research

The research has advanced the state of knowledge with regard to the following:

- The developed recording method (ie pro-forma and relational database) is a unique design, tailored to the changing characteristics of market crosses in terms of their composition and environment.

- The research represents the first systematic study of the condition and environment of market crosses. The degree of detail in the recording and analyses made for the sampled monuments is unprecedented, and will form a 'base-line' for the future monitoring of their condition and the rate of decay and soiling.

- The risk assessment model is an original technique developed by the candidate. It is based upon risk assessment in other industrial and corporate spheres, and adapted to the nature of the collected data types in the sample. Risk assessment models developed in other fields are mostly inappropriate for predicting the degradation of monuments, as they incorporate personal and financial risks as significant elements and they deal mostly with episodes and accidents. Additionally, risk assessments are often undertaken in the design phase of a project, with a view to incorporating the benefits of such foresight into the system design. We cannot re-design our historical monuments, rather we must design our intervention for optimum preservation of these assets. Furthermore, the events of stone degradation contrast with the subjects of existing industrial and corporate models since stone decay usually advances over a long period of time, the impact is often delayed, and the agents interact throughout the process. The developed risk assessment method is therefore a unique design.

- An understanding of the scale and processes of decay and soiling on this monument type and the factors contributing to these has been provided by the analysis of the collected data. This will allow future predictions to be made regarding the dynamics of monument condition in various environments, and is thus an original contribution to knowledge in the field of conservation. The trends revealed by the data analysis could be used to infer those which could be expected at other market crosses, and indeed at other similar monument types.

Benefits offered by the research are an increased understanding of the scale and sources of risks to market crosses, and a methodology which could allow improved prediction of weathering and soiling patterns. The timing of intervention can be difficult to judge; however, the developed intervention criteria attempts to address this. In particular there are certain decay types that appear to proceed gradually prior to causing a sudden episode of stone loss from the surface, eg spalling. It can be difficult to predict when such damaging episodes will occur. However, systematic monitoring, reference to the supplied intervention criteria and modification of the exposure to factors of influence could help to prevent this type of degradation. In addition to correct intervention timing, it is important that appropriate conservation material and methods are used. This ought to be informed by monitoring the effects of conservation upon monuments, and the application of conservation treatment should also be adequately documented. These needs could be achieved through the regular application of the designed risk assessment in which the advance of decay and soiling are quantified and logged. Generally, an improved management strategy could be generated in the future by application of the designed recording and assessment method, and by implementation of the suggestions for the promotion of market crosses outlined in Appendix E. The research as a whole has breathed some life into the study of market crosses which has remained static for some time. It should serve to justify their historical importance, their current value as an element of heritage and townscape, and their relevance to current research into stone weathering and conservation.

6.4 Areas for further research

Decay and soiling rates

Decay and soiling generally advance over lengthy periods of time. The cyclical nature of certain decay types, eg the increase of spalling to produce multiple delaminating layers, has an unresearched time factor, which is likely to vary according to the specific circumstances at each monument. The act of regularly monitoring and recording the condition of monuments using the designed risk assessment pro-forma will incidentally allow a greater understanding in the future of the rate and trajectory of decay and soiling types.

The effects of various conservation materials

Because conservation materials also weather over fairly lengthy periods of time, their long-term performance and effect upon the stonework is not fully understood. Again systems of monitoring the applied conservation materials could allow improved knowledge about this, and such research could be undertaken in conjunction with investigating decay and soiling rates.

The causes of stone decay

The root causes of stone decay are still not fully understood. The present research allowed the identification of a series of statistically significant relationships between decay/soiling types and factors of potential influence; however, the extent to which these represented a cause-and-effect relationship was not always clear. The results of future observations and assessments could serve to confirm or refute the links suggested in the present research. Future work could also allow the examination of other variables that did not arise or exhibited very low frequencies in the sample. Since the study of stone weathering is still in relative infancy and some environmental variables are liable to fluctuate over time, eg the amount and nature of pollutants from emissions, there is scope for continuing research in this area.

Risk modelling

There is scope to develop further the application of risk modelling to monument degradation. The risk assessment model designed in this research could be developed and refined through the procurement of more data to link factors of influence to decay and soiling patterns. Additionally, if these studies were made over a longer time period this could allow greater information regarding weathering rates, which would allow more accurate prediction of its advance and of the corresponding risk of stone loss.

Market cross studies

Historical studies could attempt to examine the origins and evolution of market crosses in more depth and by reference to increased sources of evidence. This is currently still an area of uncertainty and speculation. Additionally, further fieldwork could be undertaken to expand upon the market cross data obtained in the present survey. Only twenty-seven of the crosses were examined in detail during the research. Data for the condition of the remainder could be gathered to complete the record. This would increase knowledge regarding the sets of circumstances in which they are vulnerable to decay, or conversely contexts in which they have survived well.

6.5 Publications and other presentations from this research

Thomson, L 1998. 'Scottish Mercat Croces. Their Spiritual And Secular Significance'. In Fladmark, J M (ed) *In Search Of Heritage: As Pilgrim Or Tourist?* Proceedings of the Robert Gordon University Heritage Convention 1998. Donhead Publishing Ltd, Shaftesbury, Dorset, 461-472.

Thomson, L and Urquhart, D 1999. 'Scottish Market Crosses: Towards The Development Of A Risk Assessment Model'. In Jones, M S & Wakefield, R D (ed) *Aspects Of Stone Weathering, Decay And Conservation.* Proceedings of the Stone Weathering and Atmospheric Pollution Network Conference (SWAPNET), 15-17 May 1997, The Robert Gordon University, Aberdeen, 138-146.

Thomson, L 1999. *Scottish Market Crosses: Understanding The Impacts For Improved Care.* Presentation delivered at the Stone Weathering and Atmospheric Pollution Network Conference (SWAPNET), 13-14 May 1999, University of Wolverhampton. (Publication to follow in 2000).

REFERENCES

Adams, I H 1978. *The Making Of Urban Scotland.* Croom Helm Ltd, London.

d'Alviella, G 1914. *Les Perrons De La Wallonie Et Les Market-Crosses De L'Ecosse.* Hayez, Brussels.

Andrew, C, Young, M. and Tonge, K (1994). *Stone Cleaning: A Guide For Practitioners.* Technical Conservation, Research and Education Division, Historic Scotland and The Robert Gordon University.

Ansell, J 1992. 'Reliability: Industrial Risk Assessment'. In Ansell, J and Wharton, F (ed) *Risk Analysis, Assessment and Management.* John Wiley and Sons, Chichester, 105-122.

Arnold, T 1885. *History Of The Cross Of Edinburgh Commonly Called The Mercat Cross.* William Paterson, Edinburgh.

Ashurst J and Ashurst N 1988. *Practical Building Conservation - English Heritage Technical Handbook. Volume 1: Stone Masonry.* Gower Technical Press, Aldershot.

Atkinson, K B 1980. *Developments In Close-Range Photogrammetry - 1.* Applied Science Publishers Ltd, London.

Baer, N S and Snethlage, R 1997. 'Introduction'. In Baer, N S and Snethlage, R (ed) *Saving Our Architectural Heritage: The Conservation Of Historic Stone Structures.* Dahlem Workshop Report, Freie Universität, Berlin, 1-6.

Baldwin, J 1997 (2nd edn). *Exploring Scotland's Heritage: Edinburgh, Lothians And Borders.* RCAHMS, The Stationary Office, Edinburgh.

Ball, J and Young, M E 2000. 'A Simple Technique For Rapid Field Assessment Of Stone Decay On Buildings'. In Fassina, V (ed) *Proceedings Of The Ninth Internation Congress On Deterioration and Conservation of Stone*, 19-24 June 2000, Venice, 13-21.

Ballard, G M 1992. 'Industrial Risk: Safety By Design'. In Ansell, J and Wharton, F (ed) *Risk Analysis, Assessment And Management.* John Wiley and Sons, Chichester, 95-104.

Beaton, E 1992. *Ross and Cromarty: An Illustrated Architectural Guide.* RIAS.

Beaton, E 1996. *Caithness: An Illustrated Architectural Guide.* RIAS, the Rutland Press.

Bell, E, Dowding, P and Cooper, T P 1994. 'The Biodeterioration Of Granite'. In Bell, E and Cooper, T P (ed) 1994. *Granite Weathering And Conservation.* Proceedings of a Conference held at Trinity College Dublin, September, 1993. The Director of Buildings' Office, Trinity College, Dublin, 28-32.

Bell, D 1997. *The Historic Scotland Guide To International Conservation Charters.* Historic Scotland, Edinburgh.

Birse, E L 1971. *Assessment Of Climatic Conditions In Scotland. 3. The Bioclimatic Sub-Regions. Map And Explanatory Pamphlet.* The Macaulay Institute for Soil Research, Aberdeen.

Bjordal, E N 1987. 'Risk From A Safety Executive Viewpoint'. In Singleton, WT and Hovden, J (ed) *Risk And Decisions.* John Wiley and Sons, Chichester, 41-45.

Black, W G 1928. *The Scots Mercat 'Cross': An Inquiry As To Its History And Meaning.* William Hodge and Co Ltd, Glasgow and Edinburgh.

Blythe, F G H and de Freitas, M H 1984. *A Geology For Engineers.* Edward Arnold, London (7th edn).

Boreland, J 1997. Personal communication. RCAHMS.

Bravery, A F and Jones, S C 1977. 'Occurrence Of Biological Growths On Concrete Dams In North Scotland'. Unpublished paper, summarised in *Biodeterioration Society Newsletter 3.* Princes Risborough Laboratory, Department of the Environment.

BRE 1989. *The Assessment Of Wind Loads. Part 1: Background And Method.* BRE Digest 346, 2-5. BRE, Department of the Environment, HMSO.

Brehmer, B 1987. 'The Psychology Of Risk'. In Singleton, W T and Hovden, J (ed) *Risk And Decisions.* John Wiley and Sons, Chichester, 25-39.

Bristow, I 1990. 'An Introduction To The Restoration, Conservation And Repair Of Stone'. In Ashurst , J and Dimes, F G (ed) *Conservation Of Building And Decorative Stone Vol 1.* Butterworth-Heinemann Ltd, London, 1-18.

Britton, J 1807. *The Architectural Antiquities Of Great Britain Vol I.* London.

Browne, S 1994. 'Heritage In Ireland's Tourism Recovery'. In Fladmark, J M (ed) *Cultural Tourism.* Papers presented at the Robert Gordon University Heritage Convention 1994, Donhead Publishing Ltd, London, 13-25.

Buchanan, T 1983. *Photographing Historic Buildings.* RCHME, HMSO, London.

Burns, J A 1985. 'Photogrammetry And The Historic American Building Survey/Historic American Engineering Record, National Parks Service'. In American Society of Photogrammetry *Close-Range Photogrammetry And Surveying State-of-the-Art.* Proceedings of workshop of the American Congress on Surveying and Mapping, 9-14 September 1984, 432-437.

Butlin, R N 1989. 'Acid Deposition And Stone'. *Structural Survey* Vol 7, no 3, 316-321.

Calder-Ross, J 1892. 'The Market Crosses Of Scotland'. *Scottish Notes And Queries*, Nov 1892, 88-89.

Cameron, S, Urquhart D, Wakefield, R. and Young, M 1997. *Biological Growths On Sandstone Buildings. Control and Treatment.* Technical Advice Note 10. Technical Conservation, Research and Education Division, Historic Scotland, Edinburgh.

Cameron, D 1998. 'New Pilgrims Old Towns. The Historic Burghs Of Scotland'. In Fladmark, J M (ed) *In Search Of Heritage: As Pilgrim Or Tourist?* Proceedings of the Robert Gordon University Heritage Convention 1998. Donhead Publishing Ltd, Shaftesbury, Dorset, 445-460.

Close, R 1992. *Ayrshire And Arran: An Illustrated Architectural Guide.* RIAS.

Coe, J A, Sherwood, S I, Messerich, J A, Pillmore, C L, Andersen, A and Mossotti, V G 1992. 'Measuring Stone Decay With Close Range Photogrammetry'. In Rodrigues, J D and Henriques, F. and Jeremias, F T (ed) *Proceedings Of The Seventh International Congress On Deterioraton And Conservation Of Stone.* Lisbon, Portugal, 15-18 June 1992, 917-926.

Cooper, D and Chapman, C 1987. *Risk Analysis For Large Projects: Models, Methods And Cases.* John Wiley and Sons, Chichester.

Council of Europe 1975. *The European Charter Of The Architectural Heritage.* Amsterdam, October 1975.

Council of Europe, 1985. *Convention For The Protection Of The Architectural Heritage Of Europe.* Granada, 1985.

Dallas, R W A 1980a. 'Architectural And Archaeological Recording'. In Atkinson, KB (ed) *Developments In Close-Range Photogrammetry - 1.* Applied Science Publishers Ltd, London, pp81-116.

Dallas, R W A 1980b. 'Surveying With A Camera: Rectified Photography'. *Architects Journal* 171, no. 8, 395-399.

Dallas, R 1980c. 'Surveying with a Camera: Photogrammetry'. *Architects Journal* 171, no. 5, 249-255.

De Leo, F, Criseo, G and Urzi, C 1996. 'Impact Of Surrounding Vegetation And Soil On The Colonisation Of Marble Statues By Dematiaceous Fungi'. In Riederer, J (ed) *Proceedings Of The Eighth International Congress On The Deterioration And Conservation Of Stone Vol 2.* Berlin, 30 Sep-4 Oct 1996, 625-630.

Dennison, E P and Stones J 1997. *Historic Aberdeen: The Archaeological Implications Of Development.* The Scottish Burgh Survey Series. Historic Scotland in association with Scottish Cultural Press.

Department of the Environment 1990. *Acid Deposition In The United Kingdom 1986-1988.* Third Report of the UK Review Group on Acid Rain.

Dimes, F G 1990. 'Determination Of A sample'. In Ashurst , J and Dimes, F G (ed) *Conservation Of Building And Decorative Stone Vol 1.* Butterworth-Heinemann Ltd, London, 150-2.

Douglas, R 1936. *Market, Other Crosses In Moray.*

Dowman, I J and Scott, P J 1980. 'Photogrammetric Theory, Techniques and Problem'. In Atkinson, K B (ed) *Developments In Close-Range Photogrammetry - 1.* Applied Science Publishers Ltd, London, 15-38.

Drummond, J 1860-1. 'Notice Of Some Stone Crosses, With Especial Reference To The Market Crosses Of Scotland'. *Proceedings Of The Society Of Antiquaries For Scotland* 4, 86-115.

Dukes, W H 1972. 'Conservation Of Stone: Causes Of Decay'. *The Architects' Journal Information Library,* Vol 156, 23 August, 429-432.

Dunbar, J G 1966. *The Historic Architecture Of Scotland.* B T Batsford Ltd, London.

Dunbar, J G 1976. 'The Organisation Of The Building Industry in Scotland During the Seventeenth Century'. In *'Building Construction In Scotland: Some Historical And Regional Aspects'.* Scottish Vernacular Buildings Working Group, Edinburgh and Dundee, 7-15.

Duthie, N 1999. Personal Communication. Conservation Officer, Planning and Transportation Department, Dundee City Council.

Everitt, A 1976. 'The Market Towns'. In Clark, P (ed) *The Early Modern Town: A Reader.* Longman, London, 181.

Ewan, E 1990. *Townlife In Fourteenth-Century Scotland.* Edinburgh University Press.

Fetterman, M 1985. 'Photogrammetry For Architecture And Historic Preservation'. In American Society of Photogrammetry *Close-Range Photogrammetry And Surveying State-of-the-Art.* Proceedings of workshop of the American Congress on Surveying and Mapping, 9-14 September 1984, 429-431.

Fisher, I 1996. Personal Communication. RCAHMS.

Fitzner, B and Kownatzki, R 1989. 'Studies On Natural Stone Monuments - Methodology And Examples'. In *Science, Technology And European Cultural Heritage: Proceedings Of The European Symposium.* Bologna, Italy, 13-16 June 1989. Butterworth-Heinemann, Oxford, 930-934.

Fitzner, B, Heinrichs, K and Kownatzki, R 1992. 'Classification And Mapping Of Weathering Forms'. In Rodrigues, J D and Henriques, F, and Jeremias, F T (ed) *Proceedings Of The Seventh International Congress On The Deterioration And Conservation Of Stone.* LNEC, Lisbon, Portugal, 15-18 June 1992, 957-968.

Fitzner, B, Heinrichs, K and Volker, M 1995. 'Stone Deterioration Of Monuments In Malta'. In *Preservation And Restoration Of Cultural Heritage: Proceedings Of The LCP Congress.* Montreux 24-29 September, 89-100.

Foramitti, H 1972. 'Classical And Photogrammetric Methods Used In Surveying Architectural Monuments'. In UNESCO *Preserving And Restoring Monuments And Historic Buildings.* Paris, 67-81.

Fraser, G M 1908. 'The Market Cross Of Aberdeen'. *Scottish Historical Review*, Volume V. James Maclehose and Sons, Glasgow, 177-180.

Friar, S 1991. *The Batsford Companion To Local History.* B T Batsford Ltd, London.

Fry, M F 1985. 'The Problems Of Ornamental Stonework - Lichen'. *Stone Industries* 20, 2, March, 22-25.

Fry, M F 1995. 'Ravages Of Time. The Debate On Protecting Outdoor Stone Carving In The North Of Ireland'. *Ulster Local Studies*, Vol 17 No. 1, Summer 1995, 7-22.

Gammack, J 1891. 'Market Cross'. *Scottish Notes And Queries*, May 1891, item no 534, 239.

Gifford, J 1996. *The Buildings Of Scotland: Dumfries And Galloway.* Penguin Books in association with the Buildings of Scotland Trust.

Gifford, J, McWilliam, C, Walker, D, and Wilson, C, 1984. *The Buildings Of Scotland: Edinburgh.* Penguin Books in association with the National Trust for Scotland.

Gifford, J 1988. *The Buildings Of Scotland: Fife.* Penguin Books in association with the National Trust for Scotland.

Gifford, J 1992. *The Buildings Of Scotland: Highland And Islands.* Penguin Books in association with the Buildings of Scotland Trust.

Glen, M H 1994. 'Interpreting St Andrews'. In Fladmark, J M (ed) *Cultural Tourism.* Papers presented at the Robert Gordon University Heritage Convention 1994, Donhead Publishing Ltd, London, 261-273.

Glendon, A I 1987. 'Risk Cognition'. In Singleton, W T and Hovden, J (ed) *Risk And Decisions.* John Wiley and Sons, Chichester, 87-107.

Godfrey, W H 1919. 'War Memorials: Suggestions From The Past. III Market Crosses And Halls'. *The Architectural Review*, Vol 46, Jul-Dec, 63-69.

Gordon, G and Dicks, B (ed), 1983. *Scottish Urban History.* Aberdeen University Press.

Gordon, S 1996. Personal communication. Historic Scotland.

Grant, I F 1930. *The Social And Economic Development Of Scotland Before 1603.* Oliver and Boyd, Edinburgh.

Gray, T and Ferguson, L 1997. *Photographing Carved Stones: A Practical Guide To Recording Scotland's Past.* The National Committee on the Carved Stones of Scotland, in association with Historic Scotland, Pinkfoot Press, Balgavies, Angus.

Hale, A R 1987. 'Subjective Risk'. In Singleton, W T and Hovden, J (ed) *Risk And Decisions.* John Wiley and Sons, Chichester, 67-85.

Hamilton-Grierson, Sir P 1914. *The Boundary Stone And The Market Cross.* Scottish Historical Review, October 1914, 24-36.

Harper, E 1979. 'Where Money Changed Hands'. *Town and Country Planning* 48, 275-6.

Hedge, A 1987. 'Major Hazards And Behaviour'. In Singleton, W T and Hovden, J (ed) *Risk And Decisions.* John Wiley and Sons, Chichester, 139-153.

Heinrichs, K and Fitzner, B 2000. 'Deterioration Of Rock Monuments In Petra/Jordan'. In Fassina, V (ed) *Proceedings Of The Ninth International Congress On Deterioration And Conservation Of Stone,* Vol 2. Venice, 19-24 June 2000, 53-61.

Hill, P R and David, J C E 1995. *Practical Stone Masonry.* Donhead Publishing, London.

Historic Scotland 2000. Website http://www.historic-scotland.gov.uk

Historic Scotland 2000a. *The Stirling Charter. Conserving Scotland's Built Heritage.* Edinburgh.

Historic Scotland 2000b. *A Guide To The Preparation Of Conservation Plans.* Edinburgh.

Honeyborne, D B 1990. 'Weathering And Decay of Masonry'. In Ashurst , J and Dimes, F G (ed) *Conservation Of Building And Decorative Stone Vol 1.* Butterworth-Heinemann Ltd, London, 153-178.

Houston, J 1997. Personal communication. Building Research Establishment, Department of the Environment, UK.

Hovden, J and Larsson, T J 1987. 'Risk: Culture And Concepts'. In Singleton, W T and Hovden, J (ed) *Risk And Decisions.* John Wiley and Sons, Chichester, 47-59.

Howard, D 1995. *The Architectural History Of Scotland: Scottish Architecture From The Reformation To The Restoration, 1560-1660.* Edinburgh University Press.

Hutcheson, A 1900. 'Introduction'. In Small, J W *Scottish Market Crosses.* E Mackay, Stirling.

ICOMOS 1964. *The Venice Charter.*

ICOMOS Australia 1979. *Burra Charter: Australian ICOMOS Charter For The Conservation Of Places Of Cultural Significance.*

ICOMOS 1987. *Washington International Charter For The Conservation Of Historic Towns And Urban Areas.*

ICOMOS, 1990. *Guide To Recording Historic Buildings.* Butterworth Architecture, London.

Inkpen, R 1999. 'Gravestones: Problems And Potentials As Indicators Of Historic Changes In Weathering'. In Jones, M S and Wakefield, R (ed) *Aspects Of Stone Weathering, Decay And Conservation.* Proceedings of the 1997 Stone Weathering and Atmospheric Pollution Network Conference (SWAPNET), 15-17 May 1997. Imperial College Press, London, 16-27.

International Office of Museums 1931. *Athens Conference Conclusions And Recommendations.*

Jackson, A 1989. *The Pictish Trail: A Traveller's Guide To The Old Pictish Kingdoms.* Kirkwall Press, Orkney.

Karara, H M (ed) 1979. *Handbook Of Non-Topographic Photogrammetry.* The American Society of Photogrammetry, Virginia, USA.

Karara, H M 1985. 'Close-Range Photogrammetry: Where Are We And Where Are We Heading?'. In American Society of Photogrammetry *Close-Range Photogrammetry And Surveying State-of-the-Art.* Proceedings of workshop of the American Congress on Surveying and Mapping, 9-14 September 1984, 925-927.

Kelly, M 1997. Personal communication. Conservation Architect, CADW Welsh Historic Monuments.

W Kidd 1901. *The Dundee Market Crosses And Tolbooths.* Published for private circulation, Palace Buildings, Whitehall Street, Dundee.

Leary, E 1986. *The Building Sandstones Of The British Isles.* Building Research Establishment Report, Department of the Environment, Watford.

Lejeune, R and Stiennon, J 1971. *The Legend Of Roland In The Middle Ages.* Vol I and II. Phaidon Press Ltd, London (translation of 1966 publication).

Leslie, A and Gibbons, P 1999. *Scottish Aggregates For Building Conservation.* Technical Advice Note 19. Technical Conservation, Research and Education Division, Historic Scotland, Edinburgh.

Lindsay, I G 1948. *The Scottish Tradition In Burgh Architecture.* Published for the Saltire Society by Thomas Nelson and Sons Ltd.

Livingston, R A and Baer, N S 1984. 'Stone Damage Rates Measured At Historic Buildings And Monuments'. *Seventy-seventh Annual Meeting Of The Air Pollution Control Association.* San Francisco, USA, 24-29 June 1984, 1-21.

Livingston, R A 1997a. 'Development Of Air Pollution Damage Functions'. In Baer, N S and Snethlage, R (ed) *Saving Our Architectural Heritage: The Conservation Of Historic Stone Structures.* Dahlem Workshop Report, Berlin, 3-8 March 1996. Published on behalf of Freie Universität Berlin, by John Wiley and Sons, Chichester, 37-62.

Livingston, R A 1997b. 'Air Pollution Standards For Architectural Conservation'. In Baer, N S and Snethlage, R (ed) *Saving Our Architectural Heritage: The Conservation Of Historic Stone Structures.* Dahlem Workshop Report, Berlin, 3-8 March 1996. Published on behalf of Freie Universitat, Berlin by John Wiley and Sons, Chichester, 371-387.

Love, D 1989. *Scottish Kirkyards.* Robert Hale, London.

Lynch, M, Spearman, M and Stell, G (ed) 1988. *The Scottish Medieval Town.* John Donald Publishers Ltd, Edinburgh.

McCulloch, W T (c.1854). 'Notices Of The City Cross Of Edinburgh, Etc, Etc, Illustrated By A Model And Drawings Of The Existing Remains'. *Proceedings Of The Society Of Antiquaries Of Scotland* Vol 2, Part 2, 287-294.

MacGibbon, D and Ross, T 1887-92. *The Castellated And Domestic Architecture Of Scotland V* (1971 facsimile copy of 1887-92 edition by James Thin, Edinburgh, originally published by David Douglas, Edinburgh).

McKean, C 1985. *Stirling And The Trossachs: An Illustrated Architectural Guide.* RIAS Landmark.

McKean, C 1990. *Banff And Buchan: An Illustrated Architectural Guide.* RIAS, Mainstream Publications (Scotland) Ltd.

McKean, C and Walker D 1984. *Dundee: An Illustrated Introduction.* RIAS and Scottish Academy Press, Edinburgh.

McKean, C, Walker, D and Walker, F 1989. *Central Glasgow: An Illustrated Architectural Guide.* RIAS.

Mackenzie, H 1953. *Third Statistical Account Of Scotland, Volume IV, the City of Aberdeen.* Oliver and Boyd, Edinburgh.

MacMillan, A 1992. *Six Scottish Burghs.* Canongate Press, Edinburgh, Scotland.

McWilliam, C 1975. *Scottish Townscape.* Collins, London.

Mair, C 1988. *Mercat Cross And Tolbooth: Understanding Scotland's Old Burghs.* John Donald Publishers Ltd, Edinburgh.

Mansfield, T 1992. 'Sources Of Building Soiling And A Review Of The Stone Cleaning Industry 1991'. In Webster, R G M *Stone Cleaning and the Nature, Soiling and Decay Mechanisms of Stone.* Donhead Publishing, London, 84-93.

Messent, C J W 1936. *The Market Crosses Of Norfolk.* East Anglian Magazine Vol 2, Part 1, 29-32.

Meierding, T C 1993. 'Marble Tombstone Weathering And Air Pollution In North America'. *Annals Of The Association Of American Geographers* 83 (4), 568-588.

Miller, P 1886. 'The Mercat Cross Of Edinburgh, From 1365 To 1617: Its Site And Form'. *Proceedings of the Society of Antiquaries for Scotland* Vol 4, 377-389.

Mikhail, E 1985. 'Introduction To Metrology Concepts'. In American Society of Photogrammetry *Close-Range Photogrammetry And Surveying State-of-the-Art.* Proceedings of workshop of the American Congress on Surveying and Mapping, 9-14 September 1984, 25-82.

Mirwald, P W 1989. 'Evaluating Damage And Accelerated Exposure And Field Studies; Modelling Techniques'. In Baer, N S, Sabbioni, C and Sors, A I (ed) *Science, Technology And European Cultural Heritage.* Proceedings of the European Symposium, Bologna, Italy, 13-16 June 1989. Butterworth-Heinnemann Ltd, 111-123.

Mirwald, P W and Brüggerhoff, S 1997. 'Requirements For And Interpretation Of Accelerated And Field Testing'. In Baer, N S and Snethlage R (ed) *Saving Our Architectural Heritage: The Conservation Of Historic Stone Structures.* Dahlem Workshop Report, Berlin, 3-8 March 1996. Published on behalf of Freie Universität Berlin, by John Wiley and Sons, Chichester, 255-268.

Mohr, E and Schmidt, J 1997. 'Aspects Of Economic Valuation Of Cultural Heritage'. In Baer, N S and Snethlage, R (ed) *Saving Our Architectural Heritage: The Conservation Of Historic Stone Structures.* Dahlem Workshop Report, Berlin, 3-8 March 1996. Published on behalf of Freie Universität Berlin, by John Wiley and Sons, Chichester, 333-348.

Morey, E, Rossmann, K, Chestnut, L and Ragland, S 10/07/97, 10:33. *Valuing Acid Deposition Injuries To Cultural Resources.* National Acid Precipitation Assessment Program. Website http://www.spot.Colorado.EDU/~morey/monument/chapters/ch1.htm.

Mulvin, L and Lewis, J O 1994. *Architectural Detailing, Weathering And Stone Decay.* Building and Environment, Vol 29, no 1, 113-138.

Munro, A M 1910. *The History Of The Aberdeen Market Cross.* Aberdeen Philosophical Society.

Munsell 1975. *Munsell Soil Colour Charts.* Munsell colour, Balitmore, USA.

Naismith, R J 1989. *The Story Of Scotland's Towns.* John Donald Publishers Ltd, Edinburgh.

Nappi, A and Côte, P 1997. 'Nondestructive Test Methods Applicable To Historic Stone Structures'. In Baer, NS and Snethlage R (ed) *Saving Our Architectural Heritage: The Conservation Of Historic Stone Structures.* Dahlem Workshop Report, Berlin, 3-8 March 1996. Published on behalf of Freie Universität Berlin, by John Wiley and Sons, Chichester, 151-166.

NORMAL, 1988. 'Macroscopic Alterations In Stone Materials: Glossary'. *Normal Recommendations* series, *NORMAL - 1/88.* Groups B, C and P. CNR Centres of Milan and Rome for Studies into the causes of deterioration and methods of conservation of works of art and ICR Central Institute of Restoration.

Petzsch, H 1971. *Architecture In Scotland.* Longman, London.

Phillips, W G B 1992. *The Development Of A Fire Risk Assessment Model.* BRE Information Paper IP 8/92, May 1992.

Pride, GL 1990. *The Kingdom Of Fife: An Illustrated Architectural Guide.* RIAS.

Rainey, M M and Whalley, W B 1994. 'The Importance Of Microfractures In Granitic Rock Breakdown With Reference To Building Stone Decay'. In Bell, E and Cooper, T P (ed) *Granite Weathering And Conservation.* Proceedings of a Conference held at Trinity College Dublin, September 1993. The Director of Buildings' Office, Trinity College, Dublin, 36-45.

Rasmussen, J 1987. 'Risk And Information Processing'. In Singleton, W T and Hovden, J (ed) *Risk And Decisions.* John Wiley and Sons, Chichester, 109-122.

RCAHMS 1963. *Stirlingshire: An Inventory Of The Ancient Monuments.* Vol I and II. HMSO, Edinburgh.

RCAHMS, 1996. *Tolbooths And Town-houses: Civic Architecture In Scotland To 1833.* The Stationary Office, Edingburgh.

Rennie, R C and Gordon, T Crouther 1966. *Third Statistical Account Of Scotland, Volume XVAAA, The Counties of Stirling And Clackmannan.* Collins, Glasgow.

Ritchie, A 1996. *Exploring Scotland's Heritage: Orkney.* RCAHMS, The Stationary Office, Edinburgh.

Ritchie, G and Harman, M 1996. *Exploring Scotland's Heritage: Argyll And The Western Isles.* RCAHMS, HMSO, Edinburgh (2nd edition).

Robertson, J K 1973. *About St Andrews - And About.* Citizen Office, St Andrews, Fife.

Ross, N 1999. Personal communication. Historic Scotland.

Sanpaolesi, P 1972. 'Preliminary Surveys'. In UNESCO *Preserving And Restoring Monuments And Historic Buildings.* Paris, 63-66.

The Scotsman (author anonymous) 1892. 'The Market Crosses Of Scotland'. *The Scotsman*, 26 September 1892, 8.

Scott-Moncrieff, G (ed) 1938. *The Stones Of Scotland.* London.

Scottish Office Development Department 1997. *Planning In Small Towns.* Planning Advice Note PAN 52. April 1997.

Searls, C L, Binda, L, Henriksen, J F, Mirwald, P W, Nappi, A, Price, C A, Van Balen, K E P, Vergès-Belmin, Wendler, E and Wittmann, F H 1997. 'Group Report: How Can We Diagnose The Condition Of Stone Monuments And Arrive At Suitable Treatment Programs?'. In Baer, N S and Snethlage, R (ed) *Saving Our Architectural Heritage: The Conservation Of Historic Stone Structures.* Dahlem Workshop Report, Freie Universität, Berlin, 199-221.

Shepherd, I 1996. *Exploring Scotland's Heritage: Aberdeen And North-East Scotland.* RCAHMS, HMSO, Edinburgh (2nd edn).

Simpson, G G (ed) 1972. *Scotland's Medieval Burghs: An Archaeological Heritage In Danger.* Council of the Society of Antiquaries of Scotland, Edinburgh.

Small, J W 1890. 'Scottish Market Crosses'. *Transactions Of The Stirling Natural History And Archaeological Society*, 51-8.

Small, J W 1895-6. 'The Market Crosses Of Scotland'. *Transactions Of The Stirling Natural History And Archaeological Society*, 96-99.

Small, J W 1900. *Scottish Market Crosses.* E Mackay, Stirling.

Smith, B, Whalley, B and Fassina, V 1988. 'Elusive Solution To Monumental Decay'. *New Scientist*, 2 June, 49-53.

Smith, B, Whalley, B and Magee R 1992. 'Assessment Of Building Stone Decay: A Geomorphological Approach'. In Webster, RGM *Stone Cleaning And The Nature, Soiling And Decay Mechanisms Of Stone.* Donhead Publishing, London, 249-257.

Spjøtvoll, E 1987. 'Probability: Interpretation And Estimation'. In Singleton, W T and Hovden, J (ed) *Risk And Decisions.* John Wiley and Sons, Chichester, 13-24.

Stell, G 1996. *Exploring Scotland's Heritage: Dumfries And Galloway.* The Stationary Office, Edinburgh.

Stephan, F 1996. 'MONUFAKT - A Database System For Improved Information Transfer In Conservation'. In Riederer, J (ed) *Proceedings Of The Eighth International Congress On Deterioration And Conservation Of Stone Vol 3.* Berlin, 1745-1750.

Stevenson, J 1995. *Exploring Scotland's Heritage: Glasgow, Clydeside And Stirling.* RCAHMS, HMSO, Edinburgh (2nd edn).

Stewart, J 1997. Personal communication. National Trust for England.

Strang, C A 1994. *Borders And Berwick: An Illustrated Architectural Guide To The Scottish Borders and Tweed Valley.* RIAS, The Rutland Press.

Stuart, J 1856-67. *The Sculptured Stones Of Scotland.* Vol 1 and 2.

Swan, A 1987. *Clackmannan And The Ochils: An Illustrated Architectural Guide.* RIAS, Scottish Academic Press.

Thomas, L C 1992. 'Financial Risk Management Models'. In Ansell, J and Wharton, F (ed) *Risk Analysis, Assessment And Management.* John Wiley and Sons, Chichester, 55-70.

Tittler, R 1991. *Architecture And Power: The Town Hall And The English Urban Community c1500-1640.* Clarendon Press, Oxford.

Torlegård, A K I 1980. 'An Introduction To Close Range Photogrammetry'. In Atkinson, K B (ed) *Developments In Close-Range Photogrammetry - 1.* Applied Science Publishers Ltd, London, 1-14.

Torraca, G 1988. *Porous Building Materials: Materials Science For Architectural Conservation.* ICCROM, Rome (3rd edn).

Tranter, N 1974. *The Queen's Scotland: The North-East.* Hodder and Stoughton, London.

UNESCO 1962. *Recommendation Concerning The Safeguarding Of The Beauty And Character Of Landscapes.*

UNESCO 1976. *Recommendation Concerning The Safeguarding And Contemporary Role Of Historic Areas.*

Urquhart, D C M, Jones, M, Nicholson, K, Wakefield, R and Young, M E 1995. *Biological Growths, Biocide Treatment, Soiling And Decay Of Sandstone Buildings And Monuments.* Report to Historic Scotland.

Urquhart, D C M, Young, M E, Wakefield, R D, Tonge, K and Nicholson, K 1996a. 'A Field Investigation Of Algal Growths And Biocide Efficacy On Sandstone Buildings And Monuments'. *Journal Of Architectural Conservation,* 1, March 1996, 55-73.

Urquhart, D C M and Young, M E and MacDonald, J and Jones, M S and Nicholson, K A 1996b. 'Aberdeen Granite Buildings: A Study Of Soiling And Decay'. In Smith, B J and Warke, P A (ed) *Processes Of Urban Stone Decay.* Donhead Publishing Ltd, 66-77.

Urquhart, D, Young, M and Cameron, S. 1997. *Stonecleaning Of Granite Buildings.* Technical Advice Note 9. Technical Conservation, Research and Education Division, Historic Scotland, Edinburgh.

Urquhart, D 1999. *The Treatment Of Graffiti On Historic Surfaces.* Technical Advice Note 18. Technical Conservation, Research and Education Division, Historic Scotland, Edinburgh.

Vallance, A 1920. *Old Crosses And Lychgates.* B T Batsford Ltd, London.

Van Balen, K 1997. 'Monitoring Of Degradation: Selection Of Treatment Strategies'. In Baer, NS and Snethlage R (ed) *Saving Our Architectural Heritage: The Conservation Of Historic Stone Structures.* Dahlem Workshop Report, Berlin, 3-8 March 1996. Published on behalf of Freie Universität Berlin, by John Wiley and Sons, Chichester, 167-180.

Van Hees, R P J, Van der Klugt, L J A R, Naldini, S, Van Balen, K, Mascarenhas Mateus, Binda, L, Baronio, G, Francke, L and Schumann, I 1996. *'The Masonry Damage Diagnostic System'.* In Riederer, J (ed) *Proceedings Of The Eighth International Congress On Deterioration And Conservation Of Stone Vol 3.* Berlin, 30 Sep - 4 Oct 1996, 1737-1739.

Vassilakos, C and Salta, A 1993. 'Synergistic Effects Of Sulphur Dioxide And Nitrogen Dioxide In Their Action On Marbles Studied By Reversed Gas Flow Chromatography'. In Thiel, M J (ed) *Proceedings Of The International RILEM/UNESCO Congress, Conservation Of Stone And Other Materials* Vol 1. Paris, 29 Jun - 1 Jul 1993, 99-106.

Verhoef, L G W (ed) 1988. *Rilem Report: Soiling And Cleaning Of Building Facades.* Chapman and Hall, London.

Viles, H and Antill, S 1999. 'Deciphering The Impacts Of Traffic On Stone Decay In Oxford: Some Preliminary Observations From Old Limestone Walls'. In Jones, M S and Wakefield, R (ed) *Aspects Of Stone Weathering, Decay And Conservation.* Proceedings of the 1997 Stone Weathering and Atmospheric Pollution Network Conference (SWAPNET), 15-17 May 1997. Imperial College Press, London, 28-42.

Watt, A 1976. *Highways And Byways Round Stonehaven.* Aberdeen Waverley Press.

Whalley, B, Smith, B and Magee, R 1992. 'Effects Of Particulate Air Pollutants On Materials: Investigation Of Surface Crust Formation'. In Webster, R G M (ed) *Stone Cleaning And The Nature, Soiling And Decay Mechanisms Of Stone.* Donhead Publishing, London, 227-234.

Wharton, F 1992. 'Risk Management: Basic Concepts And General Principles'. In Ansell, J and Wharton, F (ed) *Risk Analysis, Assessment And Management.* John Wiley and Sons, Chichester, 1-14.

White 1873. *Archaeological Sketches In Scotland: District Of Kintyre,* 97.

Whitehead, W Y 1937. *History Of Ormiston,* 86-8.

Williamson, E, Riches, A, Higgs, M 1990. *The Buildings Of Scotland: Glasgow.* Penguin Books in association with the National Trust for Scotland.

Willsher, B 1985. *Understanding Scottish Graveyards.* Council for Scottish Archaeology, (ed E Proudfoot). W and R Chalmers Ltd, Edinburgh.

Wilson, K 1995. *'The Use Of Digital Data For The Archaeological Recording Of Historic Buildings And Monuments'.* In Andrews et al (ed) *The Survey And Recording Of Historic Buildings.* Association of Archaeological Illustrators and Surveyors, Technical Paper 12, Part IV, 24-35.

Winkler, E M 1994. *Stone In Architecture: Properties, Durability.* Springer-Verlag, London. (3rd edn).

Wright, D B 1997. *Understanding Statistics: An Introduction For The Social Sciences.* SAGE Publications Ltd, London.

Yates, T, Butlin, R and Houston, J 1999. *Assessment Methodology Handbook. Carved Stone Decay In Scotland.* Technical Conservation, Research and Education Division, Historic Scotland, Edinburgh, September 1999.

Young, A R M 1987. 'Salt As An Agent In The Development Of Cavernous Weathering'. *Geology,* v 15, October, 962-966.

Appendix A

List of names and locations of surviving market crosses

The following table contains a list of all the surviving market crosses in Scotland. Their location and date of construction has been extracted from archived and published data and is also shown below. A question mark is used to indicate cases in which the details of these are occasionally uncertain or unknown, and < and > signs are used to indicate date brackets.

Town	Region	National Grid Reference	Construction date
Aberdeen (Castlegate)	City of Aberdeen	NJ 9449 0637	1686
Aberdeen (High Street)	City of Aberdeen	NJ 9391 0846	1545
Aberlady	E Lothian	NT 4642 7993	1700's
Abernethy	Perth & Kinross	NO 190 163	1920
Airth	Falkirk	NS 8991 8706	1600's?
Airth	Falkirk	NS 8990 8753	1697
Alloa	Clackmannan	NS 8855 9268	1690
Alyth	Perth & Kinross	NO 2451 4883	1670
Ancrum	Borders	NT 6282 2457	Late 1500's
Anstruther Easter	Fife	NO 5669 0360	1677
Banff	Aberdeenshire	NJ 6896 6397	1900
Beauly	Highland	NH 5268 4645	1430
Biggar	S Lanarkshire	NT 0426 3783	1632
Bowden	Borders	NT 5540 3051	Late 1500's
Campbeltown	Argyll & Bute	NR 7204 2044	1380
Carnwath	S Lanarkshire	NS 9792 4639	1600's
Cellardyke	Fife	NO 5732 0360	1642
Clackmannan	Clackmannan	NS 9110 9188	1600's
Cockburnspath	Borders	NT 7742 7110	?, >1503, <1900.
Coldingham	Borders	NT 9024 6597	1815
Crail	Fife	NO 6136 0783	Early 1600's
Crailing	Borders	NT 68 24	?
Crawford	S Lanarkshire	NS 95 21	?
Crieff	Perth & Kinross	NN 8648 2155	1600's
Cromarty	Highland	NH 7898 6739	1578
Cullen	Moray	NJ 5128 6711	1871 (shaft from 1600's?)
Cullen	Moray	NJ 5087 6702	1696
Culross	Fife	NS 9868 8594	1588
Cumnock	E Ayrshire	NS 5679 2013	1703
Cupar	Fife	NO 3752 1457	1683
Cupar	Fife	NO 3754 1205	1683
Currie	City of Edinburgh	NT 1815 6775	?
Dallas	Moray	NJ 1218 5183	Early 1500's
Dingwall	Highland	NH 5495 5876	1600's
Dipple	Moray	NJ 3277 5757	?
Dornoch	Highland	NH 7975 8970	1628
Doune	Stirling	NN 7270 0157	1620
Duffus	Moray	NJ 1760 6863	1300's
Dull	Perth & Kinross	NN 807 491?	?

Town	Region	National Grid Reference	Construction date
Dunbar	E Lothian	NT 6793 7895	1500's
Dundee	Angus	NO 4016 3008	1586
Dunfermline	Fife	NT 0911 8747	1868
Duns	Borders	NT 7864 5357	1792
Edinburgh (Canongate)	City of Edinburgh	NT 2647 7381	1500's
Edinburgh (High Street)	City of Edinburgh	NT 2577 7359	1450
Elgin	Moray	NJ 2220 6301	?
Elgin	Moray	NJ 2163 6285	1650
Errol	Perth & Kinross	NO 25 23	1900
Falkirk	Falkirk	NS 8881 7991	?, ≤1817
Fettercairn	Aberdeenshire	NO 6504 7355	1504 or 1670
Findhorn	Moray	NJ 0386 6444	?, <1900
Forfar	Angus	NO 4563 5063	1684
Forres	Moray	NJ 0370 5890	1844
Fortrose	Highland	NH 7260 5655	1590 or 1800's
Fowlis Easter	Perth & Kinross	NO 3220 3344	?, <1793
Fowlis Wester	Perth & Kinross	NN 9278 2404	700's
Fowlis Wester (replica)	Perth & Kinross	NN 9278 2404	1991
Fraserburgh	Aberdeenshire	NJ 9979 6710	1736
Fyvie	Aberdeenshire	NJ 77 38	1902
Galashiels	Borders	NT 4927 3577	?, 1695 or 1800's
Gifford	E Lothian	NT 5337 6802	1780
Glamis	Angus	NO 388 466	?
Glasgow	City of Glasgow	NS 5966 6490	1930
Glenhapple	Dumfries & Galloway	NX 3775 7080	?, <1845
Greenlaw (Church tower)	Borders	NT 7114 4614	1696
Greenlaw (the Square)	Borders	NT 71 46	1829
Haddington	E Lothian	NT 5161 7387	1881
Hawick	Borders	NT 4933 1458	1600's
Houston	Renfrewshire	NS 4053 6692	1300's
Inveraray	Argyll & Bute	NN 0966 0856	1400's
Inverbervie	Aberdeenshire	NO 8316 7268	1737
Inverkeithing	Fife	NT 1301 8287	?, 1398 or 1500's
Inverness	Highland	NH 6668 4521	1768
Irvine	N Ayrshire	NS 3225 3885	?, 1800's
Jedburgh	Borders	NT 6499 2057	1887
Kelso	Borders	NT 73 34	1921
Kettins	Angus	NO 2381 3905	?, <1873
Kilmarnock	E Ayrshire	NS 4285 3799	?, >1444
Kilmaurs	E Ayrshire	NS 4104 4121	1830
Kilwinning	N Ayrshire	NS 3046 4335	?, >1956, <1982
Kincardine-on-Forth	Fife	NS 9312 8751	Late 1600's
Kinneddar	Moray	NJ 2231 6958	?, <1931
Kinross	Perth & Kinross	NO 1191 0187	?, >1300's, ≤1600's
Kinrossie	Perth & Kinross	NO 1885 3237	1686
Kirk Yetholm	Borders	NT 83 28	?
Kirkcudbright	Dumfries & Galloway	NX 6807 5089	1610
Kirkwall	Islands	HY 448 108	1621
Kirkwall (replica)	Islands	HY 4489 1089	≤1954
Langholm	Dumfries & Galloway	NY 3648 8447	?, Early 1600's. (<1723)
Legerwood	Borders	NT 5821 4633	?

Town	Region	National Grid Reference	Construction date
Leven	Fife	NO 38 01	1600's
Liberton	City of Edinburgh	NT 27 69	?, <1780
Linlithgow	W Lothian	NT 0021 7717	1807
Lochgoilhead	Argyll & Bute	NN 1987 0140	1626
Lochmaben	Dumfries & Galloway	NY 0805 8256	1612
Longforgan	Perth & Kinross	NO 3108 3000	?, Late1600's, <1790
Lossiemouth	Moray	NJ 2357 7038	1700
Macduff	Aberdeenshire	NJ 7012 6438	?, ≤1783
Marykirk	Aberdeenshire	NO 6862 6564	?, Late 1600's, <1796
Maxton	Borders	NT 613 302	<1881
Meikleour	Perth & Kinross	NO 1575 3954	?, 16(9)8 inscribed on cross
Melrose	Borders	NT 5477 3397	1645
Milton	Highland	NH 58 49	1799
Minnigaff	Dumfries & Galloway	NX 4115 6637	?
Moniaive	Dumfries & Galloway	NX 7785 9092	1638
Musselburgh	E Lothian	NT 3463 7273	Late 1700's
Nairn	Highland	NH 8838 5651	1757
Ness	Highland	NH 74 56	?
New Scone	Perth & Kinross	NO 1335 2572	1820
Newbigging	S Lanarkshire	NT 0152 4592	1693
Ochiltree	E Ayrshire	NS 5081 2118	1836?
Ogston	Moray	NJ 1928 6892	?
Old Fochabers	Moray	NJ 3477 5923	?, <1800
Old Rayne	Aberdeenshire	NJ 6746 2831	Late 1600's
Old Scone	Perth & Kinross	NO 1158 2665	?, 1400's, <1803
Oldhamstocks	E Lothian	NT 7391 7061	1700's
Ormiston	E Lothian	NT 4142 6927	1400's
Paxton	Borders	NT 53 93	?
Peebles	Borders	NT 2529 4047	1699
Pencaitland	E Lothian	NT 4409 6890	1695
Perth	Perth & Kinross	NO 2280 2744	1668
Perth	Perth & Kinross	NO 11 23	?
Pittenweem	Fife	NO 54 02	1600's
Preston	Borders	NT 7937 5731	<1900
Preston	Dumfries & Galloway	NX 968 564	?
Prestonpans	E Lothian	NT 3915 7405	1617?, early 1600's
Prestwick	S Ayrshire	NS 3517 2616	c.1300? <1473
Reay	Highland	NC 9590 6455	1500's or 1600's
Rossie	Perth & Kinross	NO 292 307	1746
Rothesay	Argyll & Bute	NS 0883 6452	?, >1893, <1964
Rutherglen	S Lanarkshire	NS 614 616	1926
Ruthven	Aberdeenshire	NJ 5062 4692	?
Sanquhar	Dumfries & Galloway	NS 7834 0976	1864
Selkirk	Borders	NT 469 284	1898 or 1903 (shaft older?)
Spynie	Moray	NJ 228 655	<1810
Stenton	E Lothian	NT 6213 7421	<1799
Stirling	Stirling	NS 7932 9370	?, early 1600's
Stonehaven	Aberdeenshire	NO 8766 8551	≤1645
Strathmiglo	Fife	NO 21 10	≤1605
Strowan	Perth & Kinross	NN 8192 2119	?, 1400's, <1940
Swinton	Borders	NT 8351 4740	1769

Town	**Region**	**National Grid Reference**	**Construction date**
Tain	Highland	NH 7800 8212	1500's
Thornhill	Dumfries & Galloway	NX 8787 9547	1714
Thurso	Highland	ND 1185 6852	?, ≤1900
Turriff	Aberdeenshire	NJ 7232 4979	1865
Weem	Perth & Kinross	NN 85 50	?, <1900
West Linton	Borders	NT 1499 5176	1666
Wester Pencaitland	E Lothian	NT 4409 6890	1699
Wigtown (old)	Dumfries & Galloway	NX 4328 5529	1738
Wigtown (new)	Dumfries & Galloway	NX 4328 5529	1816
Woodhead	Aberdeenshire	NJ 7895 3854	1846

Appendix B

The construction date of sampled market crosses in relation to their component dates

Note that some construction dates are only approximately recorded in the consulted archives. Uncertain dates are indicated by question marks in the table below.

Sampled market cross	Construction date	Component dates	Cross components
Old Aberdeen	1545	1545	Capital
		1880	Shaft and steps
		? (post-1545)	Socket stone
Ancrum	Late 1500's	Late 1500's	Shaft and socket stone
		?	Steps
Banff	1900	1900	Steps
		1994	Shaft and finial
		? (1900's)	Socket stone
Beauly	1430	1430	Shaft and capital
		? (1430 or later)	Upper steps
		1992	Lower steps
Bowden	Late 1500's	Late 1500's	Socket stone and finial
		1919	Steps and shaft
Campbeltown	1380	1380	Socket stone and cross-shaft
		? (post-1380)	Steps
Cromarty	1578	1578	Steps, shaft, frieze and finial
Culross	1588	1588	Steps and socket stone
		1902	Shaft, frieze and finial
Cupar	1683	1683	Shaft
		1897	Pedestal base
		1987	Capital and finial
Dallas	Early 1500's	Early 1500's	Steps, socket stone, shaft and finial
Duffus	1300's	1300's	Steps, socket stone shaft and finial
Dunbar	1500's	1500's	Shaft
		1913	Steps
		?	Capital
Dundee	1586	1586	Shaft
		1874	Steps and pedestal base
		1960	Finial
		? (1586 or later)	Capital
Edinburgh Canongate	1500's	1500's	Shaft
		1866	Steps
		1888	Pedestal base, capital and finial
Edinburgh High Street	1450	1450	Capital
		1869	Finial
		1885	Built tower-base and steps
		1970	Shaft
Fowlis Wester	700's	700's	Cross-slab

Sampled market cross	Construction date	Component dates	Cross components
Houston	1300's	1300's	Steps and socket stone
		1713	Frieze and finial
		? (1300's or later)	Shaft
		? (post-1400's)	Steps
Inveraray	1400's	1400's	Cross-shaft
		? (post-1400's)	Steps
Inverbervie	1737	1737	Plinth, steps, shaft and finial
Inverkeithing	?1398 or 1500's	1500's	Shaft
		1688	Frieze and finial
		1889	Steps
		? (1398 or 1500's)	Capital
		?	Socket stone
Ochiltree	1836	1836	Shaft
		1897	Steps
Ormiston	1400's	1400's	Cross-shaft
		? (post-1400's)	Socket stone
		1726?	Steps
Rossie	1746	1746	Steps, shaft, capital and finial
Rutherglen	1926	1926	Steps, shaft, capital and finial
Tain	1500's	1500's	Socket stone
		1895	Steps, shaft, capital and finial
Turriff	1865	1865	Pedestal base and shaft
		1997	Finial
		? (1865 or later)	Steps
Wester Pencaitland	1699	1699	Steps, pedestal base, shaft and frieze

Appendix C

Options For Database Variables

The data variables referred to in Chapter 3 *Methodology for Data Collection and Recording* are described here, grouped by the database table to which they correspond. They are presented along with classification options, shown in italics.

Cross location and designations

This information was recorded for each market cross and describes location, statutory designations, architectural type and climate.

Cross identification number
Individual identification number for each market cross.

Town
Town in which the market cross is located.

Cross street or name
Most important for towns which have more than one market cross, eg *Muckle Cross* in Elgin, or *Castlegate* in Aberdeen.

District
eg *Banff & Buchan*

Unitary Authority
The local regional authority, eg *Aberdeenshire*

National Grid Reference
Ordnance Survey National Grid Reference, up to 8-figure, eg *NJ 7045 3694*

Market cross architectural type

Tower-based	*Cross* - ie incorporates a crucifix or celtic cross
Gothic Revival	*Traditional* - ie shaft-upon-steps with traditional, heraldic finial
C20 War memorial	*Slab*
Obelisk	*Sundial*
Fountain	*Well*

Boulder	*Font*
Pillar	*Unknown*

National Monuments Record for Scotland identification number

Based upon OS map sheet, eg *NJ 73 SE 24*

Sites and Monuments Record identification number

Number within Local Authority records, also based upon OS map sheet, eg *NJ 73 SE 7*

Listed Building Category:

Statutory Listed Building Category in Scotland, as recorded in 1998. Note that occasionally crosses have two designations where they are assigned a group value as well as an individual Category. For example, Old Aberdeen cross is assigned an 'A for Group' Category due to the historical nature of other surrounding buildings, but as an individual monument it is designated a Category B Listed Building. All designations for each cross are recorded in the database.

A	'Buildings of national or international importance, either architectural or historic, or fine, little-altered examples of some particular period, style or building type'.
B	'Buildings of regional or more than local importance, or major examples of some period, style or building type which may have been somewhat altered'.
C	A non-statutory category, currently being phased out.
C(S)	Buildings of local importance; lesser examples of any period, style or building type, whether as originally constructed or as the result of subsequent alteration; simple, well-proportioned traditional buildings, often forming part of a planned group, eg an estate or an industrial complex, or grouping well in association with buildings in a higher category'.
A for group	Indicates 'group value'.
B for group	Indicates 'group value', currently being phased out.
None	Market crossed with no Listed Building designation.

Date of Listing

Year in which the market cross was first Listed, if known.

Scheduled Ancient Monument

Yes or *No*

Scheduled Ancient Monument identification number

Date of Scheduling

Year in which the market cross was first Scheduled.

Date of construction

Year of market cross construction. For some crosses the exact year of construction is unknown, and is recorded in sources simply by century eg seventeenth century. For date fields to be useful during data queries, an absolute year had to be entered here, rather than a date range or century. Therefore, for the purposes of this research, the mean date of any range was used. For a cross constructed in the seventeenth century, this would be *1650*, and for a cross built in the '1820's' the date entered would be *1825*.

Date Range

This qualifies the *'Date of construction'* field by indicating the accuracy of the recorded construction date. It is a free text field to indicate whether the construction date was calculated from a date range, eg:

n/a if the exact year of construction is known

1820's if the mean has been calculated from 1820-1830.

C17 if the mean has been calculated from the seventeenth century

Date of National Monuments Record consultation:

This is for future reference purposes, to take account of the fact that the NMRS is subject to ongoing updates. NMRS records were consulted for every Scottish market cross.

Date of Sites and Monuments Record consultation

This is for future reference purposes, to take account of the fact that the SMR's are also subject to ongoing updates. The SMR was consulted only in the case of crosses for Aberdeen City, Aberdeenshire, Moray, and for the two sampled crosses located in the Scottish Borders. In most cases the SMR data duplicates the records held in the National Monuments Record, therefore it was not considered efficient to conduct a thorough search of the SMR's.

Cross sampled?

Yes or *No*, to indicate if the market cross was among those of the sample selected for more detailed fieldwork and analysis.

Date of field survey

Records the date at which each sampled cross was surveyed during the research.

Light conditions

Records the ambient light conditions during the field survey, which may have implications for the visibility of the monument condition:

Sunshine *Bright but overcast*

Dull *Artificial light,* ie for any cross sited indoors

Moisture conditions

Records the moisture conditions during field survey, which may have implications for the visibility of monument condition or recording of stone colour:

Raining

Damp

Dry

Survival of monument

Indicates the degree to which the cross still consists of its original parts:

0 all parts original

1 localised repairs

2 some components replaced/missing, plus localised repairs

3 most or all components modified or replaced/missing

Conservation requirements

Classification assigned to each cross following the field survey:

A no repairs necessary

B localised repairs desirable

C immediate intervention necessary (to slow advanced decay, or to counter serious risk)

Cross altitude

Height Over Datum in metres of each market cross, an approximate measurement derived from OS maps (often the mid height between two map contours is assumed). This measurement was included in order to check that there was no great height difference between each monument and the corresponding climate station from which meteorological data was obtained.

Coastal proximity

The classification scheme is a four-point scale to indicate the relative degree of coastal proximity for crosses within Scotland. Distance to the sea in eight directions was measured from each cross (ie N, NE, E, SE, S, SW and W, NW). The classifications includes consideration of the number of directions from the cross in which the sea (includine firths and large sea lochs) is located in close proximity.

Very coastal: Lowest distance from the cross to the coast is <2km in at least 3 directions (eg N, NE, E)

Coastal: Lowest distance from the cross to the coast is <5km, in at least 2 directions (eg N, NE)

Inland: Lowest distance from the cross to the coast is between 5-20km in any direction

Very inland: Lowest distance from the cross to the coast is >20km in *all* directions

Site aspect

Orientation of the site aspect for sampled crosses sited on a slope.

Other topographic features

This field records the presence of any nearby topographic features which might affect the climate at the cross. Such features can include hills, valleys or geographic features which could create greater or lesser exposure to wind, fog, frost and sunlight at the cross site.

Humidity

System of classification adopted from map of bioclimatic zones in Scotland by Birse (1971). Note that the even numbers are intermediate classifications introduced for the data-base, to deal with borderline instances on the map.

1 P: Perhumid
2 P-H
3 H1: Extremely humid
4 H1-2
5 H2: Very humid
6 H2-3
7 H3: Humid
8 H3-4
9 H4: Fairly humid

Wind speed

Derived from an isogram in BRE (1989 Fig 1, p2). Recorded values represent the basic hourly mean wind speed in metres per second. Values generally increase towards the N and the W of Scotland. Note, however, that since most crosses are located in town centres the actual wind speed here will be lower than the recorded basic values, since the built topography tends to reduce wind speed and simultaneously increase turbulance.

Annual temperature

Annual average of daily mean temperature, in degrees Centigrade, to one decimal place. Values derived from corresponding local climate station.

Annual precipitation

Average of annual precipitation in mm. Values derived from corresponding local climate station.

Air frost

Average annual number of days of frost, to one decimal place. Values derived from corresponding local climate station.

Fog

Average annual days of fog (at 9am), to one decimal place. Values derived from corresponding local climate station.

Climate station

Local climate station from which meteorological data was obtained.

Station altitude

Height Over Datum (m) of the local climate station.

Recorded history of cross

Free text field to describe the historical background of the market cross, where documentary details are available. For example, this field was used to describe any record of former market crosses in the burgh prior to the existing one, the date and details of the burgh foundation, and any historical anecdotes relating to the crosses.

Site history data

This data set includes information about successive sites occupied by each market cross since its construction.

Site no.

Site number within the overall sequence of locations.

Location in town

Indicates the location of each successive site within the town, eg *High Street* or *Churchyard.*

Erection date

Year in which the cross was erected at each site. Similar to the Date of Construction field, this is occasionally a mean value in cases where only a date range is known.

Land-use type

For each site, this is the land-use type around the immediate base of the cross.

Pedestrian thoroughfare
Communal green
Pasture field
Arable field
Museum
Roads - ie where the market cross is a traffic island
Verge
Churchyard (in use)
Churchyard (disused)
Indoor storage

Height OD

Recorded for previous sites of the crosses, expressed in metres above sea level. Data was derived from OS maps, by looking at the nearest contour. In the vast majority of cases, re-sitings of crosses have only involved very short distances with no change of altitude.

Documented damage

This is a free text field used to record any previously documented instances of damage, or historical observations regarding the condition of the cross, eg Airth High Street cross steps noted as being '*delapidated*' in 1900. This information could help to explain the existence and/or severity of decay visible today on certain crosses, and could help elucidate the rate of decay on some crosses.

Environmental features

This data set includes environmental features relating to the successive sites of each market cross,which may have an influence upon the observed stone condition.

Site no.

Site of cross to which the enviromental data relates.

Environmental feature

Includes ameliorating factors as well as factors which may pose a risk of damage. Each site can have an unlimited number of environmental features. Note data for traffic levels is recorded for all crosses and is contained in separate data fields described further on.

Sheltered (ie by a nearby wall)
Highly exposed
Fenced-off
Exposure to vehicle exhaust emissions
Run-off from over-hanging vegetation
Flowerbed (potential risk from the use of pesticides or increased watering)

Orientation of environmental factor

The orientation of the environmental factor in relation to the monument. This could help to highlight the link between environmental factors and the observed decay severity and soiling density on different facade orientations.

Proximity to factor

Where relevant, the proximity to the cross of environmental factors was recorded to the nearest metre. This data was only measured in the case of sheltering walls and traffic exhaust emissions.

Date range for environmental factor

Where the existence of the environmental factor was temporary, a date range was recorded here (eg Aberdeen Castlegate market cross had a greater risk posed by motor exhaust fumes until several years ago when the area around it was pedestrianised). This takes account of the fact that environmental features can be subject to change over short time periods.

Road class:

The database only accommodates one *Road class* entry per site, thus the classification was based upon the busiest road in close proximity. Information about additional, less significant roads nearby is recorded in the text field *'Environmental comments'*. The road classifications were:

A
B
Secondary
Urban
Residential

Traffic density:

Traffic density was estimated for the recorded road class, based upon casual observation made during the course of a day while undertaking the field survey. Note that such an estimate may be biased if traffic flow is uneven, eg concentrated at different times of the day or year. A note was added to the *Environmental comments* in cases where the road was on a common route for buses and lorries, since diesel fumes are a significant cause of soiling on stonework. Traffic densities were:

Busy
Moderate
Quiet

Environmental comments

Free text field to record any additional information about any of the recorded environmental factors.

Cross components data

A set of data was recorded for each individual component in the market crosses, and included variables on the themes of stone properties and architectural characteristics.

Cross component type

Describes the architectural form of the component, eg steps or shaft.

Age of component

Number of years before 2000AD when the component was carved.

Material

The material from which the cross component was made:

Sandstone
Granite
Marble
Whinstone
Fibreglass
Chlorite schist
Cement
Bronze
Iron

Stone colour

Expressed in Munsell values eg *Buff 7.5YR 7/2*, along with a brief worded description.

Type of carving

This indicates the carved features which the component incorporates. The morphology of these may be contributing to the observed decay or soiling pattern. Some of the carved features apply only to the more elaborate crosses and tower-base crosses. A component could have an unlimited variety of features eg *bcg*.

a	*Ashlar*	*k*	*Relief, high-level*
b	*Incision/inscription*	*l*	*Pinnacles*
c	*Local feature* (eg coat of arms/inset stone panel/plaque)	*m*	*Crocketting*
d	*Horizontal moulding/cornice*	*n*	*Water spouts*
e	*Vertical moulding*	*o*	*Gablettes*
f	*Fluting*	*p*	*Niches*
g	*Panelling*	*q*	*Flying butresses*
h	*Arcading*	*r*	*Parapet*
i	*Sculpture*	*s*	*Door*
j	*Relief, low-level*	*t*	*Turrets*

Degree of carved detail

Each component was classified according to a four-point scale. A high surface-to-volume ratio could allow greater moisture ingress to the stone.

1 plain

2 plain surface, moulded features (includes stop-chamfered shafts)

3 moderate surface decoration, less intricate infill

4 extensive surface ornamentation with elaborate infill

Source of stone

Quarry or locality of the stone, if known.

Sandstone cement type

This field was not much used due to difficulties experienced in classifying the components encountered during fieldwork. Only twelve crosses could be classified.

Calcareous	*Argillaceous*
Siliceous	*Ferruginous*

Sandstone grain size

Estimated by visual observation.

Fine	*Medium-Coarse*
Fine-Medium	*Coarse*
Medium	

Degree of sandstone grain sorting

Uniform or *Poor*. Poor sorting was only seen in one case, athough further nuances could perhaps have been identified microscopically.

Sandstone inclusions

Free text field to describe any inclusions seen in the sandstone, eg clay or pebbles.

Details of damage

Free text field to allow detailed notes to be made of the decay and soiling exhibited by a component. These notes complement the recorded classifications in the decay/soiling data table.

Attachments and applied substances

Records the existence of any other materials adhering to the stonework, possibly contributing to the decay. Each component could have more than one feature recorded.

Paint	*Other stone type* (eg inset panel)
Cement render	*Copper* (sundial gnoma)
Portland cement	*Bronze* (plaques, sundial gnoma)
Lead	*Iron* (dowells, staples, jougs, weathervanes, wire, railings)

<u>Ownership details</u>

This data set recorded any information about changing ownership of the market crosses through time. This data table was much under-used, since the sources consulted only rarely indicated any owners of the crosses other than the Local Authority.

Market cross identification number

Owner

Owner of the market cross, now usually the local authority. In the past local aristocratic individuals actually purchased these monuments on occasion (eg Banff cross).

Date of ownership

Records the year in which ownership of the cross commenced.

<u>Decay and soiling data</u>

These variables record information about decay and soiling observed on the market cross components during the field survey phase of the research. Note that more specific information regarding the distribution and extent of decay and soiling types is indicated upon the drafted mappings. Decay and soiling data was recorded for each individual sampled cross component.

Decay or soiling type

Each decay and soiling type observed upon each component was recorded in this field in the database. The classification options were as follows:

DECAY/SOILING GROUP	DECAY/SOILING TYPE
Biological soiling	*Algae*
	Fungi
	Higher plants
	Lichen
	Moss
Non-biological soiling	*Bird exrement*
	Black crust
	Staining
	Efflorescence
	Painted graffiti
	Particulate soiling
Planar disaggregation	*Blistering*
	Delamination
	Flaking (planes <5mm)
	Scaling (planes >5mm)
	Spalling
Granular disaggregation	*Crumbling*
	Differential weathering
	Dissolution
	Granulation
	Honeycomb weathering
	Pitting
Fracture types	*Fissures*
	Mechanical damage

Decay severity or soiling density rating

Classified per decay or soiling case, per component:

1 Low

2 Moderate

3 High

Extent of surface distribution

A basic classification of surface extent was made for each decay and soiling type, on each component. The drafted mappings provide an exact depiction of the surface distribution patterns. The classifications were:

Local, ie localised in extent, affecting under half the surface area of that component.

General, ie a general decay/soiling feature, affecting at least half the surface area of that component.

Orientation of affected facade

Records the orientations of the component affected by each decay and soiling type. Up to eight orientations could be recorded for each decay/soiling incidence, eg */N/* or */N/NE/* or */S/SE/SW/W/* or even */ALL/*. An entry such as */W/ALL/* indicated that this decay type affected all sides, but was noticably worse on the W side.

Intervention history

This data set records episodes of intervention since the erection of the market cross. This data was obtained both from archived sources and from deductions made during the field survey phase of the research. A separate set of data was recorded for each intervention episode, for each cross.

Intervention type and effects

The classification options for recording both intervention type and the correponding possible effects are listed below. Note that the proliferation of the '*unknown*' option is due to the frequent lack of details recorded for intervention in the archived sources.

Intervention type	Options for corresponding intervention effects
Redesigned	*Part removed; Stone replaced; Part added; Stone removed; Painted; Stone added; Stone redressed; Render application;*
Conserved	*Repointed; Plastic repairs; Waterproofed; Part removed; Part added; Cleaned; Flashings/capping; Brackets/clamps; Re-erected; Redowelled; Unknown; None;*
Resited	*Re-erected; Parts scattered; Part buried; Stored; Unknown;*
Restored	*Stone replaced; Unknown;*
Field visit	*Recommendations; None;*
Site altered	*Part buried;*
Unknown	*Unknown;*

Year of intervention

Year of intervention, where known.

Intervening body

This records the body who undertook the actual intervention work or who recorded the field notes. This data is often unknown. However, the options used were:

Royal Commission for the Ancient and Historical Monuments in Scotland, or *the National Monuments Record for Scotland*

Historic Scotland (includes work done by the predecessor, Historic Buildings and Monuments)

National Trust for Scotland (in the case of Culross cross only)

Ordnance Survey

Local Authority

Scottish Development Department

Unknown

Cross components affected

Market cross component(s) subject to this intervention episode, ie the part of the monument affected by the work.

Intervention details

Free text field to record details about the nature of each intervention episode, eg conservation method and materials used.

Type of records consulted

This data field contains a reference to the source of information from which the intervention data was derived. The classifications commonly used were:

Sites and Monuments Records

Historic Scotland Restoration Records

Listed Buildings Records

Scheduled Ancient Monument data

Publications, eg *Small 1900*

National Monuments Record photographic archives

LT fieldwork (Data deduced during the field survey undertaken during the present research)

CANMORE (On-line facilty to query the National Monuments Record for Scotland archives)

Appendix D

Examples of fieldwork reports on the condition of sampled market crosses

Fieldwork Report, 1998: Cromarty Market Cross

NGR: NH 7898 6739 **NMRS no:** NH 76 NE 3


Morphology

This fairly plain and poorly preserved cross consists of a rectangular-shaped base of three steps, surmounted by a stop-chamfered shaft. The capital sitting on top of the shaft is decorated with a lozenge pattern on the front face, and the stylised cross-shaped finial that crowns this is in the form of an upright block ending in a small trefoil.

Dating, survival and designations

The present shaft dates from 1578, and the capital and finial look suitably old to date from this time also. The steps probably date from the later re-erection of the cross around 1772, when the old cross was taken down from its original pedestal a little nearer the shore and re-erected upon its present site in front of the Courthouse. In the 1820's local writer Hugh Miller described an incident of vandalism to the cross immediately following this re-erection. Three local men had broken up the cross in spite, because they had not been invited to a ball. The application of subsequent conservation materials (cement render, Portland cement and iron) has inadvertently posed new risks to the condition of the monument. The survival of this cross can be graded as '2: *some components replaced plus localised repairs*'. The cross is a Scheduled Ancient Monument and is also a Category B Listed Building.

Site details

Cromarty is a small town in the Highlands which sits at the N edge of the headland where the Cromarty Firth meets the North Sea. The site is therefore very coastal. The cross sits on a small bed of pebbles within a grassed area in the Courthouse grounds. Some shelter from the elements is provided by the Courthouse wall, which stands about 0.5m to the rear (SW) of the cross. There is no direct exposure to motor vehicle emissions at this site.

Stone properties

The monument seems to have been built entirely from sandstone, although some parts are now covered over with cement render and Portland cement. The shaft is carved from a coarse-grained, amber-yellow sandstone, while the steps are cut from a medium-grained, red-pink coloured sandstone.

Summary of main types of decay and soiling

Eighteenth and nineteenth century conservation materials pose a significant threat to the monument condition. Large areas of the cement render have now cracked and broken away. The supportive iron straps and wire have expanded outward from the shaft. The oxidation of these iron fixings has caused the Portland cement to crack and become displaced from the shaft surface, placing stress upon the underlying stonework and perhaps even pulling surface flakes away from the shaft. It is widely appreciated that Portland cement encourages the accumulation of moisture within adjacent, more porous, sandstone. Additionally the cracked state of the Portland cement here on the shaft has allowed the developments of small pockets, in which damaging moisture could accumulate. The full extent of this ongoing, latent decay will only be seen at the removal of the offending materials.

The exposed areas of sandstone also show severe types of decay. Delamination is advanced, and has caused deep fissures extending down the middle section of the shaft. Severe scaling and crumbling are also causing the loss of surface stone. Biological soiling (particularly moss) is dense upon the steps.

Condition of affected areas

Shaft

The shaft is generally in a poor condition. The exposed shaft areas exhibit severe crumbling, scaling and fissures, due to delamination of the sandstone bedding. This decay seems most severe upon the rear of the cross shaft. Two deep fissures extend down the front and the rear side of the shaft, from which significant surface stone loss could imminently occur. During my fieldvisit crumbs and scales of stone were seen to be on the point of dislodging. There is a dense patch of green algae upon the cement render at the base of the shaft, and the rendered areas are also colonised by a sprinkling of lichen.

Capital and finial

The capital exhibits a general, heavy covering of green algae, particularly on the rear side. A heavy patch of moss also sits on top of this stone. A little spalling was seen around the bottom edge of the capital on the front (NE side). Cement render has also become detached from the capital. At the rear of the capital an area of cracked render has exposed a corroded iron dowel. The finial appears in a poor condition as large parts of the render covering have broken away, and the profile of the finial tip is very irregular when viewed from the side where stone has broken away. Some dense algal growth is apparent towards the top of the finial.

Steps

The steps appear to be in a reasonable condition although they exhibit dense biological soiling in the form of an extensive, thick layer of moss, particularly on the lower step. Algal growth is moderate, particularly on the top of the steps towards the rear of the cross shaft, and there are also some light patches of lichen. Loose, dusty particulate soiling forms a moderate general covering on the steps. None of the decay types observed on the steps are severe or extensive. The top step exhibits moderate pitting, where pits are rounded and measure up to 2cm in diameter. A light patch of delamination affects the S corner of the top step and the E corner of the lowest step. The middle step has some superficial fissures on the N corner, and minor mechanical damage is in the form of a chip knocked off the edge of the middle step on the front (NE side).

Suggested causes of decay

As described above, previous conservation attempts are likely to have adversely affected the condition of the cross. It is possible that some sea-salt introduced into the stone from the atmosphere may also be a factor in the decay.

Intervention history and requirements

Around 1772, presumably following the vandalism of the cross, the shaft, capital and finial were totally covered with render. Two iron bands were secured around the shaft some 60cm apart and linked together by a further vertical strap running down the rear of the shaft. The iron bands were affixed with further iron straps to the Courthouse wall to the rear to help support the cross. An iron cramp was affixed to the NW side of the shaft towards the top, along with several coils of wire, and Portland cement was liberally applied on top of these. The application of Portland cement to the upper rear (SW) side of the shaft, as well as to a smaller patch on the upper front (NE) side, may date from the 1840's when work was undertaken on and around the Courthouse. These conservation measures could be regarded as part of the history of the cross. However, as described above, they pose significant risks to the preservation of the cross and accordingly should be removed.

The conservation of this cross is an issue currently under consideration by the Local Authority who already have the necessary funds, but are seeking suitable methods and materials. The cross was subject to examination and recommendations for its conservation were issued in 1992 and again in 1993 by independent conservation consultants. The main options explored in these recommendations were whether or not to affix new stone to make up the original profile or to use plastic repairs. Another intervention solution put forward was to carve replicas for parts or even all of the cross, with the possibility of even moving and displaying the original cross indoors permanently:

What is without question is that the cross requires immediate attention to halt further material loss from the shaft surface. Large delaminating fissures down the length of the shaft require immediate consolidation. The corroded iron bands, dowels, wire, cement and render should all be removed and replaced with the conservation materials recommended by the consultants. Some repointing of the steps is also required. However, due to the friable nature of the exposed sandstone it is questionable whether the scaling and crumbling surface of the middle shaft section could be consolidated sufficiently to withstand many more seasons of weathering effectively. It might therefore be best to remove and display it indoors, perhaps in the Courthouse, and to erect a replica outside. The decisions regarding the conservation methods and materials should be based upon the current condition of the stone which would be fully revealed during the removal of the cement and render, and upon subsequent consideration of the vulnerability of the conserved stone to future weathering. Aside from the fragile condition of the cross shaft, the steps also require some repointing.

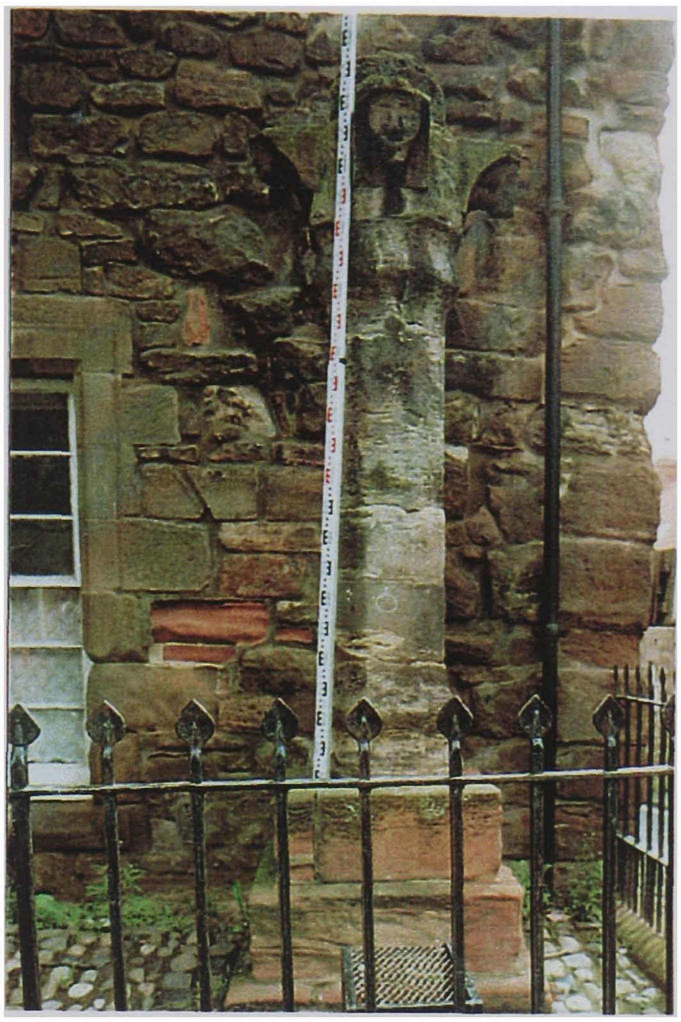
Decay rate

Archived photographs held by the NMRS were consulted with the aim of gauging the decay rate of this monument over time. The soiling (moss, algae, lichen and particulate soiling) on the monument can be seen to have increased in photographs since the 1960's. With regard to stone decay, very little difference was observed in the extent of the scales and delamination on the shaft in photos from 1957 to the present. Even the delamination cracks in 1961 appeared the same as today. Differential weathering on the SE side of the top step appears the same today as it did in 1979. On the top shaft section, render is seen to progressively detach in photographs from 1961 and 1963. Note also at this time the top left-hand stop of the shaft was visible with its profile modelled in the render, whereas today this has all eroded away. Photographs from 1992 show render extent identical to today. From 1963, photos show the increasing corrosion and displacement of the iron components. In 1963 the iron wire was not visible. Although the iron cramp was visible on the right-hand side of the shaft, it protruded less than today and lay almost flat against the side of the shaft. In 1979 and 1984 bands of wire, in quantities greater than today, could be seen encircling the top of the shaft. Today these have mostly eroded away, or have been removed. At this time the iron cramp still protruded less than today and was only just visible at the side. However, by the 1992 photography the iron cramp had been displaced outwards, as seen today.

In conclusion, the last 40 years have produced little visible change in the severe scales and delamination on the shaft, although the conservation materials (iron and render) have degraded significantly. However, if no intervention were performed the dislodging of surface material from the areas of fissures, scaling and crumbling would continue from the exposed sandstone on the lower shaft section. Increasing stresses would be placed upon the cross shaft by the expanding iron, which may prove too much for the thinning lower shaft section to support. Urgent intervention is recommended.

Fieldwork Report, 1998: Dunbar Market Cross

NGR: NT 6793 7895 **NMRS no:** NT 67 NE 6



Morphology

Dunbar market cross has been altered and now has a rather unusual design. The shaft comprises six octagonal blocks of stone with weathered moulding on the top and bottom sections. At the top of the shaft are three skewputts bearing grotesque human heads, protruding to the N, W and S, and above this the capital terminates in a dome-shape. The shaft is mounted upon a base of three square steps, the lowest of which is buried for much of its depth within the cobbles. Some small attachments include a piece of lead retained on the N side of the shaft within a small square recess indicative of a former attachment, and the remains of two rusty iron nails still embedded in the stone flush with the surface on the N side.

Dating, survival and designations

The shaft dates from the 1500's, and the steps date from 1913. The skewputts were also added in 1913; however, they pre-date this. They are thought to be relics of the old parish church, which has since been replaced by a modern structure. The NMRS data cites the tradition that the shaft *"may well be that of the 'castle cross' referred to in the historical note on NT 67 NE 36"*.

The right to erect a market cross in Dunbar was granted in 1369. The town was later granted royal burgh status in 1445, and was sacked twice during the 1500's. It thrived as a market town, port and fishing harbour, and from the late 1700's until 1945 it was a garrison town. The former site of the market cross is marked nearby in cobbles, in the road at the mini-roundabout. The cross components lay in the garden of the bank from 1736. The shaft was rediscovered here at around 1913 and was subsequently re-erected behind the bank. At this time the cross had a further finial component, a small, sculpted thistle, which has since disappeared. The cross was moved soon after this to its present site in front of the Town House.

The state of survival of the cross can be rated as '*2: some components replaced, plus localised repairs*'. It is designated a Category B Listed Building, and is not a Scheduled Ancient Monument.

Site details

Dunbar is located in the region of E Lothian, in the SE of Scotland. The location is very coastal, since the North Sea lies immediately to the NW, N, NE and E of the town, while the Firth of Forth is located 23km to the W. The market cross currently stands outside the Town House, in a former flowerbed, which is now a small cobbled and fenced area in the angle of the building. Immediately beyond the railings the land-use is pedestrian thoroughfare. The main road through the town is an 'A' road, with moderate traffic flow, and is located about 10m W of the monument. There is another quiet side street 2m to the S. Shelter is provided by a wall 0.5m to the E of the cross, and another wall of the same building lies about 2m to the N.

Stone properties

The shaft is made from a uniformly sorted, fine-to-medium grain size, yellow-coloured, siliceous sandstone. The capital appears to be carved from an orange-red coloured sandstone. The steps are built from a uniformly sorted, medium grain size, red sandstone. No evidence of inclusions was apparent in the sandstone.

Summary of main types of decay and soiling

The monument exhibits a variety of severe decay types on all its components. The most significant types can be summarised as follows. Differential weathering has severely affected all components.

Crumbling is a problem around the shaft joints and on the shaft's sheltered E face, and also on the steps, particularly on the S side. Granulation occurs around the joints of the shaft, and is severe upon the step facades, again particularly on the S side. A few light patches of spalling are evident around the shaft. Black gypsum crust is dense upon the sheltered and unwashed parts of the shaft and capital. Particulate soiling is moderate and extensive on all the less eroded parts of the shaft. It also occurs with varying density across the step facades, but is particularly heavy on the N and E sides. Green algae grow densely upon the capital and skewputts. Algal growth also features on parts of the steps, and is most dense upon the N side.

Condition of affected areas

Shaft

Generally the shaft appears very weathered. At the base on the E side a large area has been eroded inward, profoundly altering the symmetry of its profile. Although some plastic repairs have previously been made to the N side of the shaft base, some of this material has now come away to reveal underlying parts. Severe differential weathering occurs on all sides of the shaft, mostly on the upper three sections where it is extensive. Here many small deep pits have been weathered out within the differentially weathered layers, which could perhaps represent the beginnings of honeycomb weathering (the pits average about 1cm across). There is a further band of differential weathering at the base of the shaft. Crumbling is most advanced at the top of the shaft on the sheltered E face, and it also affects the stone around the joints. The crumbling is a severe problem which needs attention. Granulation of mostly moderate severity is also evident around the joints on all sides. There is a severe black gypsum crust on the E sheltered face of the shaft, and on the unwashed zones beneath the skewputts. A fissure is apparent on the middle of the shaft running around the NW, N, NE, and E sides. There are some small patches of light spalling on the S, E and W sides of the shaft. A small, light, patch of green algae grows on the W side of the shaft on the lower moulding. A small patch of very minor, painted graffiti is apparent on the W side of the shaft. Particulate soiling is extensive on all sides of the shaft with the exception of the eroded zones, and tends to be moderate in density. There is some light staining on the N side of the shaft from iron oxidation, due to the rusty nails embedded at this point in the shaft.

Capital

The skewputts were difficult to view in the field due to their height and the proximity of the townhouse wall on one side. Severe differential weathering covers the entire dome of the capital above the skewputts. It has weathered some deep pits in places. Green algae are extensive and very dense upon all sides of the capital, and could be considered disfiguring. A dense gypsum black crust occupies the unwashed areas of the capital beneath the skewputt protrusions.

Steps

There is some moderate differential weathering upon the steps, which has a localised surface distribution, mainly on the S and W sides. Crumbling is severe on the S face of the steps, on the differentially weathered zone, and it also affects the lower corners of the middle step. Granulation is very severe on the N, E and S sides of the steps. It is most serious on the S side where the grains detach abundantly from the surface when the stone is touched. Here the grains have been left behind in the sheltered layers of the sandstone while the cementing material has been dissolved. Unlike the N side, the surface material on the S side is quite unsoiled, probably due to the more rapid rate of granulation. A small zone of light flaking is apparent on the N side of the middle step. There are two fissures apparent on the facade of the upper step. One fissure follows the bedding alignment on the W face, while the fissure on the E side runs vertically down the facade. Particulate soiling is very dense on the N and E side of the steps. It is loose and dusty, mixed with loose sand grains from the stone. This soiled mixture drops away from the surface when touched. Green algae grow most densely upon the lowest step and upon the upper surfaces of the steps, and tend to be most dense on the N side of the monument. Lichen grows lightly upon the upper surfaces of the steps on the W side only. Note that the pitted appearance of the facade of the top step is due to tooling marks rather than decay.

Suggested causes of decay

The extensive protrusions of the skewputts and the shelter provided by the nearby wall to the E of the monument have caused the relatively large area of black gypsum soiling on this monument. The high sea-salt and moisture content in the atmosphere may have aggravated decay, particularly the granulation, crumbling and planar disaggregation.

Intervention history and requirements

The shaft has been dismantled and re-erected on two occasions. The skewputts were 'grafted on' at around 1913. Photographic evidence indicates that the sculpted thistle finial was removed at some point between 1937 and 1961. Photographs also indicate that a cap of mortar or cement was added to the top of the capital sometime between 1951 and 1970, probably when the carved thistle finial was removed. The cement 'cap' was later removed sometime after 1990. Some repairs have been made to the shaft base on the N side, although part of these repairs have come away to reveal underlying layers. It appears that at least three different cement mortars have been used as a plastic repair material on the shaft during and since its re-erection. The lowest step has been buried increasingly since 1913. Originally the steps were all the same height. However, by 1951 the area around the base of the cross had become a flower- or shrub-bed and the lowest step became partly buried. Today it is buried in the cobbles for most of its depth. The site has been surrounded by railings on-and-off since 1913. From photographic evidence there were railings in 1937, but no railings in 1951. Then in 1961 and in 1976 a low set of railings surrounded the site; however, these were no longer in place by 1990. However, railings were again added after 1990.

Today the severe crumbling on parts of the shaft requires consolidation, and the void left in the shaft by the erosion of the former plastic repair could be refilled. Repointing is also needed in some of the joints of the steps. The voids in the vacant joints are currently trapping dirt and water.

Decay rate

Photographs held in the NMRS archive were consulted in order to assess decay rates on the cross. All archived photographs were taken from a W or SW orientation. No significant changes were seen with regard to decay or soiling over the period from 1913 to 1998, with the exception that algae and lichen were a little less dense upon the steps in 1990 than they are today. However, substantial stone loss is ongoing due to the severe crumbling and granulation, and the monument will rapidly degrade if treatment is not soon administered.

Appendix E

Recommendations for the interpretation and promotion of Scottish market crosses to the public

The recommendations presented in this section step beyond the bounds of conservation and enter the realms of heritage interpretation and presentation. Such a discussion contributes towards more fully justifying the preservation and conservation of market crosses. Additionally, it ensures that the research and recommendations presented in this thesis comprise a comprehensive management framework for this monument type.

Market crosses are traditionally the focal point of Scottish burghs and have value historically, culturally, architecturally, socially and as a heritage asset. They also contribute towards generating a sense of pride in the local heritage amongst the population. Their existence today enhances the townscape of historic burghs and, wherever possible, their preservation on these sites should be favoured.

The economic and cultural value of the Scottish burgh is currently being reasserted. Whilst being aware of the risks posed to such monuments by the immediate urban environment, Local Authorities could also seek to raise the profile of the market cross within the visitor promotion, interpretation and general management strategy for our historical town centres. Recent initiatives are developing the idea of improving the environment in and increasing the promotion to visitors of our historic burgh centres, eg the Historic Burgh Association of Scotland (Cameron 1998) and the small towns Planning Advice Notes (The Scottish Office PAN 52 1997). The role of the market cross within this ought to be asserted.

Most Scottish burghs are relatively small towns, concentrated in the south and east of Scotland. Smaller towns in Scotland have clearly undergone significant changes in recent decades, due to population change, economic restructuring, the displacement of employment and services, traffic growth and insensitive development (The Scottish Office PAN 52 1997). For example, changes in the traditional industries and markets have required towns to seek new roles with regard to the local economy and employment. Populations have tended to migrate or commute to larger towns, and the increase of motor vehicles has demanded the upgrading and widening of roads and building of new ones. The recent conversion of properties and construction of new buildings has often corrupted the traditional character and appearance of the area. Tourism and recreation is one avenue that would seem to offer some prospects to smaller towns in the current climate. Similar lines of development have been pursued in Ireland in the 'Heritage Towns' scheme (Browne 1994). The historical attractions, traditional characteristics and charm of the

Scottish burgh could be further promoted as a heritage asset, in combination with interpretative aids and a variety of innovative and appropriate modern visitor facilities. Retail facilities could be more specialised and geared towards visitors who, in timeless pursuit, may wish to purchase souvenirs.

Existing examples of such developments include that at Culross, where the National Trust for Scotland's 'Small Buildings Scheme' has restored the sixteenth and seventeenth century remains of the historical burgh. While in this case the result is a static and rather sanitised version, it nevertheless provides an attractive and stimulating historic environment, attracting many visitors to the town. Preserved structures include the market cross, and selected buildings are open to the public. An alternative approach in St Andrews sought to improve visitor orientation and interpretation facilities in the town through a group of consultants (Glen 1994). This improvement, for example, began with a heritage audit of the town and a consideration of the existing and potential visitor market, vehicular traffic systems, environmental capacity, tourist advice in the town and the visitor potential of the hinterland. Interpretation and signage followed five broad themes perceived to be formative in the identity of the town. One of these focused upon the medieval heritage of the *mercat toun,* the remains of which still thrive as a retail centre. In the case of St Andrews the market cross no longer survives but its vivid history features in the interpretative material as the site of the burning of martyrs. Additionally the study sought to further promote lesser-known attractions in the town and in the surrounding area of NE Fife within the strategy. The competitive development and promotion of every historic burgh centre in Scotland for the purposes of tourism would be inappropriate, not least due to limitations in size of the visitor market. However, we might choose to focus promotion upon one with suitable historical and cultural attractions to represent a region, such as St Andrews in north-east Fife.

Interpretative material (eg information boards and guidebooks) could seek to convey to the visitor points of interest regarding the market cross architecture and inscriptions. Additionally, interpretation could include reference to specific episodes of interest in which the cross was involved. Thus our interpretations should seek to draw upon the documented evidence of Scotland's historic burghs (eg local burgh records and minutes), which conveys a highly-coloured, romantic and dynamic picture, in which market crosses were very much caught up in the historical context of:

- Rallying activity
- Highly emotionally-charged scenes of public outbursts and execution
- Crowded sites of public celebrations, some of historic and national themes
- Bustling scenes of trade
- Noisy point of contact between the national and local authorities on the one hand, and the general population on the other, in an age pre-dating mass media

Despite the benefits that could be offered by the increased promotion to visitors of historical Scottish burgh centres, difficulties would be posed by the limited carrying capacity in many of the smaller towns, especially with regard to provision for vehicular traffic. Increased provision for pedestrian and vehicular traffic and car parking in burgh centres might demand the obliteration or alteration of the historical buildings and layout. Thus, paradoxically, the development of facilities to cope with increased tourist numbers could threaten the very assets that one would wish to promote, thereby destroying the historical resources and traditional character of the towns. Careful thought is required in advance of any such development programme. Larger towns and cities could perhaps cope with the modest increase in visitors that such promotion might entail; however, smaller settlements would require out-of-centre traffic facilities and car parks.

Additionally there are also important ethical considerations to bear in mind. We should not aim to turn our town centres into 'themeparks', nor would it be desirable for historical Scottish burgh centres to be preserved as if in a time-warp. It is advised that the local characteristics and individual identity of small towns should be recognised in future developments and expressed in building styles, materials and street furnishings (The Scottish Office PAN 52 1997). However, it is also important that we avoid being overly conservative, stifling creativity in future building design and planning. The legacy of today's innovation contributes to the variety of tomorrow's expanding heritage resource. It is important to strike a balance. PAN 52 (The Scottish Office 1997) rightly advises cross-community and business involvement in issues and methods of town centre development and the pursuit of a shared vision. Local award schemes and design competitions can offer incentives and opportunities.