Development of Sustainable Georesources for the Built Environment in the United Kingdom

Andrew A McMillan and Ewan K Hyslop

British Geological Survey, Murchison House, West Mains Road, Edinburgh EH9 3LA, Scotland UK; aamc@bgs.ac.uk, ekh@bgs.ac.uk

Abstract. The character of the UK's built heritage has been largely determined by the country's diverse geology. Indigenous natural stone forms a major component of the nation's pre-1919 building stock. Stone has been used traditionally for roofing, roads, pavements and bridges and engineering works and all forms of walling. Today it is mostly employed as thin panel cladding to concrete frameworks in modern construction and is now increasingly being used in large volumes for new city streetscapes.

This paper outlines the material requirements for the repair and maintenance of the stone-built heritage and illustrates a range of initiatives across the UK aimed at safeguarding and redeveloping indigenous resources. The importance, particularly for the repair and conservation sector, of selecting appropriate replacement stone is being recognised by architectural and conservation professionals and by local authority officials. There is also increasing recognition of the importance to the economy of the local character of the built environment in terms of its value to tourism and to architectural, historical and cultural identity. The paper also examines the historical sources of information on stone in the UK and offers recommendations for databasing and disseminating stone resource information. This may assist the redevelopment of a healthy indigenous stone industry and ensure that the unique built heritage character of the UK is maintained and enhanced.

Keywords: Mineral resources, building stone, United Kingdom

INTRODUCTION

During the mid- to late-1800s the UK had several thousand working building stone quarries and mines in sandstone, limestone, igneous and metamorphic rocks that supplied local and national requirements. Quarries ranged in scale from those supplying material for individual buildings (e.g. farmsteads) to the needs of villages, towns and cities. As their reputation for producing good quality stone increased, quarries of national importance developed export markets for masonry stone, pavement and setts to Europe and North America. In the early part of the 20th century the decline of the building stone industry coincided with the manufacture and utilisation of other building materials, most notably concrete. In 2005 there were approximately 440 working quarries in the UK supplying exclusively building and pavement stone. In some cases, specific rock types are no longer quarried. In Scotland, for example, new supplies of indigenous slate, principally for roofing, have not been available since the 1950s, and there are currently less than 20 quarries supplying sandstone, one of the most important building materials in northern Britain.

NATIONAL INITIATIVES TO IDENTIFY AND SAFEGUARD INDIGENOUS RESOURCES

The safeguarding of resources for future use is a crucial element of the sourcing of indigenous stone. The UK Government's response to the Rio Earth Summit on Sustainable Development (1992) noted that '.... it will become increasingly important to have reliable information about the nature, quantity and location of mineral resources as workable reserves in environmentally acceptable areas become scarcer.'… Legislative planning for minerals working varies from country to country in the UK but Government minerals planning policies now make specific reference to the identification and safeguarding of building stone resources (Department for Communities and Local Government 2006; Scottish Executive 2006).

The development and use of locally sourced sustainable natural stone for the built environment is an important consideration for the construction industry. Today's global market has encouraged the importation of stone for new-build cladding and for new city streetscapes. Whilst this may positively influence public acceptance of the use of natural stone, consideration needs to be given to the use of 'like for like' indigenous materials for repairs and conservation work and the use of indigenous stone for some new build developments. This should ensure that the unique local character of buildings and urban environments is not lost for future generations. The importation of stone, produced more cheaply in less regulated environments overseas, greatly exceeds UK exports of this commodity (Figure 1). There is nevertheless an urgent need to examine the many benefits of using a higher proportion of local resources that may reduce transport and processing energy requirements and, in turn, reduce the related carbon footprint of the industry.

Figure 1

Scotland

In Scotland the Scottish Stone Liaison Group was established in 2000 by the Government heritage agency Historic Scotland (Historic Scotland 2000) to identify critical resource and skills needs and to promote the sustainable redevelopment of sources of stone which were formerly available (McMillan et al. 2006). There are now examples of former quarries being re-opened to supply the growing needs of major towns and cities. Petrographic studies of external stone masonry in the cities of Edinburgh (Hyslop 2004) and Glasgow (Scottish Stone Liaison Group 2006) have highlighted a range of issues including the condition of stone facades, the use of inappropriate stone and other materials for repair, the effects of various methods of stone cleaning and the general poor maintenance of buildings. In addition the Glasgow research has identified a significant proportion of buildings for which appropriate sandstone types (originally

sourced locally) needed for repairs, are not currently produced in the UK. The British Geological Survey (BGS) is developing a geodatabase of former quarry sources, accessed via a Geographical Information System to assist decision-making for repair and maintenance, the selection of stone for both conservation and new build, and planning for the reopening of former quarries. In addition the BGS provides petrographical advice on the selection of appropriate replacement stone for specific building repair projects throughout the UK.

England and Wales

Initiatives in Wales and England also reflect a growing awareness of the importance of safeguarding indigenous stone resources. The Welsh Stone Forum was formed as a result of a conference held in 2002 (Coulson 2005). Its aim is to promote understanding of the use of natural stone as a sustainable material in the Welsh environment. Public awareness and understanding of the stone built heritage is an important consideration which could provide support for the redevelopment of important georesources in areas where the stone industry may have been dormant for many decades.

Research undertaken under the sponsorship of the UK Government resulted in the publication in 2004 of the report *Planning for the supply of Natural Building and Roofing Stone in England and Wales* (Thompson et al. 2004). Following on from this report, National Mineral Planning Statement 1 for England reflects the requirement to safeguard these indigenous materials for future use (Department for Communities and Local Government 2006). To assist in this process an audit of quarry sources has recently been initiated by English Heritage. Initiatives developing from these publications, supported by participants at a recent Conference *England's Heritage in Stone* (March 2005, see www.geoconservation.com/GCCdocs/yorkconf.htm; Doyle 2007) have resulted in the formation of the English Stone Forum (ESF). A Strategic Stone Research project has commenced recently to examine the indigenous resources of each county following earlier

pilot studies, commissioned by English Heritage in the West Midlands of England and in the southern part of the County of Shropshire.

GEODIVERSITY AND ITS INFLUENCE ON THE BUILT HERITAGE

The UK's geological heritage dates back to some 3.1 Ga. A wide range of sedimentary, igneous and metamorphic rocks have been used for building purposes. Processes during the last 2.6 Ma (Quaternary) have redistributed surface materials and scoured the landscape providing ready sources of sands, gravels and clays for building purposes. This rich geodiversity has led to the use of many different building materials and as a result stone forms a major component of the pre-1919 building stock. Stone has been used for masonry, roofing, streets, pavements and bridges and all forms of walling, and is today being used in large volumes for new city and town streetscapes.

An example of the use of sandstone resources in the Midland Valley of Scotland

Principal sources of building stone in Scotland include Carboniferous and Devonian sandstones and flagstones (thinly bedded sandstones used for pavement and roofs) of the Midland Valley; Lower Palaeozoic greywacke sandstones, red sandstones and granites of southern Scotland; and Palaeozoic to Mesozoic sandstones, Proterozoic to Palaeozoic granites and metamorphic rocks of the Highlands and Islands (e.g. the Highland slate belts which supplied slate, principally for roofing, until the 1950s). Limestone was quarried as a source of lime for agricultural and building purposes (i.e. lime mortar) throughout Scotland.

In the Midland Valley of Scotland good quality Devonian and Carboniferous sandstone was quarried for constructional, paving and monumental purposes (MacGregor 1945) (Figure 2). For example, as the 18th to 19th century New Town of the City of Edinburgh (now a World Heritage Site) developed, mainly Early Carboniferous sandstones were utilised (Hyslop &

McMillan 2004) (Figure 2). The most famous quarries west of the city included those of Craigleith which supplied exceptionally durable, thickly bedded, massive, quartz arenite sandstone (Figure 3) (McMillan et al. 1999; Hyslop 2004). The City of Glasgow also utilised locally available Carboniferous sandstone (Clough et al. 1925; Lawson 1981; Scottish Stone Liaison Group 2006).

Figure 2.

Figure 3.

In the 18th and 19th centuries, the development of firstly canal and then railway networks allowed large quantities of stone to be transported to the Scottish cities (Figure 4) (McMillan et al. 1999). Numerous sandstone quarries across central Scotland supplied stone for prestigious public buildings, houses and tenements. In 1858 Scotland had 674 registered quarries (there were many more small workings) supplying local, national and, in some cases, international needs (Hunt 1859) (Figure 5). A high proportion (over 60%) of these quarries supplied Carboniferous sandstone from the Midland Valley of Scotland. As the railway system developed and local sources of the pale coloured Carboniferous sandstones dwindled supplies were imported from northern England, particularly Northumberland where new quarries became increasingly mechanised (Lawrence et al. 2007). By the end of the 1800s sources of Permian to Triassic red sandstone from the south of Scotland (Dumfries and Galloway, Ayrshire and Arran) became popular (Boyle 1909). Utilising the different sedimentary characteristics and the striking colour contrasts compared with the local pale coloured Carboniferous stone, the cities of Glasgow and Edinburgh used large quantities of this building material. Together with similar sandstones quarried in Cumbria, England (e.g. St Bees) the red sandstones also reached North America, often as ship ballast. Corsehill Quarry near Annan, Dumfriesshire, was favoured because it was particularly adaptable to fine carving.

Figure 4.

Figure 5.

After the 1st World War (post-1918) the building stone industry in the UK witnessed a steep decline in the number of quarries and the skills required to work and use stone for building

purposes. Throughout the century knowledge on the ground became an increasingly scarce commodity. By the 1990s, Scotland was left with approximately 20 quarries supplying exclusively building and pavement stone (McMillan 1997). In Edinburgh much stone for new building cladding projects and for repair work was imported from England (see McMillan et al. 1999; Hyslop 2004). During the 20th century it is estimated that only 31 % of stone used for repair and new building projects in this city originated in Scotland (Figures 6a, b). Of around 53 quarries in production in Scotland in 2005 (Figure 5), most were producing crushed rock aggregrate. Of quarries producing building stone, eleven worked sandstone, nine were in granite, four in flagstone and two in limestone (Cameron et al. 2005) (Figure 7). The decrease in the use of Scottish-sourced stone has been accompanied by an increase in imports from other parts of Europe. Several recent new build projects in central Scotland have used sandstone imported from Germany.

Figure 6a.

Figure 6b.

Figure 7.

Hyslop (2004) highlighted the importance, particularly for the repair and conservation sector, of selecting appropriate replacement stone on the basis of petrographic characteristics. In recent years, the increasing use of stone for both repair and new build has encouraged the opening of new quarries and the re-opening of long abandoned workings. An example in the Midland Valley of Scotland is the reopening of a former sandstone quarry in Fife (Cullalo) in 2003. Carboniferous sandstone from this working was recognised by architects in the early 19th century as a suitable alternative to Craigleith Sandstone (see above), and modern analysis confirms the petrographical similarity of the two sandstones (Hyslop & McMillan 2004). Sometimes, planning restrictions may constrain a quarry or a new excavation adjacent to old workings to be opened only for a short duration to supply material for specific building projects. An example of this practice (known as ‘snatch’ quarrying) was at Binny, West Lothian, west of Edinburgh, in the 1990s to supply material for specifically to repair the Walter Scott Monument in the city.

SOURCING INFORMATION ON STONE RESOURCES

Over the past three centuries with the rapid increase in use of mineral resources to feed firstly the development of the industrial revolution followed by subsequent economic prosperity, the requirement to locate, understand and quantify mineral resources became essential. In 1835 the quest for such knowledge was identified as a key factor in the establishment of the Geological Survey of Great Britain. Today, information on stone resources is available from a variety of archival and modern sources. However, largely because in earlier centuries stone was often locally sourced, worked and used, there are few detailed accounts of these resources and their properties. Despite the fact that knowledge transfer from generation to generation during the 20th century was patchy, both anecdotal and factual publications of the stone industry offer a valuable information source today to provide new generations with improved decision-making concerning the selection and use of indigenous stone materials.

At index level there is much useful information on former quarries. At the acme of building with stone during the mid-19th century 2348 quarries were registered as supplying building stone in the UK (Hunt 1859) (Figure 5). Subsequently, under the Quarries Act, Lists of Mines and Quarries were published regularly. In 2005 active quarries producing building and roofing stone in the UK stood at 440 (Figure 7). Many of the 19th century and early 20th century memoirs and economic memoirs of the Geological Survey contain summary information on local stone sources. Detailed accounts of stone mineralogy and weathering started to appear in scientific journals and in source reference works such as those of Hull (1872) and Howe (1910; recently reprinted 2001). Information is also available through trade testimonials, fact sheets and publications such as *The Builder*, *Quarry Managers' Journal* and *Natural Stone Specialist*.

As huge numbers of quarries were abandoned during the 20th century some were re-used as sources of hard rock aggregate. However many were abandoned, later to be infilled in a variety of ways (e.g. with colliery spoil, domestic refuse and other landfill schemes), and, particularly in urban settings, some became sites for new housing or retail development. Other quarries lie dormant, either water-filled or open vegetated holes. Some have significant biodiversity and/or geodiversity interest, and others in recent years have been recognised for their recreational potential (e.g. rock climbing).

Regional publications

From the 1980s onwards geologists working in the UK have recognised the value of documenting known sources of stone and linking those sources to the stone built heritage. Early studies (see Robinson, 1984 - and subsequent volumes for London - and Bennett, 1996) showed the concept of geodiversity and the links between natural and built heritage could be developed. In Scotland initiatives such as those for Glasgow (Lawson 1981) and for Edinburgh (Bunyan et al. 1987; McMillan et al. 1999) have stimulated much interest beyond the geological fraternity. Volumes documenting stone sources in Dumfriesshire, Moray, Iona and Caithness have begun to chronicle the industry. Working with Historic Scotland, BGS has prepared an illustrated volume on Scottish quarries (McMillan 1997) and most recently has been updating and validating a Scottish quarries database comprising many thousands of former workings. Recent publications have included a volume on *Building with Scottish Stone* (Natural Stone Institute 2005) which has alerted architectural, planning and building professionals to the value and use of indigenous stone, and *Stone in Scotland* (Hyslop et al. 2006), published by UNESCO Publishing in association with the International Association of Engineering Geology, Historic Scotland and the British Geological Survey. This book provides an index to the principal sources and uses of stone. The next stage of research is to develop in depth regional volumes, from which it may be possible to identify key resources worthy of detailed modern resource assessment.

MODERN RESOURCE ASSESSMENTS

Sourcing of indigenous stone is vital particularly as conservationists and architects are increasingly conscious of the need to use natural stone appropriately both for repair and for new building. Recent publications have aided the initial evaluation of the resource process, for example the first Building Stone Resources Map of Britain (British Geological Survey 2001). This map, underpinned by databases, outlines the principal sources of stone and links them to geological formation and lithology. Such data when used with other sources (e.g. BGS resource publications, archival data) are valuable aids for a range of building stone enquiries.

The BGS is developing its UK-wide database BRITPITS to assist in accessing information on quarry sources, products and geology. BRITPITs contains over 2400 entries covering active mineral workings in the UK of which a small proportion are currently producing building stone, together with approximately 15000 entries for inactive and former sites. It forms the basis for the Directory of Mines and Quarries published regularly by the BGS (Cameron et al. 2005). Summary data are available for a range of minerals, including building stone, via a Minerals-GIS Online Service for the regions of England and Wales (see www.mineralsuk.com). BRITPITS is also being used to store information on sources of stone used in buildings. Quarries information together with geological map data may be reviewed in a Geographical Information System (GIS) (Figure 8). These databases used together with the BGS's extensive rock and thin section collections aids the identification of original stone sources and appropriate replacement stone for building repair from currently active quarries.

Figure 8.

CONCLUSIONS

Concern for the repair and maintenance of the stone-built heritage has grown in the last decade with the recognition of the importance of local character to the UK economy in terms of value to tourism and to architectural, historical, cultural identity. Public interest in the natural and the historic built environment has increased in recent years. Consistently 'exit poll' surveys of

tourists indicate that a high proportion of visitors appreciate the UK's landscape, built heritage and history.

The need to meet international and government sustainability targets has encouraged a fresh examination of the benefits of using local resources, for example by a reduction in transport and processing energy requirements. There is a steadily increasing recognition that natural stone is not only aesthetically more pleasing and durable but also compares favourably with other building materials in terms of life cycle cost analysis (Historic Scotland 1997; Natural Stone Institute 2005).

Provision of accessible information on stone is a pre-requisite for informed decision-making to maintain and enhance the UK's built heritage. Fullest utilisation of information sources should be made to enable strategic planning of building stone resources. This involves thorough archival and literature research coupled with field assessment.

Dissemination of resource information via regional publications and an online service such as www.mineralsuk.com may provide ready access for those requiring information, such as architectural practices, local and central government. The applicability of methods employed by the Strategic Stone Research initiatives being developed by English Heritage for England and a new Natural Stone Database for Northern Ireland, shortly to be launched, should be assessed. In this way, the necessary information can be accessed to conserve and sustain the UK's stone built heritage for future generations.

Acknowledgements: Mr Mike Browne and Mr Andrew Bloodworth (BGS) are thanked for constructive reviews of this paper. Ms Alice Custance-Baker is thanked for help in producing the figures. The authors publish with permission of the Executive Director, British Geological Survey, NERC.

REFERENCES

Bennett, M.R. (editor). 1996. *Geology on your doorstep: The role of urban geology in earth heritage conservation*. Geological Society of London, London.

Boyle, R. 1909. The economic and petrographic geology of the New Red Sandstones of the south and west of Scotland. *Transactions of the Geological Society of Glasgow*, **13**, 344-383.

British Geological Survey. 2001. *Building Stone Resources Map of Britain* (1: 1 000 000). Lott, G. K. British Geological Survey, Keyworth, Nottingham.

Cameron, D.G., Bartlett, E.L., Highley, D.E., Lott, G.K. & Hill, A.J. 2005. *Directory of Mines and Quarries 2005: 7th Edition*. British Geological Survey, Keyworth, Nottingham.

Clough, C.T., Hinxman, L.W., Grant Wilson, J.S., Crampton, C.B., Wright, W.B., Bailey, E.B., Anderson, E.M., & Carruthers, R.G. 1911. The geology of the Glasgow district (Glasgow District Map, including parts of sheets 30, 31, 22 and 23). *Memoirs of the Geological Survey of Scotland*. HMSO, Edinburgh.

Coulson, M.R. 2005. *Stone in Wales – materials heritage and conservation*. Papers from the Welsh Stone Conference, Cardiff 2002. CADW Cardiff, Wales.

Department for Communities and Local Government, 2006. *Minerals Policy Statement 1: Planning and Minerals, Annex 3: Natural building and roofing stone*. TSO: The Stationery Office. (http://www.communities.gov.uk/documents/planningandbuilding/pdf/152993)

Doyle, P. (editor) 2007 in preparation. *England's Heritage in Stone*. Proceedings of a Conference in York 2005. English Stone Forum.

Historic Scotland. 1997. *A Future for Stone in Scotland*. Historic Scotland, Edinburgh.

Historic Scotland. 2000. *Scottish Stone Liaison Group Launch Abstracts*. Historic Scotland, Edinburgh.

Howe, J.A. 1910, reprinted 2001. *The geology of building stones*. Donhead Publishing Ltd, Shaftesbury.

Hull, E. 1872. *A treatise on building and ornamental stones of Great Britain and foreign countries*. Macmillan, London.

Hunt, R. 1859. *Mineral statistics of the United Kingdom of Great Britain and Ireland (for the year 1858), Part 1*. Memoir of the Geological Survey of Great Britain. Geological Survey of Great Britain.

Hyslop, E.K. 2004. The performance of replacement sandstone in the New Town of Edinburgh. *Historic Scotland Research Report*. Historic Scotland, Edinburgh.

Hyslop, E. & McMillan, A. 2004. Replacement sandstone in the Edinburgh World Heritage Site: problems of source and supply. 777-784 in *Proceedings of the 10th International Congress on Deterioration and Conservation of Stone*, Volume 2, Kwiatkowski, D & Löfvendahl, R (editors).: ICOMOS Sweden, Stockholm.

Hyslop, E.K, McMillan, A.A., & Maxwell, I. 2006. *Stone in Scotland*. Earth Science Series. Paris: UNESCO Publishing, Paris.

Lawrence, D.J., Arkley, S.L.B., Everest, J.D., Clarke, S.M., Millward, D., Hyslop, E.K., Thompson, G.L., and Young, B. 2007. Northumberland National Park: Geodiversity Audit and Action Plan.

Lawson, J. 1981. *The building stones of Glasgow*. Geological Society of Glasgow, Glasgow.

MacGregor, A G. 1945. The mineral resources of the Lothians. *Wartime Pamphlet*, **45**. Geological Survey of Great Britain.

McMillan, A.A. 1997. Quarries of Scotland. *Historic Scotland Technical Advice Note*, **12**. Historic Scotland, Edinburgh

McMillan, A.A., Gillanders, R. J. & Fairhurst, J. A. 1999. *Building stones of Edinburgh*. 2nd edition. Edinburgh Geological Society, Edinburgh.

McMillan, A., Hyslop, E., Maxwell, I. & McKinney, A. 2006. Indigenous stone resources for Scotland's built heritage. International Association of Engineering Geology Paper Number 825 Abstract. The Geological Society (London) (www.iaeg2006.com)

Natural Stone Institute, 2005. *Building with Scottish Stone*. Arcamedia, Edinburgh.

Robinson, E. 1984. *London Illustrated geological walks. Book 1*. Scottish Academic Press, Edinburgh and London.

Scottish Executive Development Department, 2006. *Planning for Minerals*. Scottish Planning Policy SPP 4 (www.scotland.gov.uk/Resource/Doc/146319/0038293.pdf)

Scottish Stone Liaison Group 2006. Safeguarding Glasgow's stone-built heritage.

Thompson, A., Hine, P., Clayton, J., and Stow, B. 2004. *Planning for the supply of natural building and roofing stone in England and Wales*. Research Report to the Office of Deputy Prime Minister.

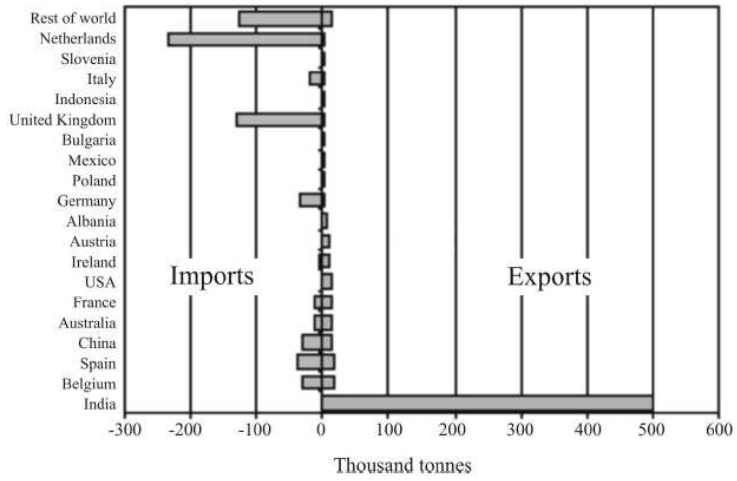

Fig. 1. Imports of sandstone to the UK in 2005 (from BGS 2005. Data source UN Comtrade database).

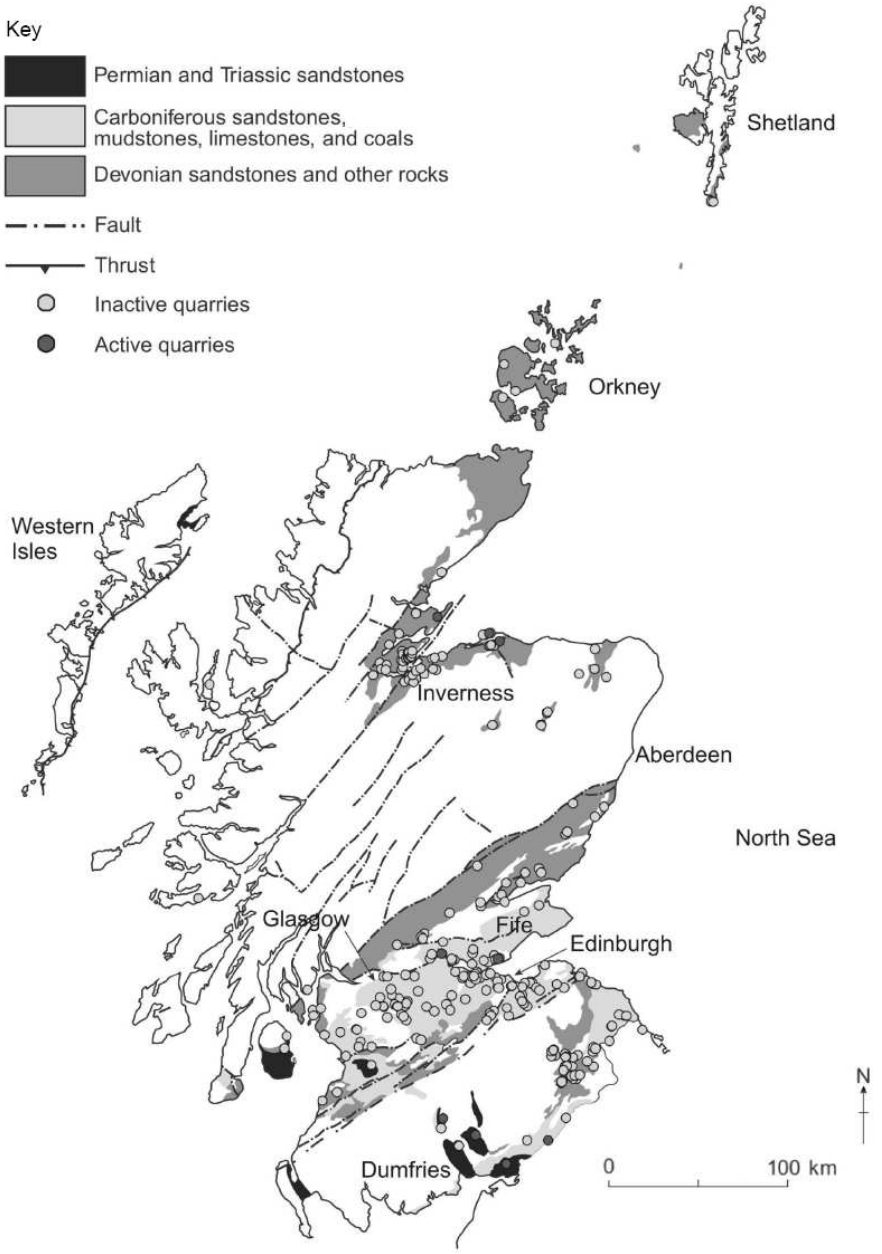

Fig. 2. Sandstone quarries in Scotland (after Hyslop et al. 2006).

Fig. 3. The requirement for thick continuous beds of good quality sandstone is exemplified by the columns of the Royal Scottish Academy in the New Town of the City of Edinburgh (1826). Stone from Craigleith and other Scottish quarries in central Scotland was used for construction of the columns and for pavement (Photo: A. A. McMillan).

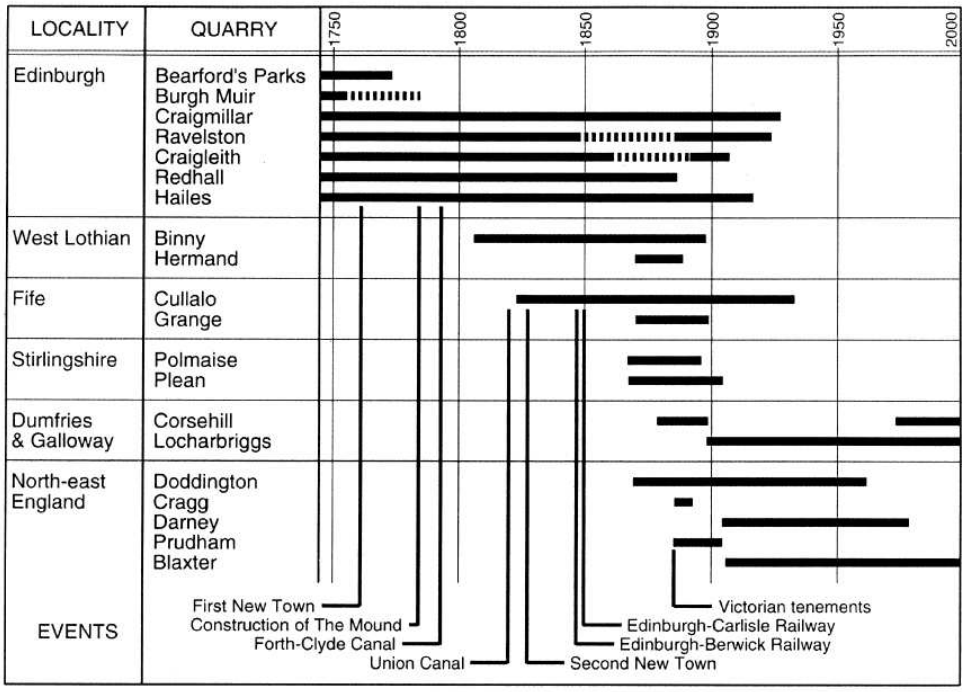

Fig. 4. The influence of historic events and development of transport upon the use of stone from selected quarries for Edinburgh's buildings (McMillan et al. 1999).

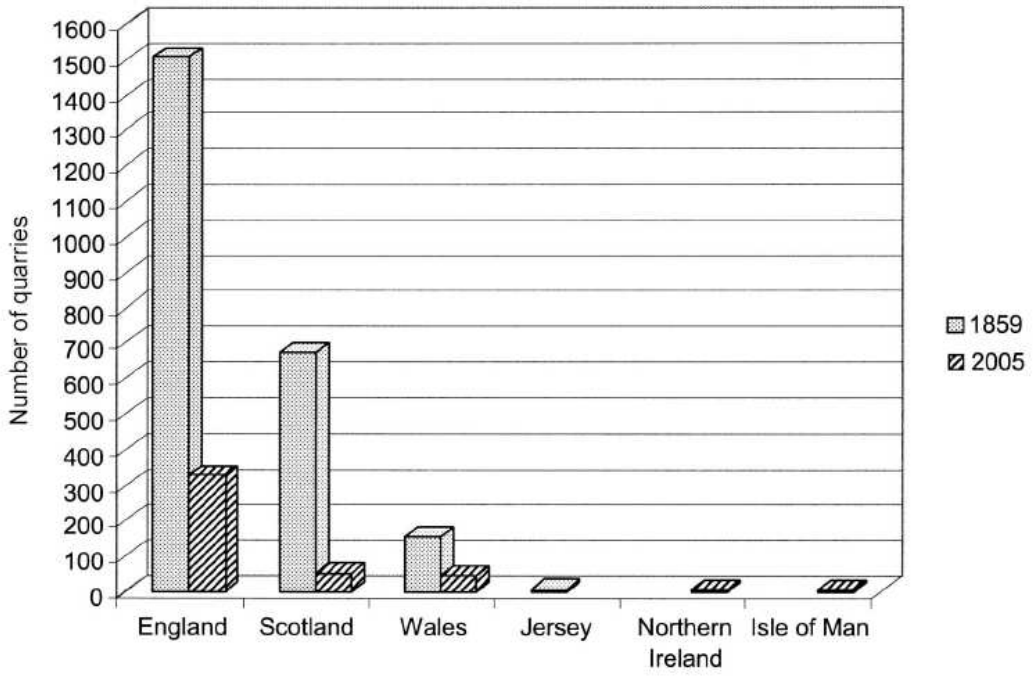

Fig. 5. UK quarry sources of stone 1860 (Hunt 1860) and 2005 (Cameron et al. 2005).

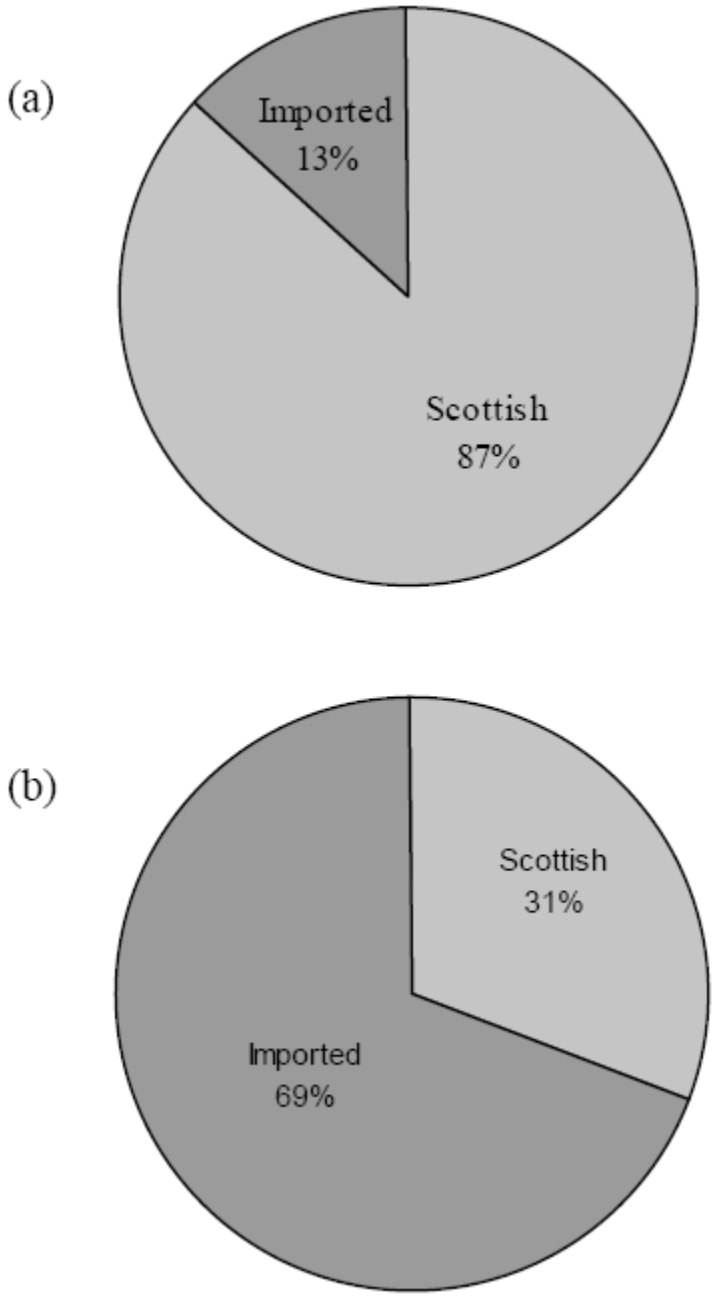

Fig. 6. Sources of building sandstones used in Edinburgh in the 19th (a) and 20th (b) centuries. Data from McMillan et al. (1999) and Hyslop (2004).

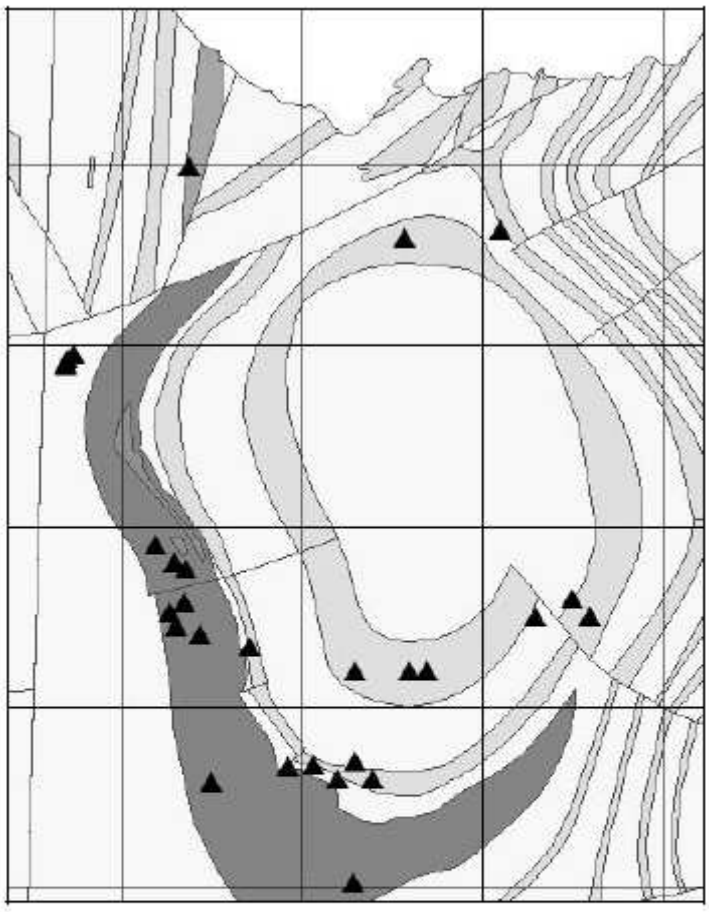

Fig. 7. Extract from a GIS of former quarry sources in Edinburgh with geological backdrop. Location of former quarries shown by filled triangles. Dark grey ornament: igneous rock (dolerite), light grey ornament: sandstone. Map grid boxes are 1 km × 1 km.

Table 1. Distribution of active building stone quarries in the UK, March 2005 (source BGS)

	Scotland	England	Wales	Northern Ireland	Isle of Man	Total
Building sandstone	19	159	14	1	0	193
Building limestone, incl. chalk	5	117	11	2	2	137
Granite & other igneous rocks	25	16	3	3	1	48
Slate & marble	1*	23	16	0	4	44
Ironstone flint, serpentine, etc.	3	14	1	0	0	18