The Edinburgh Geologist

No. 26 Autumn 1991

Saltire Court, Castle Terrace, Edinburgh

THE EDINBURGH GEOLOGIST
No. 26 Autumn 1991
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Cover Illustration

Saltire Court, Castle Terrace, Edinburgh. The building, erected on the former site of the Synod Hall, is faced with Stainton Sandstone; with quoins of Gatelawbridge red sandstone from SW Scotland. BGS photograph MNS 5592A; photographed by Mr F I MacTaggart, Photographic Unit, BGS Murchison House, reproduced by permission of the Director, British Geological Survey, NERC copyright reserved.

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Editorial

I hope that this edition of The Edinburgh Geologist will be one that many members of the Society (especially those who live or work in Edinburgh) will find to be of particular interest. The three articles deal with aspects of the geology, geomorphology and history of the Edinburgh Castle Rock and the nearby Castle Terrace site (which was formerly the famous, or infamous, 'Hole in the Ground') that was a feature of the city landscape for more than 24 years.

Phil Davies' article deals with the engineering geology work associated with the construction of the recently completed vehicular access tunnel to Edinburgh Castle. Nigel Ruckley's article focuses on the influence of geology and geomorphology of the Rock on the form and development of the Castle itself. Norman Butcher, for many years an enthusiastic member of the Society, writes on the saga of the 'Hole in the Ground' in Castle Terrace. The site, once occupied by The Synod Hall which was the Society's home in its early years, was earmarked for a new opera house that was never built; the recently completed Saltire Court building now stands in its place.

I wish to thank Scottish Metropolitan Property PLC for their sponsorship of the printing of the front cover of this special edition of the magazine. It is hoped that an article dealing with engineering geology aspects of the construction of Saltire Court will be included in the next issue of the magazine.

The remainder of Issue 26 covers the Proceedings of the Society for the 156th Session (1989-90). These provide details of the many meetings (both lectures and field meetings) held by the Society, including the lecture given by Professor J Horner, of the University of Montana, on the social behaviour of dinosaurs, which was jointly sponsored by the Society and the Royal Museum of Scotland and attracted an audience of some 300 people.

Articles for inclusion in future editions of the magazine are always welcome from all members of the Society. Please keep them coming (in double-spaced format, if possible). Those contributors who have access to a word-processor can submit text as ASCII files on diskette, accompanied by a printed manuscript. Please use standard 3½" or 5¼" diskettes. Both double density (DD) and high density (HD) diskettes are acceptable. Make sure, however, that the diskette is formatted according to its capacity (HD or DD) before copying files on to it. The use of electronic text speeds the production of each article and hopefully the magazine as a whole.

Clive Auton
November 1991

Engineering Geology in Edinburgh: The Castle Tunnel

Philip Davies
James Williamson and Partners

Background

This paper has been assembled following the talk given to the Society on 10 October 1990. It covers many of the points which were brought out in the talk and aims to highlight the principal geological findings from both the investigation and construction phases of work on the new vehicular service tunnel at Edinburgh Castle. The talk also covered geological aspects of Saltire Court at Castle Terrace; these are described in a companion paper which will be included in a subsequent issue of this journal.

The Castle is arguably the best known landmark in the country and dominates the city. It is Scotland's premier tourist destination, and attracts over one million visitors each year. Intensive geological studies have been carried out in connection with the current improvement programme, and it is therefore particularly appropriate that the work should be reported to this Society.

Geological Setting

The geology of central Edinburgh is shown in Figure 1, which is based on the published 1:25000 scale BGS sheet. The main features are the gently dipping Carboniferous age Cementstones Group surrounding the basalt plug of Castle Rock. An eastward moving ice sheet sculpted the terrain, forming a classic 'crag and tail' morphology, with the relatively weak rocks of the elevated ground of the Castle Esplanade and the Royal Mile lying in the glacial shadow of the basalt crag. Superficial deposits in the tail area include till, this being generally masked by the substantial thicknesses of infill material which have accumulated since the Middle Ages.

Other relevant features of interest include the Postglacial landslip area within Prince Street Gardens, to the north of the Castle and the faulting at the western end of the Esplanade, which may be seen at outcrop near Johnstone Terrace.

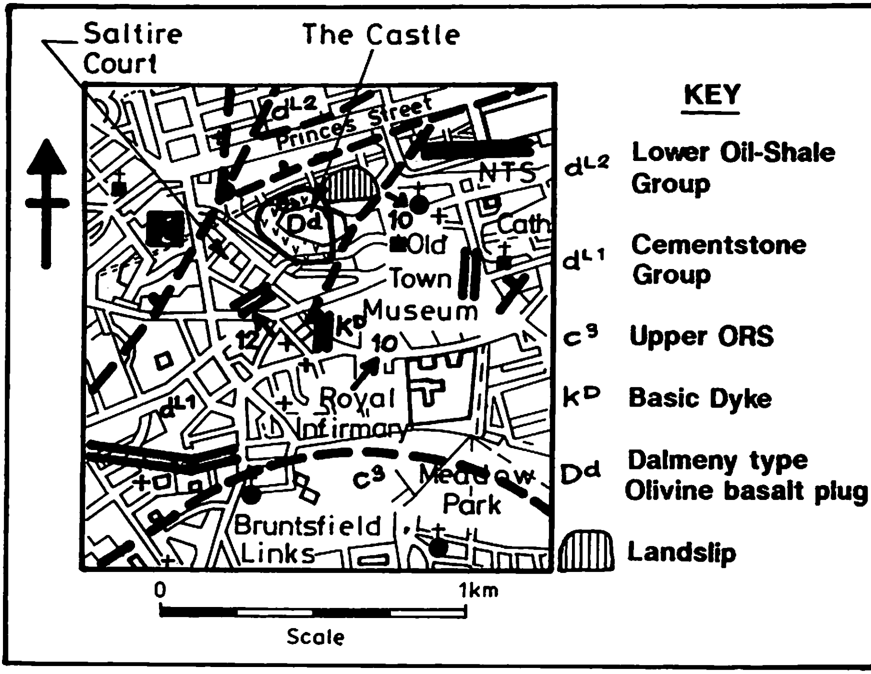

Figure 1 Location Map with local geology.

Feasibility Stage Investigations at the the Castle

Management and operation of the Castle falls within the remit of Historic Scotland, who in the late 1980s embarked on a programme to upgrade the Castle facilities, providing an environment to match its status as a major visitor attraction. Following an early wider ranging remit, it was decided to investigate the option of a service tunnel in more detail. A tunnel offered the opportunity to divert vehicular traffic within the Castle from the route most heavily used by pedestrians. Further advantages of a tunnel were enhanced access for emergency vehicles and the possibility of rerouting all the principal services, such as the water supply, which required refurbishment in any case.

The tunnel route that was studied approximated to the finally selected layout which is shown in Figures 2 and 3. Of the overall tunnel length of 164m, 97m ran through the Castle Rock, with the remaining length being cut-and-cover reinforced concrete structures. The principal objectives of the study were to elucidate the geological conditions for a tunnel; to check the suitability of the tunnel approaches for trafficking and to establish practicalities and cost for constructing a tunnel within the Castle itself. Key activities are listed below:

- Desk study – examination of all available Castle and geological records.
- Geological mapping of the area including the tunnel route, including the survey of joint sets at all outcrops and available exposures.
- Trial pit investigations at the foundations to the North Perimeter Wall to assess the reason for apparent distortion.
- Borehole investigations extending into the Postglacial landslip area north of the Castle, again to assess the stability of the Castle structure at the eastern tunnel approach.
- Investigations at the Dry Ditch Bridge to clarify reasons for its misalignment.

The main findings were:

- The rock tunnel would run mostly through the hard basalt, passing into sedimentary rock at the plug margin near the eastern end.
- The old landslips and distortion to the North Perimeter Wall did not jeopardise the route.
- The Dry Ditch Bridge foundations had settled, and would need strengthening or replacement to allow for potentially heavier vehicle loads.

These investigations clarified the feasibility of the tunnel and highlighted a number of important considerations. It was clear that care would be required to avoid loss of archaeological features and that since blasting would be required for excavation, special consideration would be needed at this sensitive location.

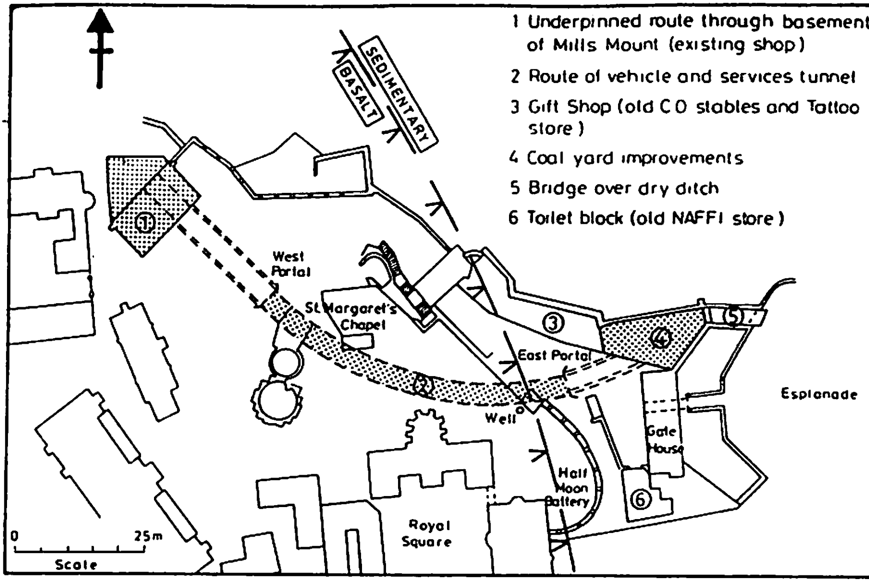

Figure 2 Plan of tunnel route in relation to other development works with in the Castle.

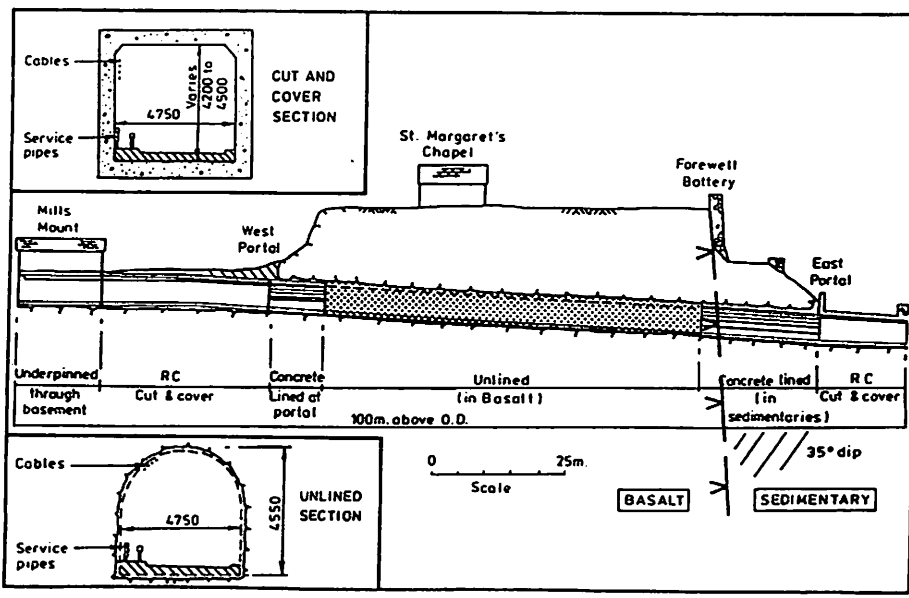

Figure 3 Longitutinal and cross sections through tunnel.

Detailed Investigations at the Castle

It was decided to progress the project and move into final investigations. These comprised the following activities:

- Archaeological investigations to clear the way along the tunnel route, these being geologically logged as well as archaeologically recorded.

- Cored boreholes to assess ground conditions at the rock portals which were potentially difficult to construct.

- Site blasting trials to establish ground rules for construction blasting without undue risk of damage to Castle buildings or excessive disturbance to members of the public.

Geological findings relevant to tunnel construction are listed below. The investigations also provided petrological and other geological information contained in the Appendix.

- The basalt rock quality deteriorated near the plug margin, possibly due to chilled margin effects. Conversely, the quality of the sedimentary rock improved near the basalt interface, perhaps due to thermal alteration.

- The basalt exhibited lower material strength than expected in laboratory tests, failing along yellow stained microfissures, which were found to contain penninitic chlorite in x-ray diffraction analysis carried out at the Grant Institute.

- The jointing pattern, important to tunnel stability, was difficult to predict in detail given the variability revealed in mapping. The jointing present at the plug has been devided into three sets (radial, dome and cicumferential) by Price and Knill (1967). The dominant set along the tunnel route, striking east-west, may correlate with the radial set.

- Blasting offered a viable construction technique subject to strict control being applied.

Tunnel design work and contract preparation were completed, and the construction contract was awarded to Lilley Construction Ltd in December 1988.

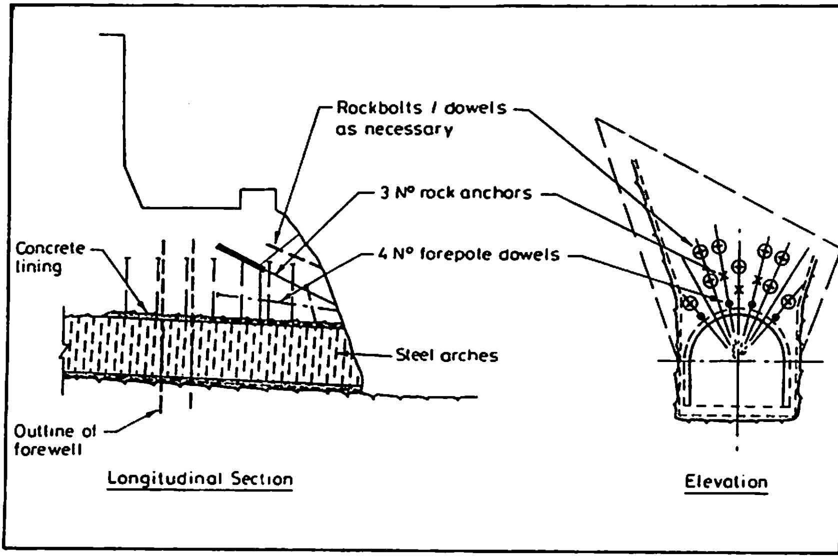

Figure 4 East portal construction details.

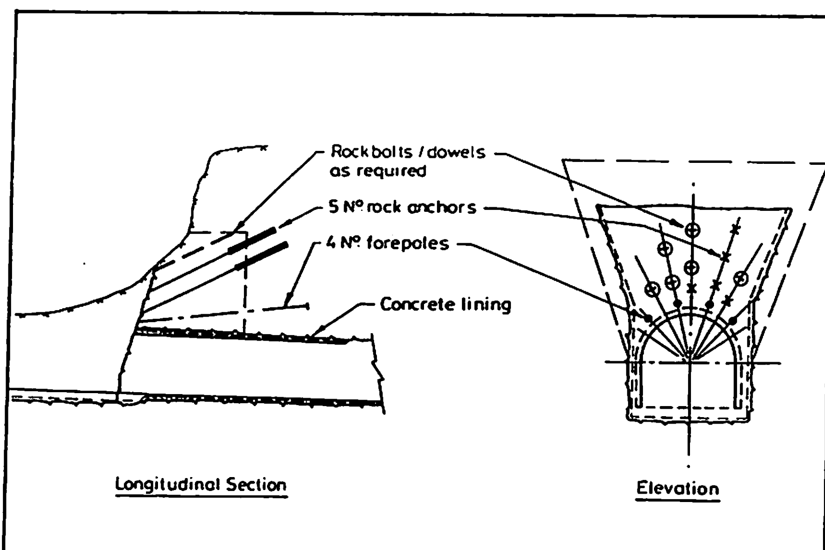

Figure 5 West portal construction details.

Geology of the tunnel

Tunnel construction commenced with the creation of secure portal faces at either end. At Mills Mount this neccessitated the construction by blasting of a box-like shaft to reach the eventual tunnel floor level. The faces at both portals were geologically mapped as they were formed to enable the detailed rock reinforcement design to be carried out. This entailed the installation of tensioned anchorages as illustrated in Figures 4 and 5. The security of the slope faces was ensured by the use of reinforced sprayed concrete and the installation of rock bolts.

At the eastern end, the tunnel into the sedimentary strata was cautiously commenced using an impact hammer and small scale blasting, and substantial steel arches were installed as the face was advanced. Given concerns over rock quality, including open and clay-filled joints, this method was continued throughout the sandstones and baked marls and into the less fractured basalt away from the plug margin. The most critical section was where the tunnel passed only 1.5m from the edge of the Fore Well, which was dewatered in advance. The well, which lies within the fractured basalt, is about 3m square and extends to a depth of 40m. Particularly careful excavation and ground reinforcement were required to pass the well successfully.

The basalt/sedimentary interface was found to be a tight 'welded' discontinuity.

From the Mills Mount shaft, the tunnel was driven by blasting into the basalt, Figure 6. Although precautions were neccessary to secure large blocks defined by major iron stained joints, the heading was advanced using ground reinforcement and without steel arches. The face was excavated as planned, using drill-and-blast with light charges. The upper part of the tunnel was excavated first, and the roof section was secured, whilst excavation of the lower section lagged some metres behind. The principal stability concern was associated with the persistent east-west joint set striking along the tunnel and dipping at approximately 40° to 70°; rock bolting was used to counter potential sliding instability. Sprayed concrete was applied to prevent any minor rockfalls. The tunnelling operation took four months to breakthrough.

Construction work was subject to a number of constraints, such as defined

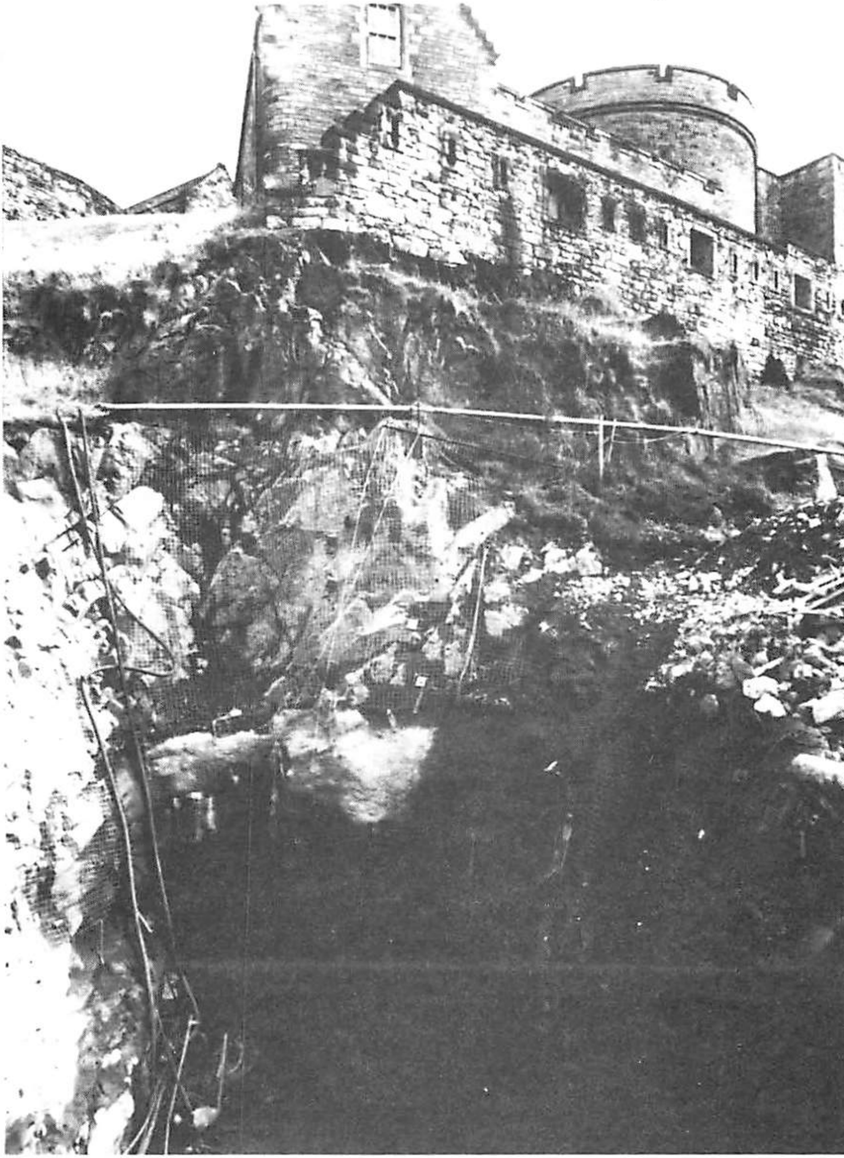

Figure 6 Temporary exposure at the Mills Mount Portal, during tunnelling work.

permitted blasting times, restricted access to construction plant and the need to phase the works to permit archaeological investigations. All blasting was monitored using automatic recording equipment. St Margaret's Chapel lies only 17m above the tunnel and is founded on the basalt. This is a valued 12th Century building, and monitoring equipment was placed at the altar to ensure that vibration limits were not exceeded. Excavation was completed without discernible structural damage to any of the Castle buildings (Isaac, 1990). A more detailed account of engineering aspects is given by Douglas and Keeble (1990).

Conclusions

The first phase of the upgrading programme, comprising the tunnel, a new shop development and toilet block, was completed in January 1990 and is now in full operation. The project earned for Lilley a Saltire Award for construction, and for the consultants a design commendation.

Acknowledgements

The author wishes to thank Historic Scotland for permission to publish this paper. The project benefitted from the enthusiastic input of the various parties which were involved. The principal parties are listed below.

Client: Historic Scotland
Castle Superintendent, Mr Alan Armstrong and his staff.
Civil engineering and lead consultant: James Williamson and Partners.
Mechanical and electrical consultant: Hulley and Kirkwood.
Project architects: Hurd Roland.
Main contractor: Lilley Construction Ltd.
Tunnelling subcontractor: Cementation Mining Ltd.
Portals/rock reinforcement subcontractor: Albion Drilling Ltd.
Site investigations: Wimpey Laboratories Ltd, Ritchies.
Blasting trials: Rocklift Ltd, Rock Environmental Ltd.
Specialist petrography: Grant Institute.

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Appendix

A generalised petrological description for the basalt is given below:

Medium to dark grey; fine, sometimes medium grained porphyritic alkali olivine basalt.

Variable alteration. In places showing pseudomorphs of chlorite, bowlingite and granular carbonate after olivine. Some quartz and feldspar phenocrysts.

Fine fissures infilled with serpentine and chlorite minerals.

Composition (indicative percentage ranges from two samples) –

Plagioclase	44–58
Fine grained groundmass	0–29
Clinopyroxene	4–17
Olivine	10–15
Opaques	7–12

Traces apatite, biotite.

Sedimentary rocks present at the eastern part of the Castle comprise greenish grey and red, thinly to thickly bedded metamorphosed mudstones, siltstones and sandstones with some calcareous nodules, calcite and siderite veins.

The Hole in the Ground

Norman E Butcher
The Open University in Scotland

One of the many advantages of working as a geologist from an office in the West End of Edinburgh is that it allows a casual eye to be cast on all building and other developments taking place in the city. In this way, we can augment the observations of James Hutton and his friends (see Craig, McIntyre and Waterston, 1978) at the end of the eighteenth century, as well as several members of the Society since its inception in 1834.

Armed with the excellent 1:25 000 Geological Special Sheet of the Edinburgh District (sadly, the only one ever produced in Scotland), it is always good fun to check any new, temporary rock exposure in foundation excavations, with the declared wisdom of the Geological Survey as conveyed in the geological map. Of all the many holes in the ground I've peered into over 21 years in the city, none has been more important to the Society than the Hole in the Ground in Castle Terrace, adjacent to the Usher Hall.

Site of the Society's former home, in the Synod Hall, this particular 'Hole in the Ground' has, over the years, assumed much the same sort of fame as has that erection on the Calton Hill. Only with the Hole it has been, until recently, a continuing saga of schemes for an Opera House that has never been built. These were the subject of an excellent exhibition in the offices of the Royal Fine Art Commission for Scotland at 9 Atholl Crescent in Edinburgh, during the Festival in 1988.

March 1988 saw the first signs of activity in the Hole which had remained an eyesore since the mid-Sixties. I recall suggesting at one point that it might be used as an inner-city site for waste disposal. In that month there took place site investigations by drilling over the whole area of the site, to determine amongst other things the depth and character of the bedrock. A small exposure of the bedrock was in fact to be seen in the western corner of the deep basement of the demolished Synod Hall. Demolition of the Little Lyceum Theatre in the western corner of the site, followed by excavation over the whole area to create a very deep basement, took place early in 1989. By May of that year, a substantial face in the Cementstone Group of the Lower Carboniferous had been exposed (Figure 1), immediately adjacent to the Usher Hall. By kind permission of the developers, Scottish Metropolitan, through Mr Andrew Lecudi, Project Manager, and Sir Robert McAlpine Management Contractors Ltd, through Mr McLean, Project Manager, the Society was able to have a site visit in the evening of 7 June 1989. The state of the exposed face in the low-dipping, thinly bedded Cementstones had already given some cause for concern with regard to stability and Mott MacDonald UK Ltd were engaged to carry out the necessary geotechnical work (see the forthcoming article by Phil Davies).

Figure 1 The Castle Terrace site: 2 May 1989 showing temporary exposure of thinly bedded sandstones and mudstones of the Cementstone Group.

This new and temporary exposure in the Cementstone Group confirmed, if anything, the geology shown on the 1:25 000 sheet. The Colinton Fault shown on the map must be close to the line of the Lothian Road, since steeply-dipping black shales, of the Lower Oil Shale Group underlie the nearby Sheraton Hotel, built in recent years.

At the time of writing (August 1991), the multi-purpose Saltire Court building occupying Edinburgh's famous Hole in the Ground is nearing completion (see photograph on cover). It is faced with Stainton Sandstone from the north of England with Gatelawbridge red sandstone from south-west Scotland. It also incorporates two Scandinavian stones, from Edalhammer and Blaubrun, both described as granites. It is thus a major addition to Edinburgh's built environment.

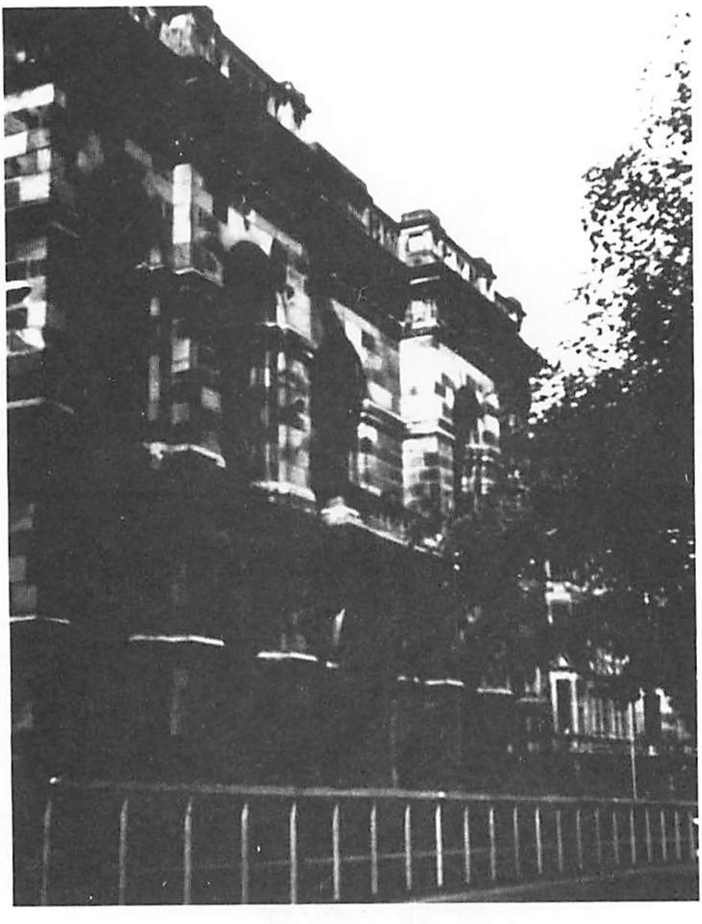

Figure 2 The Synod Hall, just before its demolition in 1966

What of the building it replaces? Demolished in 1966, the Synod Hall was also a multi-purpose building, designed by Sir James Gowans (Figure 2). It began life in 1875 as the Edinburgh Theatre, Winter Garden and Aquarium Company. In 1877, it became the Synod Hall of the United Presbyterian Church and was acquired by Edinburgh Corporation in 1902. Thereafter, the Synod Hall housed Poole's Cinema in the 1450 seat hall, while a range of other organisations had rooms in the building. These included the Royal Scottish Geographical Society, the Scottish Mountaineering Club, the Waddell School of Music and, in the basement, there were a Winter Bowling Green and a Miniature Rifle Range.

The Edinburgh Geological Society, according to its Written Archive (see David Land's article in Issue 25) occupied rooms in the Synod Hall from 1916 until 1960. Prior to 1916, the Society occupied rooms in the National Bible Society of Scotland building, at 5 St Andrew Square. Incidentally, this building too, on the south side of the square, has recently been demolished although the facade has been retained.

The Society's first meeting in the Synod Hall was the Opening Meeting of the 83rd Session held on the evening of Wednesday 18th October 1916 at 8pm. Tea was at 7.30pm. Dr Robert Campbell, President, was in the Chair. Interestingly, the Billet was produced by J J McBeath, Joint Hon. Secretary whose address was given as 1 India Buildings. This was the address occupied by the Geological Survey office from 1869-79 (see Wilson, 1977).

As is still the case today, the Society's Accounts make an interesting study in themselves. Table 1 reproduces the Abstract of Accounts for the first year after removal to the Synod Hall. Meetings of the Society were held in the RSGS Boardroom (later the Council room), so rent was paid to the sister organisation. A major feature of the Society in these earlier days was its library which had been started in the nineteenth century. Although the Written Archive contains a manuscript catalogue, it was not until I visited that mine of geological literature, the Library of the United States Geological Survey in Reston, Virginia in 1987, that I came across a copy of the printed and published 1887 Catalogue of the Library of the Society. This document also makes fascinating reading.

Towards the end of the 1950's, the Society began to hold only some meetings in the Synod Hall but others, usually those of wider appeal, were held in the Grant Institute. My former colleague at the University of Reading, Dr

TABLE 1

EDINBURGH GEOLOGICAL SOCIETY

(Library and Rooms: Synod Hall, Castle Terrace)

ABSTRACT OF ACCOUNTS FOR YEAR ENDING 30th SEPTEMBER 1917

RECEIPTS

Entry Money from 8 New Members		£ 4 3 6
Annual Subscription from 59 Ordinary Members and 5 Student Associates		37 10 0
Subscription from 2 Life Members		12 12 0
Arrears of Subscriptions recovered		7 10 0
Prepaid Subscriptions received		2 0 0
Interest on Investments and Bank Account		11 8 3
Sale of Society's Transactions		1 1 7
Income Tax returned to Society		3 2 9
Contribution to Library Fund		0 10 6
		£79 18 7
Excess of Expenditure over Receipts		7 14 11
		£87 13 6

EXPENDITURE

Rent and Expenses of Rooms at India Buildings to May 1917		£16 18 5
Rent of Synod Hall Rooms (Nov. to May)		10 9 0
Insurance, Gas, Rates, etc., at Synod Hall		2 18 9
Removal of Library (Sloan's Account) including Refitting	£26 10 0	
Furnishing of Library at Synod Hall, including new Fireplace	£13 4 8	
		39 14 8
Rent of Royal Scottish Geographical Society Board-room		2 2 0
Periodicals purchased		1 10 5
Bookbinds (Vols. of Transactions)		0 16 6
Printing Account (March 1916 to March 1917)		11 11 8
Secretary's Expenses, including charge for notice in Postal Directory		1 12 1
		£87 13 6

Roland Goldring, has recalled to me the conditions under which he laboured in giving a talk on the 12th March 1958 in the Synod Hall on 'Old Red at Sea', an account of his work in Southwest England. In contrast, L C King from Natal, addressed the Society in the Grant Institute on 27th March 1957.

The draw of the Grant Institute proved irresistible, especially with the impending demise of the Synod Hall to make way for an Opera House that was never built. The Minutes of Council held at the Grant Institute on Wednesday, 19th October 1960 at 6.30pm, record that Mr Goodlet reported that the remaining books in the library at the Synod Hall had been disposed of, and the Society had given up its rooms there. This is why many of the books and other volumes from the Society's library, bearing the Society's distinctive crest (before the Lord Lyon requested me, as then Secretary in the late 1970's to get it changed), have ended up in other collections.

Geology is of course a dynamic science but, rather like driving a car, it is always useful to look backwards as well as forwards. The Society can take pride in having been associated with Edinburgh's famous 'Hole in the Ground'.

Acknowledgements

I am grateful to the Society's Council for permission to consult the Society's Written Archive, and to Dr J V Howard, Keeper of Special Collections in Edinburgh University Library, for access to it.

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Geological and Geomorphological factors influencing the form and development of Edinburgh Castle.

Nigel Ruckley
British Geological Survey
Edinburgh

Introduction

Edinburgh Castle is sited on an easily defendable prominence with cliffs on three sides that rise to over 50m above the level of the surrounding area. Its location and subsequent development were directly controlled by the local geology; the strategic value of the site commanding the capital city was considered sufficiently important to outweigh any resulting logistical problems, such as the provision of a satisfactory water supply.

The Castle Rock (Figure 1), is the eroded remnant of a basaltic plug of an ancient volcano intruded almost vertically through a sequence of Cementstone Group sedimentary rocks of Lower Carboniferous (Dinantian) age (345 Ma). Subsequent glacial erosion of the area during the Pleistocene (2.0 Ma to about 10,000 BP) has created a classic example of a 'crag and tail'. The over deepened valleys surrounding the crag on three sides are partially filled with Glacial and Postglacial drift deposits, leaving the Castle Rock and most of the 'tail', extending eastwards from the plug, comparatively free of drift (Sissons, 1971; Figure 2).

Geology and Geomorphology

The Castle Rock is oval in plan, being elongated in a northwest to southeast direction. The axis of the plug is tilted from the vertical towards the southeast (Cheeney, 1977). The plug probably represents a series of intrusions, as several chilled margins can be seen within the basalt as illustrated by the chilled surface on the inner side of the partly opened vertical fissure that separates the main portion of the Castle Rock from the crag on which lie the ruins known as 'Crane Bastion'.

The plug consists of a Dalmeny type basalt of Lower Carboniferous age which has a microporphyritic groundmass, consisting of fine-grained

THE SOLID GEOLOGY OF CENTRAL EDINBURGH

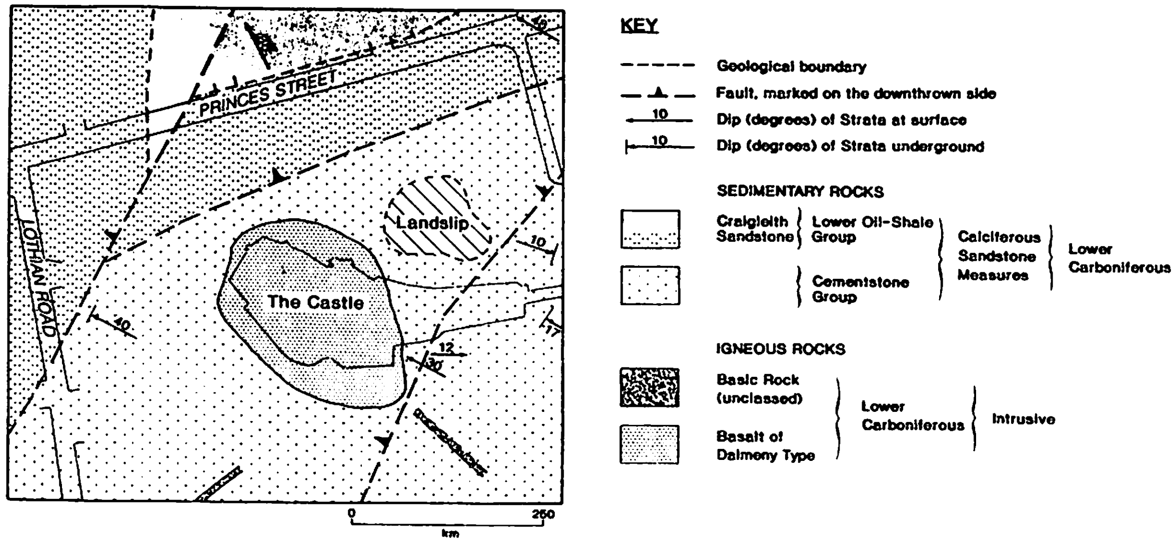

Figure 1 The solid geology of central Edinburgh (based on six inches to one mile geological sheets NT 27 SW and SE. British Geological Survey, 1965).

plagioclase feldspar, augite and magnetite, with small crystals of slightly altered olivine and augite. Most exposures show the basalt to be generally fresh and unaltered, though weathering is seen at two exposures on the eastern side of the plug, near the Fore Well. To the west of the Old Governor's House the rock exhibits a more doleritic texture (Price and Knill, 1967).

The extent of the basalt to the north and to the south of the castle is difficult to define, as its contact with the surrounding sediments is obscured by Postglacial drift deposits and made ground. The western edge of the plug can be traced in the gardens on the east side of King's Stables Road below the cliff, where marls, marly shales and sandstones of the Cementstone Group are exposed.

On the eastern side, the sedimentary rocks form an irregular terrace, utilised by the eastern defences, that rises from near the southeastern part of the plug in a northwesterly direction to with in 7.3m of the summit. These rocks mainly comprise of beds of sandstone from 0.3 to 0.6m thick, interbedded with friable cornstones and greenish grey marly shales. In places, these rocks are hardened by contact metamorphism close to their near vertical junction with the eastern side of the plug (Tait, 1942).

Note that the Fore Well lies within the basalt plug and that Tait's section (on p.31) is incorrect.

Further east, near the western end of the Esplanade, the sedimentary rocks are cut by the northeast-trending Castle Hill Fault of post Carboniferous age. The only visible exposure of the fault lies on the grassy slope below the south side of the Half Moon Battery. Here the sandstones, cornstones and baked sandy marls between the Castle Hill Fault and the eastern margin of the plug, dip steeply to the northwest at angles of 30° to 40°. East of the fault the sediments dip gently eastwards and can be seen in the south-facing bank below the Esplanade.

Superficial deposits in the vicinity of the castle which are in places up to 30m in thickness, consist of till, sand and gravel, lacustrine sediments and made ground. Landslips in the till covering the northern slope of the 'tail' are primarily due to the glacial oversteepening of the rock faces.

Lacustrine deposits in the area now occupied by Prince's Street Gardens may have represented part of an earlier Postglacial lake. The artificial Nor' Loch that provided a defensive barrier on the north side of the castle and city, occupied part of this area from it's formation early in the 15th century until it was drained early in the 19th century.

Stability of Rock Faces

The basaltic plug contains a complex pattern of prominent, closely-spaced radial, circumferential and dome joints. These are thought to be a major factor controlling the stability of the rock faces (see the first article, by Phillip Davies, for further details). Other factors which may affect the stability of the rock include the geometry of the face, the percolation of water and the natural strength of the rock itself.

Although the Castle Rock itself is a strong and stable material, oversteepening, formerly by glaciation, and latterly by man, in order to restrict access to the rock, has caused intermittent rock falls both in historical and in recent times. The primary reasons for these rock falls are probably the alternating cycles of freezing and thawing of water, coupled with plant wedging, within the joints of the oversteepened rock faces. Vibration by gunfire is not thought to contribute directly to rock falls, although historical documents suggest that it has been a contributory factor in lowering the water level in the Fore Well (Arnot, 1779, page 292).

Factors affecting the layout of the defences of Edinburgh Castle

Most of the castle's inner defences lie within the confines of the basalt plug. The eastern defences, on the weaker side, utilised all of the available high ground. The 16th century Half Moon Bastion, and David's Tower, its weaker and smaller predecessor, lie partially on the plug and partially on the uneven terrace of incompletely metamorphosed and often weathered sedimentary rocks.

The former medieval ditches of the outer defences occupied what is now the western portion of the Esplanade, where the faulted sedimentary rocks would have made their construction easier. When the outer defences were remodelled in the 16th century to form an earthen spur work, suitable for artillery, material would have been available for it's construction.

Because of the hardness of the basalt plug – first recorded in a siege engineer' s report of 1572-3 as "a massy substance" (Royal Commission on the Ancient Monuments of Scotland, 1951), any mining and counter mining, had been restricted to the tunnelling of the sedimentary rocks underlying the Esplanade (Douglas, 1898).

Only the eastern face of the castle was ever considered for infantry assault which would have followed the successful destruction of the eastern defences by mine or bombardment. Seventeenth century plans suggest that the sedimentary rocks in the vicinity of the Half Moon Battery were of a less formidable appearance than their present artificially steepened counterpart. (Public Record Office plan. MPF 245. [4021 (?1696)] Edinburgh Castle).

Building stone

The basalt of the Castle Rock was never a primary source of building material for the majority of the medieval buildings still extant on the rock today. Only the Well House Tower, constructed in 1362, uses local basalt rubble for its walls, with freestone dressings.

Although basalt is durable, it is not easily worked into ashlar or freestone and, as a result, Carboniferous sandstone from local quarries was the preferred building material from an early date (McMillan, 1987). The eleventh century St. Margaret's Chapel and the fourteenth century David's Tower are both constructed of sandstone ashlar, whilst the 16th century Half Moon Bastion is constructed mainly from rough dressed sandstone blocks.

Published building accounts between 1529 to 1649 indicate that at least four named sandstone quarries were utilised for either new work or repair of existing structures (Paton, 1957; Imrie and Dunbar, 1982). Between 1615 and 1617 the rebuilding of the upper portion of the Palace Block used sandstone from Craigleith [NT 226 745] and St. Cuthbert's quarries. The latter quarry was opened specifically for the work and proved very subject to flooding. Two other named quarries, Maidencraig (near Blackhall) [NT 223 745] and Craigmillar [NT 285 709] are specifically mentioned in the accounts of 1628 and 1639 respectively. The latter quarry provided some of the sandstone, of Upper Old Red Sandstone age, used in the reconstruction of the outer gatehouse.

THE DRIFT GEOLOGY OF EDINBURGH CASTLE AND LOCATION OF CASTLE WELLS

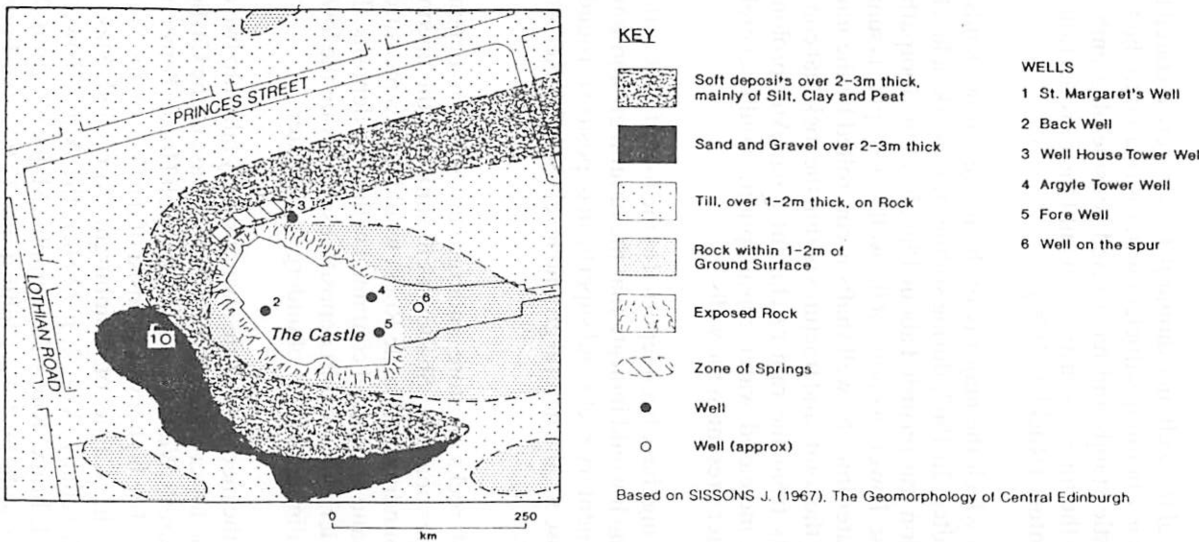

Figure 2 The drift geology of central Edinburgh (after J.B. Sissons, 1971). Showing the locations of the wells in Edinburgh Castle.

Water Supply

The locations of the wells in Edinburgh Castle were dictated by the geology. The difficulty in obtaining sufficient water is related to the types of rock on which the castle stands and has caused considerable embarrassment and expense from the time of construction until the introduction of mains water in the 19th century (Ruckley, 1990).

The basalt on which the majority of the fortress now stands, is naturally a very poor aquifer. In 1967, during stabilisation work, a level of permanent water saturation was recorded about 15m above the footpath to the west of the Well House Tower. As none of the wells on the plug is sunk to this depth, the flow of water into the well shafts is controlled by the number, size and orientation of the joints and fractures within the rock that communicate with the well shafts from the rain catchment area. Any prolonged dry spell, coupled with increased water consumption, would severely deplete the amount of water present in the wells.

Numerous springs have been reported at the foot of the Castle Rock or close to its base, which would indicate that the natural ground water table in the adjacent sedimentary rocks and superficial deposits surrounding the plug is at, or very close to, the natural ground level (Scottish Records Office Map. RPH . 35690).

The ability of rocks to store underground water is dependant on their porosity and permeability. Shallow wells sunk into the unconsolidated drift deposits surrounding the Castle Rock, would yield a measured supply from the lenses of sand and gravel contained within the deposits. The sandstones and shales underlying the drift deposits, especially on the lower ground, are ideal for an unlimited supply of underground water.

The source of the medieval castle's water supply falls into two distinct groups (Figure 2). The lower wells surrounding the base of the Castle Rock consist of Saint Margaret's Well, the well at the Well House Tower and the springs between them. The higher wells consist of the Well on the Spur, ('Journal of the Siege of the Castle of Edinburgh, April and May, MDLXXIII', Bannatyne Miscellany. Vol. 2, p.72-80.), the Argyll Tower Well (British Museum Map Library. Kings Topographic Map Collection. XLIX/73. Plan of Edinburgh Castle by John Elphinstone, 1746.), the Fore Well and the Back Well.

Saint Margarets Well has often been confused with the well at the Well House Tower. Geological information from shallow boreholes coupled with a re-appraisal of published accounts indicate that Saint Margaret's well probably lies in the vicinity of the Castle Terrace Car Park.

Under siege conditions, topography determined which wells the garrison could use to their advantage. Wells, although of limited capacity, within the defences on the summit would be more easily defended than an abundant supply of water situated at the base of the Castle Rock. Furthermore, the garrison would encounter severe military and logistical problems in transporting the water from the lower wells into the castle. For example, no water was available from the Fore Well (the only well on the summit of the rock) from it's deliberate slighting in 1314, until 1381, when war with England seemed imminent and the well was restored for use.

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Proceedings of the

EDINBURGH

GEOLOGICAL SOCIETY

156th Session

1989-1990

No. 20 **August 1991**

INTRODUCTION

This the twentieth issue of the *Proceedings* covers the 156th Session 1989-1990. Abstracts of the lectures delivered to the Society are included.

MEMBERSHIP

The total membership of the Society at 30 September 1990 was (with last year's figures in brackets 570 (580), consisting of:

Honorary Fellows	9 (10)	Senior Fellows	15 (15)
Corresponding Fellows	9 (8)	Family Fellows	34 (33)
Life Fellows	27 (27)	Glasgow Associates	9 (9)
Ordinary Fellows	460 (465)	Junior Associates	8 (13)

Numbers of Fellows and Associates elected, deceased, resigned, removed and transferred during the 156th Session, 1989-90.

Honorary Fellow deceased	1
Ordinary Fellows elected	17
Ordinary Fellows reinstated	6
Ordinary Fellow deceased	1
Family Fellow transferred to Ordinary Fellowship	1
Ordinary Fellows resigned	10
Ordinary Fellows removed	15
Ordinary Fellow deceased	1
Ordinary Fellows transferred to Senior Fellowship	2
Senior Fellow resigned	1
Family Fellows elected	2
Ordinary Fellow transferred to Family Fellowship	1
Family Fellow removed	1
Glasgow Associate elected	1
Glasgow Associate removed	1
Junior Associate resigned	1
Junior Associates removed	4

PUBLICATIONS

Three parts of the *Scottish Journal of Geology* were published during this session.

1898 Volume 25 parts 2 and 3, the latter including a complete index, compiled by Colin Will.

1990 Volume 26 Part 1; this being the first in the new A4 format, to be published in two parts per year.

Issue 24 of the Societies informal magazine, *The Edinburgh Geologist*, was published, incorporating the *Proceedings of the Edinburgh Geological Society* No. 19, covering the activities of the Society during the 155th Session 1989-90.

The leaflet on the geology of Arthur's Seat was reprinted and good progress was made in compiling the Sterling and Borders guides.

CLOUGH MEMORIAL FUND

Clough Medals were awarded to Professor A L Harris of Liverpool University for work in the Highlands especially on the Dalradian rocks, and to Professor J D Peacock, formerly of the Geological Survey for his work throughout Scotland particularly on the interpretation of Quaternary deposits. Professor Harris's medal was that for the 155th session; Professor Peacock's for the 156th.

A grant was made from the Clough Fund to David Edwards of Edinburgh University to aid the study of tephra deposits in the Yukon territory of Canada.

Until 1990 the Clough medals have been struck at the Royal Mint in Llantrisant, but Council has decided to award the contract for medals to Messrs Alex. Kirkwood & Son of Albany Street, Edinburgh.

SECOND EDINBURGH INTERNATIONAL FESTIVAL OF SCIENCE

A guided walk through Holyrood Park was organised by the Society and attended by 55 members of the public.

WALTER MYKURA MEMORIAL FUND

At the time of the Annual General Meeting of the 156th Session (15th November 1989) this newly established fund, aimed at encouraging and supporting geological fieldwork in Scotland, stood at £3,317.

RECORD OF MEETINGS

18th October 1989 Attendance 65

The Irish base-metal deposits:– style and process in an orefield context.

Dr C J Andrew, Navan Resources plc

The Lower Carboniferous carbonate-hosted zinc-lead deposits of the Central Irish Midlands cumulatively contain 10 million tons of zinc and 3.2 million tons of lead. Mineralizing activity in the Irish Midlands can be conclusively demostrated to have been initiated isochronously across the orefield in the Courceyan Age and to have been contemporaneous with the onset of extensional tectonism. The zenith and duration of this mineralizing activity varies from deposit to deposit, but across the orefield it had died out by early Arundian time, some 5 million years later.

Lead isotopic studies have conclusively demonstrated that lead (and thus presumably other metals) was derived from Caledonian basement by fluids of generally low salinity (4 to 8 weight per cent NaCl equivalent) and moderate temperature (220° to 270°C). Mixing with saline connate brines (11 to 25 weight per cent) and cooling in the ore depositional environments led to sulphide precipitation at temperatures in the range 75° to 210°C. Hydrothermal fluids appear to have temporally evolved in all of the deposits, notably in terms of salinity, temperature, chemistry and the nature of metal complexing. Stable isotopic studies ($\delta^{34}S$, $\delta^{13}C$, $\delta^{18}O$, δD) indicate variable physico-chemical controls within the depositional environment of the ore within a single deposit and between that of different deposits. The styles of the resultant mineralization are diverse, ranging from exhalative chemical/particulate sediments, through syn-diagenetic replacement and open-space infill, to epigenetic hydrothermal dissolution breccia matrices and resultant collapse-breccia void infills. As the onset of mineralizing activity is isochronous, the resultant styles of ore and gangue mineral textures largely reflect the level of emplacement and physico-chemical constraints imposed by the host-rock, which is part of a diachronous carbonate ramp succession.

Consequently, within an orefield, the nature of mineralization reflects a variety of processes within the ore-depositional environment; a concept discussed with reference to similar and contrasting examples of mineralization from elsewhere in the world.

31st October 1989 Attendance 70
How continents deform
Dr J Jackson, Cambridge University

Continental deformation is much more varied and complicated than deformation beneath the oceans. This is very apparent from the distribution of earthquakes, which follow narrow linear belts beneath the oceans but are widely dispersed beneath continents, where their occurrence does not define simple plate boundaries.

The rules of plate tectonics, useful for describing the overall relative motions of major continental masses, are inadequate when attempting to describe the deformation of continental mountain belts, for which a new conceptual framework is needed.

Perhaps the most important consideration is one of scale: only the top 10 to 20km of the continental crust deforms by faults that move in earthquakes, while the lower 90 to 100km of the lithosphere deforms by creep. At length scales which are large, compared with the thickness of the brittle upper crust, the behaviour of the continents resembles that of a fluid, being controlled by the flow of the creeping part of the lithosphere.

At smaller scales fault movement dominates the deformation, but the faults move in patterns that are able to accommodate the overall motion. The scale at which geological observations are made therefore determines the framework in which they should be discussed. Examples were presented from various actively deforming parts of the Alpine-Himalayan region.

15th November 1989 Attendance 90
Archaeopteryx
Dr W B Heptonstall, Edinburgh University

Although discovered over a century ago, *Archaeopteryx* is probably still regarded by most palaeontologists as one of the most remarkable fossils ever found. Its importance lies in the link that it provides between reptiles and birds.

Archaeopteryx comes from the Solenhofen Limestone, a lithographic stone which is extensively quarried. The limestone has yielded many fossils, for example there are some 1700 specimens in the British Museum of Natural History. The fauna is rich and includes finely preserved insects. The first specimen of *Archaeopteryx* was bought for £700 for the museum by Richard Owen; four others have since been found.

Modern birds have relatively large brains, large eyes, toothless beaks, many neck vertebrae and a short tail with long tail feathers. They also characteristically possess many hollow bones, grasping toes, a complicated respiratory system, and asymmetrical flight feathers. Flight is assisted by a short humerus, rigid rib cage and a sternum with a deep keel.

Archaeopteryx both resembles and differs from modern birds. It had large eyes, indicating binocular vision. Its beak was toothed, having 26 teeth in the upper jaw and 20 in the lower. The skull and brain case had both reptilian and avian features, but is generally bird-like. *Archaeopteryx* weighed about 500g; its brain weighed around 1g. Modern birds have no teeth, though like *Archaeopteryx*, some Cretaceous bird fossils also have teeth. *Archaeopteryx* had solid (reptilian) bones with marrow, not hollow ones. It possessed claws on the front edge of its wings, a wishbone, but only a small sternum without a keel. Its leg bones were reptilian rather than avian.

Archaeopteryx had true feathers, with two on each tail vertebra, and full body feathers. The flying feathers on the wings show the bilateral asymmetry found in those of modern birds. Its wings were rather small and could only be lifted to a horizontal position, so it could fly, if only feebly. It was probably descended from the Ornithishcian dinosaurs. Some reptiles evolved gliding but not flying. Pterosaurs were contemporaneous with *Archaeopteryx*. How flying evolved and how feathers evolved is not known. The recent question as to whether or not *Archaeopteryx* specimens were faked has made palaeontologists look even more closely at the material. Detailed re-examination has demonstrated conclusively that the fossils are genuine. The feathers in particular, were real.

29th November 1989 Attendance 65
The global pattern of soil
Dr E A Fitzpatrick, Aberdeen University

The distribution and variability of soils over the earth's surface are related to patterns of climate, vegetation and rock type. Of these factors climate and vegetation are of primary importance and geology plays a relatively minor role.

In the Arctic, patterned ground develops with peat overlying permafrost on the former beds of lakes. The soil is unstable and immature. Most of the stone polygons in Scotland are fossil features related to the last ice-sheet. In temperate forested areas podzolic soils develop, arthropods and bacteria being important agents of soil formation.

On basic igneous bedrock, brown earth soils may develop and in drier parts of the temperate zone soils similar to podzols may form. Where the downwashing of clay retards drainage during the wet season gleyed soils may develop. Iron pans can form, restricting drainage and allowing peat growth. Chernozems or black earths form in dryer regions, where grass is the natural vegetation, producing a very fertile soil. As climate becomes drier, soils become thinner and retain less moisture. These soils can only be cultivated by dry-farming methods, including the cultivation of alternating strips of land on an annual basis. Soil development in true deserts is inhibited by a lack of moisture and most of the soils are fossilised from periods when these areas received much higher rainfall.

Certain rock types produce distinctive soils. Volcanic ash deposits tend to weather quickly and produce thick soils; whereas soils developed on limestone tend to be thin, being formed of residual clay that is left after limestone dissolution (these soils are typically red in colour). Lateritic soils form in tropical areas with high rainfall. Laterites are typically deep red in colour and are formed by the concentration of alluminium (gibbsite) and iron and by the leaching of silica from the upper part of the soil profile. These soils are very infertile although efficient nutrient recycling allows them to support a dense tropical rainforest vegetation.

6th December 1989 Attendance 70

The tensile strength of rock and its influence in geological and geotechnical processes

Dr M deFreitas, Imperial College, London

Many natural geological processes of deformation utilise the weakness of rock in tension, to create and propogate fractures that eventually result in rock failure: jointing and veining are two common examples. All industrial methods of failing rock utilise its weakness in tension to gain the maximum efficiency for the minimum of effort; this is clearly seen in the drilling, blasting and comminution of rock that forms the daily life in much civil and mining engineering.

The hydrofracture that can be created in many wells and boreholes, by injecting fluids to pressures that exceed those which can be resisted by the tensile strength of the surrounding ground, has long been used to enhance the recovery of petroleum products, and has more recently become a method for measuring the orientation and magnitude of the least principal stress *in-situ*.

Although a rock's weakness in tension is so frequently used, tensile strength is rarely measured due to practical difficulties associated with the standard laboratory test. These difficulties have now been overcome by a new method of testing.

10th January 1990 Attendance 120

Stratigraphy and structure of the Scottish Highlands

Professor A L Harris, Liverpool University, Clough Memorial Medalist, 1988-89

The original Geological Survey view of the Northern Highland Moine as being divisible into tectono-stratigraphic units – the Morar, Glenfinnan and Locheil divisions – has been modified during the past 20 years, so that it is now possible to recognise an originally continuous stratigraphic succession in the Northern Highlands, disrupted by major ductile thrusts.

To the north of the Great Glen, Moine rocks rest with (an admittedly modified) unconformity on the Lewisian. The lowest part of the Moine succession, the Morar Division, crops out beneath the Sgurr Beag Slide, which separates it from the Glenfinnan Division and the overlying Locheil Division. A complete Moine succession can be mapped on the Ross of Mull however, where the Morar and Glenfinnan Division rocks can be recognised without structural dislocations obscuring their contact. The rocks are deformed, but sufficient original sedimentary structures are preserved to suggest that the units are in their correct relative stratigraphic positions.

The age of the Dalradian stratigraphic sequence is not firmly established, because the timing of deposition and that of deformation is based on a few isotopic ages on widely scattered, deformed and metamorphosed igneous bodies, and on limited palaeontological data. Acritarchs from the Tayvallich and Loch Tay limestones were considered to be early Cambrian in age and trilobites from Leny Quarry to be uppermost Lower Cambrian.

A limestone unit that crops out in the valley of the Keltie Water has, in the past, been correlated with the Leny Limestone exposed in Leny Quarry, which has yielded a Lower Cambrian trilobite fauna. Detailed remapping has cast considerable doubt on this correlation and suggests that the limestone in the valley of the Keltie Water is in fact of Precambrian age, supporting the original stratigraphy as indicated by Clough's original mapping.

Radiometric dating of the Ben Vuirich Granite, which cuts both the D1 and D2 deformations but is itself deformed by the D3 deformation was 514 Ma (Tremadoc). This granite's date has now been revised to 590Ma (late Precambrian) and the Loch Tay Limestone acritarchs are now known to have a much wider age range than previously thought. Thus the whole of the Dalradian is now interpreted as Precambrian, both in age of strata and the timing of the main deformation.

In the Strathspey region some workers (notably Piasecki) have mapped high grade gneisses, the Central Highland Division, beneath rocks of the Grampian Group which itself is continuous with the Dalradian *sensu stricto* (Appin Group). However, detailed mapping shows patches of cross-bedded psammites of lower metamorphic grade within the high grade rocks. It is possible therefore that the whole of the Grampian Group and the Central Highland (or 'Moine') rocks southeast of the Great Glen are Dalradian.

Until recently, the folding of the Moine was thought to have taken place between 453 and 420 Ma and the folding of the Dalradian between 489 and 433 Ma, (during the Ordovician and Silurian).

It is suggested that there is little difference in the age of orogenesis either side of the Great Glen. The Ardgour Granite Gneiss has a probably erroneous Grenville age of (c. 1000 Ma) and the Glenelg Eclogite has also been dated at 1004 Ma, although the true age of the granite gneiss may be c. 800 Ma.

Similarities between the metasedimentary sequences either side of the Great Glen suggest that the uppermost Moine rocks (Locheil Division) maybe correlated with the lowermost Dalradian (Central Highland/ Grampian Group) rocks.

24th January 1990 Attendance 70

Palaeoceanography of the Indian Ocean

Dr G Shimmield, University of Edinburgh

Of the world's oceans, the Indian Ocean, and particularly the Arabian Sea, has received little attention from the oceanographic community. Over the last decade advances in the technology required to retrieve long deep-sea cores (the Ocean Drilling Program) has provided palaeoceanographers with material that faithfully records the pattern of dust input, biological productivity, and climate of the ocean basin. Analytical tools are now available to measure the shift in ratio of oxygen isotopes in calcium carbonate that forms the calcareous skeletons of minute marine organisms. From such records, palaeoceanographers may reconstruct climate history through glacial/interglacial cycles as the volume of the ice caps changed, thereby influencing the oxygen isotope record.

Study of the Arabian Sea is important because the area is affected by Southwest Monsoon in summer. Recognising man's impact on climate through CO_2 emissions, lies in understanding the carbon cycle. Marine organisms use CO_2 to photosynthesize and to form calcareous skeletons, releasing carbon back to the ocean on death and decay. Where strong, unidirectional winds (such as the summer Southwest Monsoon) impinge on the surface waters, deep water containing high levels of nutrients (phosphate, silicate, nitrate) are brought to the surface ('upwelling') affecting biological productivity, and hence the carbon cycle. In the Arabian Sea, the ability to reconstruct the history of the summer Monsoon from deep-sea core records is of vital importance in helping to validate global climate models and develop an understanding of the way we are changing our climate.

The concentration of CO_2 in the atmosphere and global temperature are directly correlated, as seen from studies of ice-cores from Antarctica. These provide measures of former CO_2 concentration from air bubbles trapped within the ice and the temperature from the ratio of $\delta^{18}O$ to δD from the ice itself.

Changes in global climate can be related to three principal variables; the ellipticity of the Earth's orbit, changes in the inclination of its axis and precession, caused by the greater attraction of the sun and moon on the excess of matter at the Earth's equator. The changes in the elliplicity of the orbit have a periodicity of 100ka; the inclination of its axis varies between 21½° and 24° with a periodicity of 41Ka and the precession of the equinoxes varies in 19Ka and 23Ka cycles. These so called 'Milankovich Cycles' were infact first studied by a Scotsman, James Croll.

Major changes in the Earth's climate greatly affect the size of the Arctic and Antarctic ice caps, but integrated Milankovich cycles plotted against total ice volume do not correlate directly; a time lag develops as ice tends to accummulate slowly and melt quickly, following decreases and increases in global temperature. The major changes of the ice volume tend to follow the 100Ka cycle.

These changes in ice volume are reflected in the temperature and composition of ocean sea water, which are in turn recorded in the $^{16}O/^{18}O$ isotope ratio of calcite in the tests of benthic and plantonic calcareous forminifera. The isotope ratio varies not only with temperature, but also between individual species. It is the measurement of oxygen, isotope ratios from forminifera taken from deep sea cores that has allowed the reconstruction of the past climatic changes in the Indian Ocean and elsewhere.

7th February 1990 — Attendance 120
Fellows' Night

The Clough Memorial Medal for 1989-90 was presented to Dr J D Peacock for his distinguished and original researches, particularly in the Quaternary geology of Scotland.

The Clough Memorial Award was presented to Dr T Dempster in recognition of his work on the evolution of metamorphic terrains in the south-east Highlands.

Scandinavian Miscellany by Mr R Batchelor

The Ordovician and Silurian rocks of Sweden and the Danish island of Bornholm in the Baltic were visited. Ash beds (bentonites) interbedded with shales overlying reef limestones were studied and the Siljan Ring, an astrobleme (remnant meteorite impact crater) of Devonian age was visited. Upright and overturned Ordovician and Silurian limestones and shales rich in fossils are present in the downfaulted annular rim of the Ring. A borehole sunk in the Precambrian granite in the centre of the ring structure, with the aim of proving the presence of methane gas derived from the earth's mantle, had reached a depth of 6.5km with no methane being found.

A Greenland Layered Intrusion

by Miss S Mingard

A layered intrusion is present northwest of the southern tip of Julianahab Bay. The suite of rocks examined included dykes of basalt and troctolite (olivine and plagioclase), which appear to be the differentiates of a single magma. The dykes contain xenoliths of anorthosite and were intruded during a period of late Proterozoic rifting.

The dykes range from 200-800m in width; wide enough for convection currents to have developed during crystallisation. The dykes show a characteristic banding marked by sharply defined layers of olivine crystals. The layering varies from place to place; in some instances regular layers are found, in others, faults, disconformities and breccias are developed. Changes in chemical composition of the magma during crystallisation, causing either olivine or plagioclase to crystallise, may be responsible for the layering. The primary cause of the differentiation is thought however, to have been the development of strong convection currents as the magma rose towards the surface.

Lost 19th Century Quarries of the Duke of Richmond and Lady Gordon Cunningham

by Mr S Wood

Middle Old Red Sandstone fresh-water fish are among the best preserved fossil fish is Scotland. Locations famous in the literature include Achanarras, Altyre and Lethan Bar, as well as Tynet. Last century these were all working quarries which are now abandoned and largely overgrown. They belonged to Lady Gordon Cunningham and the Duke of Richmond. The Duke's quarry at Tynet has been re-opened and fossil fishes obtained from nodules, limestones and shales.

Visits to Russia and the International Geological Congress in Washington
by Mr N Butcher

Pictures of the Geological Institute in Moscow, the University and the new Palaeontological Museum, with its imaginative murals and displays were shown. A visit to the International Geological Congress in Washington was recorded and accompanied by photographs of the Smithsonian Institute, the Headquarters of the United States Geological Survey at Reston and some views of the Appalachian Mountains.

A number of demonstrations and exhibits were provided in a laboratory of the Grant Institute at the end of the formal presentations, and a geological quiz was organised by Mr C Porteus.

28th February 1990 Attendance 70
Glasgow – A study of Urban Geology
Mr M A E Browne, British Geological Survey

Recent studies of the environmental geology of Glasgow have been undertaken by the British Geological Survey (BGS), commissioned by the Department of the Environment (DoE), through the Scottish Development Department (SDD), and Glasgow District Council who provided a third of the funding. The aim of the study was to relate environmental geology to problems facing local and national government in planning and executing urban renewal and development in Glasgow, once the "second city of the Empire". In addition to the usual detailed geological maps of both solid and drift, maps have been made of quarrying, mining and various aspects of the Quaternary geology.

Glasgow has a long history, not only as a city, but also in mining and quarrying which have left a legacy of problems. The town grew from two nuclei, at Stockwell Street ford and the cathedral. Surrounding boroughs such as Rutherglen and Partick were formerly independent towns. Glasgow University was founded in 1452. By 1600 AD Glasgow had 4000 inhabitants; by 1900 AD there were over a million. The port and market town grew into a dynamic trading and industrial centre supported by extensive mining and quarrying of coal, ironstone, sandstone, limestone, shale and sand.

The Geological Survey has mapped the area three times, in 1860, 1920 and 1950-90, studying hundreds of mine plans and thousands of borehole records. Over 40 horizons have been mined and in places, as many as 6 worked levels occur within 70m of the ground surface. Recent mining, as at Cardowan Colliery, is by longwall methods; this results in immediate subsidence, most voids closing within a year. Older mining was by stoop and room (with very few bell pits); rooms range between 1½ and 10 feet in height, with workings extended to rock head. These workings may stay intact for a very long time, but eventually chimneys and even crown holes appear above them, causing damaging subsidence.

In some instances, the cost of repairing a building damaged by subsidence is more than it is worth and many have had to be demolished. Borehole records show that mining is much more extensive than extant mine plans indicate. Shafts may be capped, but many old shafts are not known and may well be filled, with the fill resting on rotting timbers. Rooms in old sandstone mines are up to 60 feet high: these can pose special subsidence problems.

Quite apart from mining, there are subsoil problems in the Quaternary deposits which include soft clays and peat, as well as sands and boulder clays. Man-made deposits are up to 50m thick in places; they give rise to serious differential subsidence as well as methane generation. Detailed maps have been made showing rock head, drift thickness, depth to boulder clay, made ground, landslips, peat, clays and silts, sand and gravel and boulder clay. Profile maps have also been produced; up to eight different profiles have been differentiated. With the addition of maps showing shallow mining and thin drift, the suite of maps gives a good indication of conditions likely to be found at any locality.

Geological conditions affect property values and however badly this knowledge affects individuals, it is right to have warning of hazards. The cost of incidents may easily exceed £60 000 each; the cost of the most recent geological survey was £250 000, so it can be seen to have been good value for money.

15th March 1990 Attendance 300

Public Lecture at the Royal Museum of Scotland; sponsored jointly by the Society and the Royal Museum

The Social Behaviour of Dinosaurs

Professor J Horner, University of Montana

Dinosaur studies have been revolutionised in the last few years with spectacular new fossil discoveries and re-interpretation of earlier finds. The appearance, ecology and life styles of dinosaurs are now much better understood, and they can be 'brought to life' as never before. The traditional views of the mode of life of dinosaurs such as sloth, cold-bloodedness and spread-legged waddling, are shown (for many species at any rate) to be wrong.

During the Cretaceous (80 Ma) Montana was a large fluvial plain formed by rivers from the proto Rocky Mountains draining into a mid-continental seaway. On the lowland (seaward) part of the plain most of the dinosaur fossils that have been found have been reworked by fluvial activity and yield little information on the behaviour of the animals. In the upland part of the plain however, thick mudstones were deposited that have yielded intact fossils, including nests of eggs.

The nests of *Hypsilophodon* have eggs arranged in a spiral, sharp ends uppermost, the eggs being slightly and equally separated from each other. The lower parts of the eggs are intact, showing that the hatchlings left the nest soon after birth. Some eggs still contain embryos with bones and teeth. Three nest-bearing horizons are known, each with several closely-spaced nests, indicating that the animals herded together and returned to the area time and again to nest. Its teeth show that *Hypsilophodon* was a plant eater; the adults were about 8 feet long.

In the same locality, *Troödon* nests are also found. It was a carniverous species, about 7 feet long when adult. Its nests are about 6 feet in diameter, and are sometimes littered with shell fragments. The hatchlings were 18 inches long and still occupied the nest when they had grown to 3 feet in length. This indicates that the young were nest-bound and were fed by the adults.

Unlike lizards, baby dinosaurs show juvenile features, as do the young of birds and mammals. Both *Hypsilophodon* and *Troödon* occupied the low-lying shores and islands within a lake surrounded by coniferous vegetation.

At another locality, a few miles away, 43 myosaur skeletons between 9 and 20 feet long have been found together in a mudstone largely composed of volcanic ash. This horizon has been excavated over an area of more than a quarter of a square mile. Numerous pits have been dug, each of which yielded more than 30 bones per square metre, suggesting that at least 10,000 myosaur were present. These animals moved in large herds like bison or antelope and, in this instance, a herd was overwhelmed by a fall of volcanic ash.

A few miles distant, a similar large herd of *Styracosaurus* has been found. These animals exhibited sexual dimorphism. Their horns were almost certainly used for display, both in the rut and for determining the hierarchy in the herd.

The study of bone structure indicates that cold-blooded, slow growing animals have few vascular canals. Birds have numerous vascular canals as do young dinosaurs, but in the adult these decrease in number. This shows that in dinosaurs, rapid warm-blooded growth in early life gave way to a much slower metabolism in adult life. It is hoped that further studies may show how long the animals lived.

28th March 1990 Attendance 70
James Wright Memorial Lecture
The Khubsugul Phcsphate Basin of North Mongolia: an example of ancient phosphogeneis
Dr R Volkov, Secretary USSR National Committee of Geologists

Workable deposits of phosphate may be of either igneous origin, in the form of apatite, or of sedimentary origin. It is primarily used as a fertiliser; much of the apatite mined from the Kola Peninsula being used for this purpose. Most sedimentary phosphorites are of Mesozoic or Tertiary age but deposits of Precambrian to lower Cambrian age are known from Mongolia, China, Australia, Africa and Brazil.

The Mongolian deposits were originally mapped as black cherts within areas of limestone and dolomite, but following a geochemical survey it was recognised that the 'chert' with its characteristic dark-grey to black colour and blue-grey patina, was infact phosphorite.

The Khubsugul area is part of the Baikal Rift system, and is underlain by Precambrian to early Cambrian limestones, dolomites, slates and phosphorites. The ground is around 4000m high, being an area of grassland and forest, unspoilt and undeveloped, and which is now a national park. The local in habitants depend on their horses, cattle and yaks for their livelihoods; they have a tradition against digging or mining.

In the Khubsugul area the Precambrian basement rocks are intruded by granites and overlain by a group of arkoses, basalts and rhyolites which are succeeded by tillite overlain by carbonate sediments; the sequence is about 3km thick. Phosphorites occcur towards the base of the sequence and again some 500m higher (above rocks containing the earliest trilobites).

The main phosphorite bed, some 10m in thickness comprises 60% apatite. It is overlain by 12m of dolomite and a further bed of phosphorite, 8m thick. This phosphorite sequence is overlain by black chert, 20m thick, thin-bedded dolomite and limestones, 50m thick, and a 5m thick bed with some phosphorite which is probably secondary. In hand specimen the phosphorite is black and structureless but contains thin layers of secondary dolomite.

Potassium-argon dating of the apatite gives an age of 740 Ma and dykes which are intruded into the sequence give Rb-Sr ages of 680-600 Ma.

Faulting makes reserves difficult to calculate, but outcrops of the phosphorite-bearing strata extend for more than 20km. However, as the area is a national park, mining will not be permitted. The Khubsugual phosphate assays at 39% P_2O_5. It is low in fluorine: around 1.39%, compared with about 3% in younger phosphates. Uranium is also low, 2-3ppm, compared with up to 100ppm in younger deposits. Carbonate is also low at around 1%.

The late Precambrian-early Cambrian supercontinent of which the Khubsugul area is a part, shows widespread phosphate genesis as rifting took place. Phosphates originated on passive continental margins where carbonate deposition and chemical precipitation of phosphate took place, especially in the lower parts of the sequence. Phosphate formation appears to be related to up-welling of deep cold water leading to precipitation on the continental shelf.

SOCIAL EVENING

1 December 1989 — A social evening was held in the Common Room of Murchison House (BGS), West Mains Road and was attended by some 95 members and guests.

RECORD OF EXCURSIONS 1990

		Attendance
5 May	Grieston, Megget and Dob's Linn Leaders: Dr B C Lintern and Dr P Stone	28
12 May	Randerston Leaders: Prof. E K Walton and Dr A R MacGregor	18
19-26 May	Long excursion to Rhum Leaders: Mr S M Ross, Mr A A McMillan and Mr J L Laxton	34
2 June	Ben Lawers (joint excursion with the Geological Society) Leader: Dr J Treagus	26 EGS Fellows
16-17 June	Weekend excursion to Glen Roy Leaders: Prof. J D Peacock and Dr F May	20
20 June	Bavelaw and Glencorse Leader: Prof. B G J Upton	18
23 June	Yellow Craig to Cheese Bay Leaders: Mr A D McAdam, Dr E N K Clarkson and Mrs C M Taylor	29
27 June	Holyrood Park Leaders: Mr D H Land and Dr S K Monro	14
18 August	Forth Bridge Leaders: Mr A D McAdam and Mr R Paxton	19
15-17 Sept	Weekend excursion to Berwick on Tweed (joint excursion with the Yorkshire Geological Society) Leaders: Mr D A Blythe, Mr I McCaffery, Mr W B Scott, Miss S Bower and Dr M A Whyte	35
22 Sept	Pease Bay and Cove Leaders: Mr J A Fyfe and Dr E N K Clarkson	?

COUNCIL NOTES

Dr W D I Rolfe was installed as the new President of the Society, succeding Prof. E K Walton.

The annual subscription was raised at the beginning of this session from £9 to £12 for Ordinary Fellows, and other rates *pro rata*.

Society members contributed some £600 towards the purchase by the Royal Museum of Scotland of *Westlothiana*, a unique early reptile from the Upper Oil Shale Group at East Kirkton.

The Society is now affiliated with the Lothian Branch of the Scottish Wildlife Trust, with a voting member on its Council.

Several Council members attended a forum, organised by the Royal Society of Edinburgh, to discuss the proposed splitting of the Nature Conservancy Council into three national bodies and the merger of the Scottish NCC with the Countryside Commission for Scotland, to create a National Heritage Agency. Council gave a very cautious welcome to the idea of a separate Scottish body, but would only support it if funding, especially for scientific research, was adequate.

Consultations were held with the NCC and Borders Regional Council, regarding access to Siccar Point and Council offered to provide leaflets and/ or a notice board to explain the geology of the site. Representations were also made regarding the proposed developments at Wardie Bay which would have destroyed the exposures in the bay (a geological SSSI). In the event, the proposals were modified and no longer represent an immediate threat to the site.

The Society's collection of about 5000 geological maps of many parts of the world is temporarily housed in Murchison House. Discussions are in progress to provide a permanent home for the collection. The libraries of both the British Geological Survey and Grant Institute would be willing to house the collection, but it will be around two years before the maps could be accepted by either library.

Discussions are also in progress regarding the permanent curation of the Society's archives. These archives, which include all of the Society's minute books, are presently housed on a temporary basis in the University Library in George Square. It is hoped that the archives will be housed either at George Square, or in the National Library on George IV Bridge.

Representations were made to government regarding cuts in curation and research at the British Museum of Natural History. Our voice was added to many others expressing grave concern about the damage that will be inflicted on vital work which is of international significance.

We offer our very grateful thanks to Professor G S Boulton for the use of facilities at the Grant Institute, to Mr J H Hull for the facilities provided at Murchison House and the contributions from the USSR National Committee of Geologists and the British Council towards the cost of the visit of Dr Ruslan Volkov. We also wish to thank the honorary officers of the Society for their many hours of work devoted to its affairs and to all of the lecturers and excursion leaders who provide such a varied and enlightening programme for the membership.

Report of the Auditor to the members of the Edinburgh Geological Society

I have audited the Accounts in accordance with approved auditing standards. Information supplied by individual Council members has been accepted as being correct where independent confirmation could not be obtained. The valuation of the Investments by the Bank of Scotland Investment Services has been accepted.

In my opinion the accounts which have been prepared under the historical cost convention give a true and fair view of the state of the Society's affairs at 30 September 1990 and of the net Revenue for the year ended on that date.

M. McLEOD C.A.
74 Colinton Road
Edinburgh EH14 1AT
10 November 1990

Summary of Accounts

Statement of Balances at 30 September 1990

	1990		1989	
	£	£	£	£
Fixed Assets				
Investments at Market Value		44,402		49,144
Current Assets				
Stock of Publications	6,677		7,445	
Other stocks	14		179	
Debtors	604		196	
Taxation recoverable	934		1,072	
Bank deposit accounts	9,821		3,895	
Current Account	585		1,152	
	18,635		13,939	
Less:				
Creditors due within one year				
Sundry	698		795	
Loan (Neckar Map)	700		700	
Bank Overdraft	–		586	
	1,398		2,081	
Net current assets		17,237		11,858
Net assets		61,639		61,002
Representing:				
Funds				
At 1st October 1989		61,002		54,604
Additions to Walter Mykura Fund		1,228		2,317
Increase (decrease) in valuation and disposal of Investments		(3,454)		2,525
Scottish Journal of Geology allocation		1,197		1,500
Surplus for year		4,924		1,561
		64,897		62,507
Less:				
Specific Expenditure (Scottish Journal of Geology Vol. 25)		(3,258)		(1,505)
		61,639		61,002

Revenue Account for the year ended 30 September 1990

	General £	*Publ's* £	*Clough* £	*Wright* £	*Sime* £	*Total* £	*1989* £
INCOME							
Income from Quoted Investments	1,756	2,201	441	98	123	4,619	3,887
Bank Interest	815	–	–	–	–	815	315
Subscriptions	5,771	–	–	–	–	5,771	4,649
Tax recoverable on Deeds of Covenant	388	–	–	–	–	388	21
Profit on Sales of Publications	–	700	–	–	–	700	662
Other	100	–	–	–	–	100	4
	8,830	2,901	441	98	123	12,393	9,538
EXPENDITURE							
Lectures	1,100	–	–	345	–	1,445	1,193
Excursions	382	–	–	–	–	382	752
Audit	418	–	–	–	–	418	400
Print. Post. Stat.	1,706	1,252	–	–	123	3,081	2,838
Miscellaneous	25	3	294	–	–	322	333
Insurance	104	–	–	–	–	104	100
Reception	4	–	–	–	–	4	67
Library additions	186	–	–	–	–	186	113
Bank charges	330	–	–	–	–	330	327
Non-recurrent expendure	–	–	–	–	–	–	354
	4,255	1,255	294	345	123	6,272	6,477
	4,575	1,646	147	(247)	–	6,121	3,061
Specific allocations	–	(1,197)	–	–	–	(1,197)	(1,500)
Surplus for year	4,575	449	147	(247)	–	4,924	1,561

NOTE: Scottish Journal of Geology

No provision has been made in these Accounts towards the cost of Volume 26, however the society undertakes to meet it's half share thereof at the appropriate time (estimated at £1000).

The Edinburgh Geologist
No. 26 Autum 1991

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