The Edinburgh Geologist

No. 23 Winter 1990

Dore Holm, Shetland Islands

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Cover Illustration

Dore Holm, natural arch in Old Red Sandstone volcanics near Esha Ness, Shetland. BGS photograph D 1657, reproduced by permission of the Director, British Geological Survey, NERC copyright reserved.

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Editorial

In this, the first issue of the Edinburgh Geologist of a new decade, there are articles covering a wide spread of geological interests, from places as far apart as Greenland and Malta, and dealing with rocks from Precambrain to Pleistocene age. The first paper, by Phil Stone concerns the ultramafic rocks of the Ballantrae Ophiolite Complex and follows his article on the extrusive rocks that was published in issue 21. Another contribution by a member of the BGS land survey, David Gould, recounts the exploits of the society's long field excursion to Shetland in 1988.

Two articles by recent graduates from Scottish universities have a continental flavour. Niall Fleming, formerly of Dundee University and now at Imperial College, describes his fieldwork on Gozo, the second largest of the Maltese islands. Niall spent seven weeks in the summer of 1988, studying the intriguing elliptical subsidence structures of Oligocene and Miocene age developed in sequences of marine carbonate rocks. The paper entitled "The Grant Institute Greenland Venture" describes field work on the Narsaq Igneous Complex in south west Greenland, undertaken by four students who graduated from the Grant Institute last year. Some members of the society may recall the publicity in the Edinburgh press that accompanied the start of the expedition, which was partially funded by an award from the society's Clough Fund. It is hoped that further articles on work supported by the society's Clough and Mykura funds will appear in forthcoming issues of the magazine.

The arctic flavour of this issue is continued by Ken Oakely's account of a trip to Iceland that he made in 1988.

The papers by Mike Browne and David Taylor are both concerned with the economic aspects of our science. The opening of the Birkhill Fireclay Mine in May 1989 as part of the Bo'ness Heritage area is depicted in detail by Mike Browne. In "Old stone or new?" David Taylor reports on a seminar organised by the Saltire Society, held in Edinburgh in October 1988. The seminar concerned stone extraction, working and use. Amongst the topics covered were the problems of colour matching and weathering encountered when refurbishing stone buildings, both inside and out; a subject close to the heart of anyone living in Edinburgh.

Strange Earth No. 8 by Bill Baird is once again an appropriate title to describe one of nature's curiosities. The 'roving stones' of the Racetrack Playa Lake in California require a rather unusual explanation; read the article and find out the reason for their travels!

The last contribution in issue 23 is a review by Steve Robertson of the excursion guide to the Moine of the Scottish Highlands, published for the Edinburgh and Glasgow Geological Societies by Scottish Academic Press. This pocket-sized book is a must for any geologist walking or working in the Northern and Central Highlands.

I should like to thank all of the contributors to what, I hope you will agree, is an edition of the Edinburgh Geologist that has something for everyone. Please keep the manuscripts coming (in double spaced typing, on A4 paper if possible) as this is your magazine and it should reflect the interests of all the society's membership.

Clive Auton
January 1990

Ophiolites and The Ballantrae Complex: 2

Phil Stone
British Geological Survey, Edinburgh

In part 1 of this review of the Ballantrae "ophiolite" (Edinburgh Geologist No. 21) the extrusive volcanic rocks were discussed. These form almost half of the Complex and were derived from within-plate and subduction-related environments rather than the mid-ocean source which might have been expected. The other major component of the Ballantrae Complex is ultramafic rock and this article will continue the discussion by considering its characteristics and ophiolitic relationships.

The ultramafic rock crops out mainly in two NE to SW trending zones generally known as the Northern and Southern Serpentinite belts (Figure 1). Variably serpentinised harzburgite (essential olivine and orthopyroxene) is the commonest lithology in both of the belts, but there are significant differences between the two in the accessory ultramafic components and in the fabrics developed both within them and the harzburgites. The appearance of the dominant harzburgite throughout the Complex is governed by three variables: the size and shape of the serpentine crystal mesh after olivine, the size and proportion of the orthopyroxene (bastite) phenocrysts, and the intensity of serpentinite veining.

The Northern Serpentinite Belt contains, in addition to the ubiquitous and locally banded harzburgite, a variety of petrologically and texturally diverse pyroxenites; among the latter are varieties in which either clino- or orthopyroxene is dominant and some in which the two pyroxene types are present either with olivine (lherzolite) or without (websterite). The field relationships between the harzburgite and the pyroxenites are not clear but the latter apparently form veins and irregular pods within the harzburgite. Indeed, some of the contacts may be tectonic since all of the Northern Belt lithologies are locally affected by a pervasive tectonic fabric. This is particularly marked in the vicinity of the south-east margin of the belt where a thin zone of dynamothermal metamorphic rocks, ranging from chlorite-epidote schist to garnet amphibolite, has been formed from the adjacent extrusive rocks. The schists and amphibolites have been interpreted as parts of a metamorphic sole formed beneath a hot ultramafic slab during the early stages of its obduction. (Spray and Williams, 1980; Treloar and others, 1980).

Tectonic fabrics other than those produced by high level, brittle deformation have not been recorded from the Southern Serpentinite Belt. There, harzburgite is again dominant with the orthopyroxene crystals often larger than those seen in the north. Small outcrops of dunite (90% olivine) in the south-east part of the Southern Serpentinite Belt are associated with wehrlite (essential olivine and clinopyroxene) and less commonly with troctolitic gabbro (essential olivine and plagioclase). Layered relationships are seen in some exposures but on a larger scale the dunites, wehrlites etc. appear to be enclosed as blocks within the surrounding sheared serpentinite. They form "tectonic inclusions" and suggest that the Southern Serpentinite Belt is, at least partly, a serpentinite melange. Nevertheless, the presence of the layered lithologies is significant since they form a very similar assemblage to that seen in many ophiolites at the transition between the ultramafic and gabbroic sections. As such the Ballantrae examples probably originated in the vicinity of the moho with the ultramafic rocks of the mantle below and the gabbros of the lower crust above.

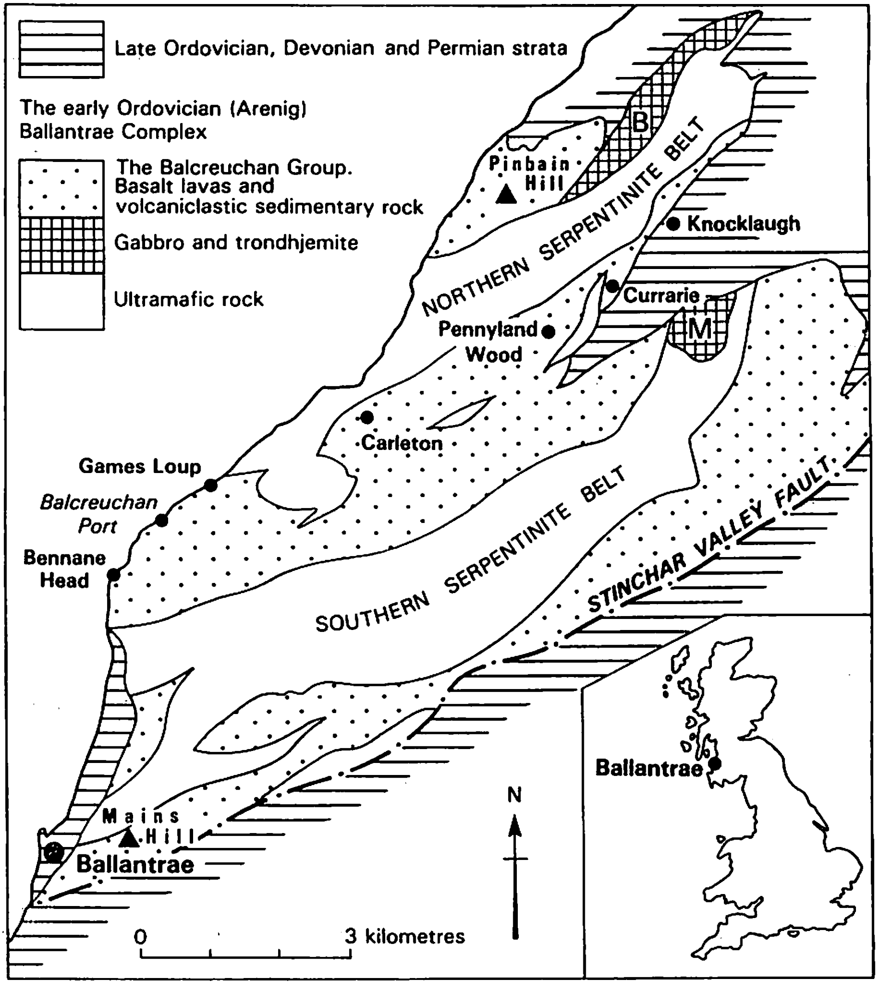
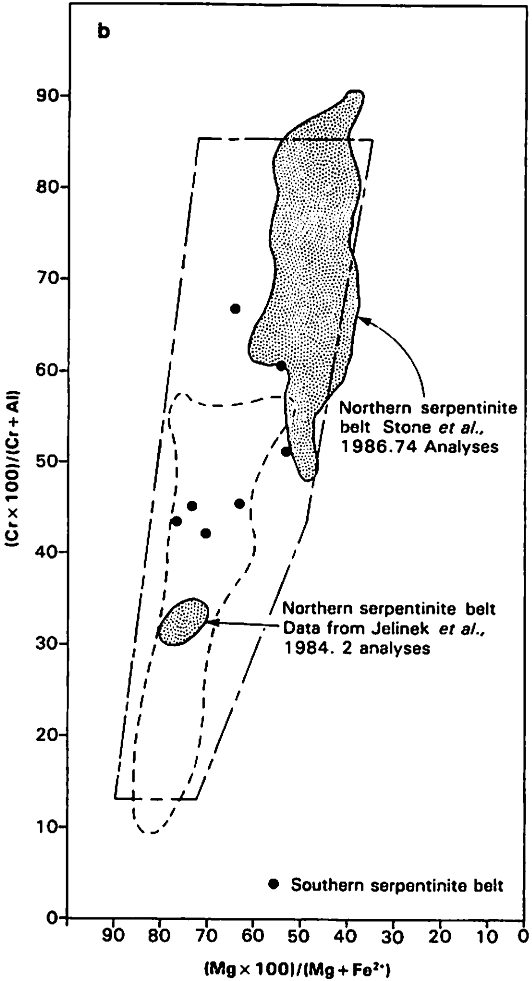


Figure 1. Location and outline geology of the Ballantrae Complex, SW Scotland.



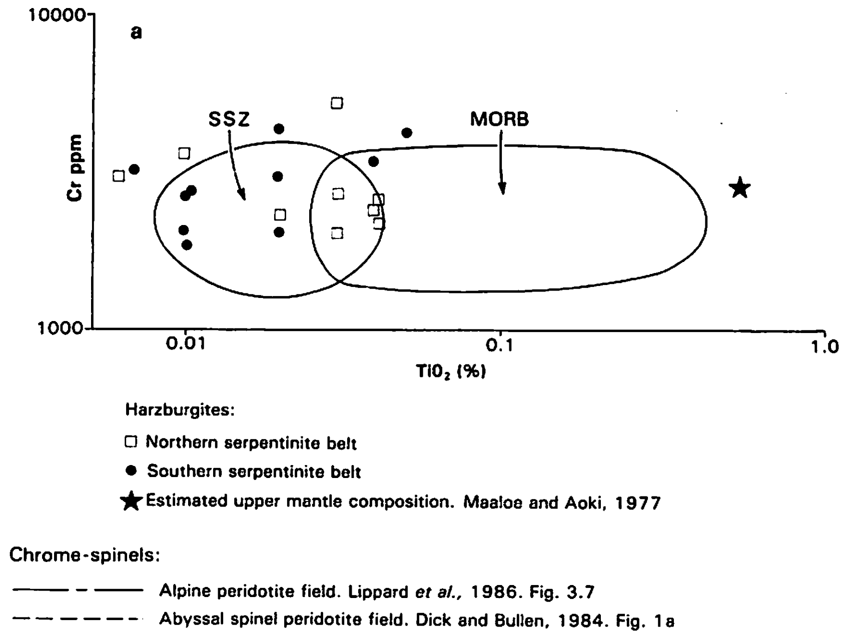


Figure 2a. Geochemical characteristics of ultramafic rocks from the Ballantrae Complex: Cr-Ti0_2 plot, Hazburgites.

Figure 2b. Complex: Cr-Ti0_2 plot, Chrome spinels.

So far, so good; from the above considerations of petrography and texture, the Ballantrae ultramafic rocks could be typically "ophiolitic". The differences between the two outcrop belts are compatible with origins at different structural depths within the same ophiolite ultramafic sequence; the southern belt being formed towards the top and the northern belt at a much deeper level, where decoupling and thrusting preceded obduction. However, when the geochemistry of the ultramafic rocks is considered their origin as oceanic mantle is by no means as clear. For example, the harzburgite, dominant in both serpentinite belts, is generally more depleted in a wide range of elements than is the case with mid-ocean ridge (MORB-type) ophiolites. This is illustrated in the Cr-TiO_2 plot of Figure 2a in which the compositions of the mantle harzburgites from the Ballantrae Complex are more similar to those of "supra-subduction zone" (SSZ) ophiolitic harzburgites as defined by Pearce et al (1984). The SSZ ophiolites have the geochemical characteristics of island arcs but the structure of oceanic crust and are believed to form by sea-floor spreading directly above subducted oceanic lithosphere.

Further support for a subduction-related origin for the Ballantrae ultramafic rocks may be provided by the composition of the ubiquitous accessory chrome spinels. In total these show the typical compositional range associated with ophiolites (Figure 2b; alpine-type peridotites of Lippard et al, 1986). However, there is a marked difference between the compositions of spinels derived from the northern and southern serpentinite belts with the former proving much richer in Cr than the latter. This may be partly explicable in terms of the difference in original structural depth of the two ultramafic belts. There is a suggestion from some ophiolites (eg Oman; Brown, 1980) that spinels in harzburgite become more Cr-rich with increasing depth. However, in a study of "abyssal spinel peridotites" dredged from oceanic ridges, and thus most likely to correspond to the ultramafic rocks of MORB-type ophiolites, Dick and Bullen (1984) showed that the spinels were, on the whole, low in Cr.

In contrast the ultramafic rock generated in subduction-related environments contains spinels richer in Cr, the levels being very similar to those seen in the Ballantrae examples. These relationships, in terms of Cr/Al and Mg/Fe ratios are illustrated in Figure 2b. As in Figure 2a, the Ballantrae ultramafic rocks would seem to have more in common with subduction zones and island arcs than with mid-ocean ridges; the same conclusion that was drawn from a consideration of the extrusive components of the complex.

Taken together the various lines of evidence provide compelling reasons for regarding the Ballantrae Complex as an island arc and within plate assemblage, rather than a fragment of oceanic crust generated at a mid-ocean ridge.

A more comprehensive review of the Ballantrae Complex is provided by a recently published BGS handbook, Classical areas of British geology : Ballantrae, by P Stone and J L Smellie. This complements a new edition of the 1:50 000 solid geology sheet for the area (Sheet 7 : Girvan) and a "shortly to be published" 1:25 000 solid geology map of the Ballantrae Complex itself.

References

BROWN, M., 1980. Textural and geochemical evidence for the origin of some chromite deposits in the Oman ophiolite. In A. PANAYIOTOU (ed) *Ophiolites*. Geological Survey Dept. Cyprus. p. 714-721.

DICK, H.J.B. and BULLEN, T., 1984. Chromian spinel as a petrogenetic indicator in abyssal and alpine-type peridotites and spatially associated lavas. *Contrib. Mineral. Petrol.* Vol. 86, p. 54-76.

LIPPARD,S.J., SHELTON, A.W. and GASS, I.G., 1986. The ophiolite of Northern Oman. *Memoir Geol. Soc. London*, No. 11, 178 pp.

MAALOE, S. and AOKI, K.I., 1977. The major element composition of the upper mantle estimated from the compositon of lherzolites. *Contrib. Mineral. Petrol.* Vol. 63, p. 161-173.

PEARCE, J.A., LIPPARD, S.J. and ROBERTS, S., 1984. Characteristics and tectonic significance of supra-subduction zone ophiolites. In B . Kokelaar and M.F. Howells (eds.) *Marginal basin geology : volcanic and associated sedimentary and tectonic processes in modern and ancient marginal basins*. Geological Society of London Special Publication No. 16, p. 77-94.

SPRAY, J.C. and WILLIAMS, G.D. 1980. The sub-ophiolite metamorphic rocks of the Ballantrae Igneous Complex, SW Scotland. *J. Geol. Soc. London*, Vol. 137, p. 359-368.

STONE, P. and SMELLIE, J.L. 1988. *Classical areas of British geology : the Ballantrae area*. London, HMSO for the British Geological Survey, 125pp.

TRELOAR,P.J. BLUCK, B.J. BOWES, D.R. and DUDEK, A. 1980. Hornblende-garnet metapyroxenite beneath serpentinite in the Ballantrae Complex of SE Scotland and its bearing on the depth provenance of obducted oceanic lithosphere. *Transactions of the Royal Society of Edinburgh : Earth Science*, Vol. 71, p. 201-212.

Shetland Saga

David Gould
British Geological Survey, Edinburgh

Sadly preparations for the Edinburgh Geological Society's annual long excursion in 1988 were severely disrupted by the sudden and tragic death of the designated leader, Wally Mykura, just one week before the start of the excursion. Fortunately he had already prepared and discussed the itinerary with Andrew McMillan, who bravely agreed to go ahead with the excursion as planned. So the anticipation of the spectacular geology to be seen in Shetland was tinged with regret that someone with such strong links to Shetland and its geology would no longer be with us.

The advance guard of the party left Edinburgh for Aberdeen on Friday 20 May, under the command of Ian Hogarth in a hired minibus, fully laden as usual with provisions, and travelled overnight to Lerwick on the St. Clair, while the majority of the party flew by Loganair from Edinburgh to Tingwall on the 21st, and a second minibus was hired in Shetland. Base was set up at Wester Houll Chalets, magnificently sited overlooking Scalloway beside a large wind generator, which has since suffered severe damage in the winter storms.

Shortly after gaining entry to the chalets and off-loading the provisions and luggage, the airborne party joined the seafarers who had been looking at the exhibits, including some very good mineral specimens, in the Lerwick museum. The remainder of the Saturday was spent examining the Old Red Sandstone exposures near Lerwick. The base of the succession consists of the Rova Head Conglomerate containing rounded clasts of granite, not presently exposed in the immediate vicinity, and Dalradian metasediments. Exposures just south of Lerwick town show cross-bedded sandstones cut by irregular calcite veins and folded into sharp monoclines; similar to those on Bressay, where they are associated with volcanic vents. The day was rounded off by a visit to the Broch of Clickhimin, a well-preserved pre-Norse fortified dwelling built on a peninsula jutting into a small loch.

Sunday's excursion was to the southern Mainland. At Fladdabister, the base of the Old Red Sandstone succession is a breccia, with smaller but more angular clasts than the Rova Head Clonglomerate. Its unconformity on Dalradian schists of the Quarff Nappe was well exposed. At Sandwick, the party climbed a small hill for a binocular view of the Broch of Mousa, noting the local flaggy siltstones in passing. The sun came out briefly at the lunch stop on the tombolo (sand bar) linking the Mainland to St. Ninian's Isle.

The afternoon itinerary took us first to the Loch of Spiggie, where highly weathered epidote-rich granite of the Spiggie Complex was seen in faulted contact with strongly folded phyllites of the Clift Hills Division (Upper Dalradian). Then followed another archaeological break at Jarlshof, where

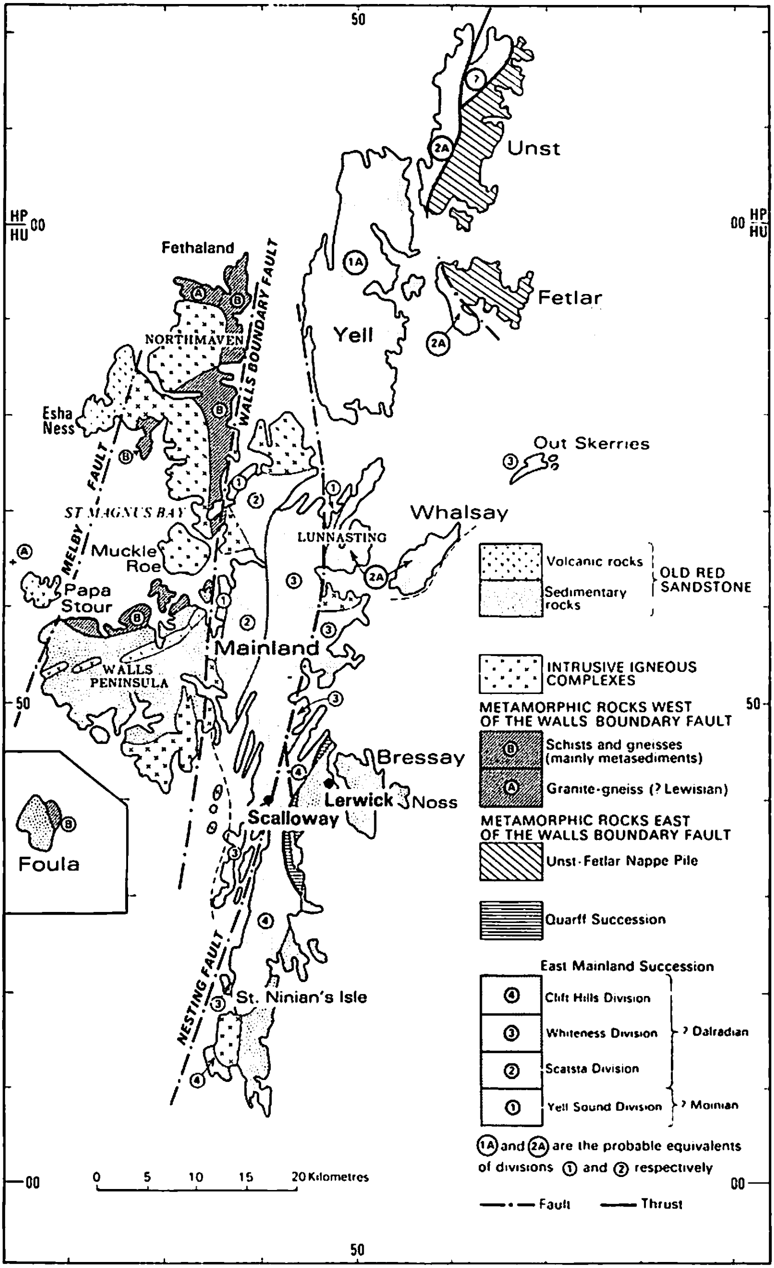


Figure 1. Geological sketch-map of Shetland (from British Geological Survey Regional Guide - Orkney and Shetland). Reproduced by permission of the Director, BGS.

successive buildings of Celtic, Viking and Mediaeval farming communities have been excavated and opened to visitors. A brief very cold and windy stop was made at the Slithers, beside Sumburgh lighthouse, in order to examine calcareous layers in the greyish flaggy Old Red Sandstone. This was followed by an excavation programme at the Exnaboe Fish Bed. The location of the Fish Bed was easily discovered from the pile of detritus left behind by previous fossil fishermen, and carbonised fish scales proved quite abundant.

On the Monday, the party made its way to Esha Ness, in the far northwest of the Mainland. This proved a good move, as the wind was from the east, and we received sunshine and shelter together. A stop was made at Mavis Grind, where a road cutting exposes wide scapolite veins in diorites of the Northmaven Complex and the Atlantic Ocean comes within 50 metres of the North Sea. We also viewed the Heads of the Grocken, where spectacular cliff scenery is developed in the Ronas Hill Granite.

At Esha Ness to the west of the Melby Fault, the local Old Red Sandstone succession is younger than that in south-east Shetland. It consists largely of volcanic rocks, which were examined in a walk from Esha Ness to the Grind of the Navir. Particularly spectacular were a volcanic breccia at Esha Ness itself and a rhyolitic ignimbrite, with flattened and welded lapilli, at the Grind of the Navir. The coastal scenery was testament to the force and erosive power of the sea on exposed coasts. At the Holes of Scraada, for example, the sea has eroded a 500 metre long subterranean passage whose roof has collapsed, while at the Grind of the Navir there is a storm beach lying 15 metres above sea level and 50 metres inland. The storm beach consists of rectangular blocks of rhyolitic ignimbrite, up to 5 metres in size, plucked from the cliffs; not a place to visit during winter storms. On the way back to Scalloway we visited the disused magnetite mine at Clothister, where specimens of massive magnetite were readily obtainable. The magnetite rock occurs within a fairly narrow band in a group of varied schists of uncertain provenance (the Queyfirth Group).

Tuesday's trip to the Walls peninsula enabled the party to see yet another facies of the Old Red Sandstone, this time that lying between the Walls Boundary Fault and the Melby Fault. These rocks are older and more strongly folded than those to the east and west and have been intruded by Caledonian granitic rocks. The Walls Sandstone Formation consists of mainly fine-grained grey sandstones which exhibit graded bedding, ripple marking and large-scale desiccation cracks. Considerable argument was generated among the party as to whether the sedimentary structures indicate deep or shallow water sedimentation, but eventually a consensus was reached that at least some of the sedimentation took place in shallow water.

In the afternoon, the party crossed the Melby Fault and attempted to find fossil fish remains in the Melby Fish Bed which is roughly contemporaneous with the Esha Ness volcanics. We had much less success fossil-hunting than at Exnaboe. Finally we travelled across the Melby Fault again to see the metamor-

Figure 2. Rova Head Conglomerate, at the base of the Middle Old Red Sandstone, near Lerwick.

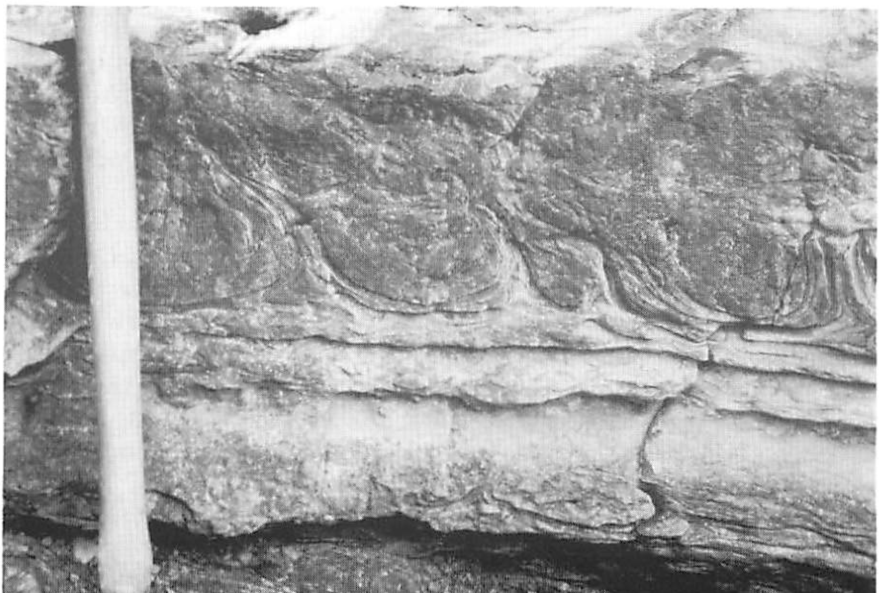


Figure 3. Flame-structures in the Melby Fish Bed.

phic rocks underlying the Walls Sandstone. The abundance of marble and calc-silicate rocks in the West Burra Firth Group (?Grenvillian) was noted, before rain and time forced a retreat.

On Wednesday the party split. While a "sedate" group visited Bressay but found the ferry to Ness inoperative, the "hard" party of 10-12 souls went to Fethaland, at the extreme north of the Mainland, and managed to combine the best geology of the week with the best weather. After noting a small patch of Old Red Sandstone breccia similar to that seen at Fladdabister (perhaps a clue to the amount of throw on the Walls Boundary Fault?), we examined the varied schists and amphibolites of the Queyfirth Group. These contained pods of talc-schist and an ultrabasic chlorite-schist with beautiful octahedral magnetite crystals weathering out of it.

After lunch, beside a sheltered gravel storm beach linking the point of Fethaland to the mainland, we visited the new lighthouse on the point, where we were rewarded with a view of Gruney Island (another Old Red Sandstone outlier) and the far off cliffs of Yell. To the west of the Queyfirth Group we traversed the Sand Voe Group, which consists mainly of psammites with thin bands of hornblendic rocks, all of which dip at moderate angles to the east. These rocks are regarded as Moine with Lewisian inliers. As we proceeded westwards, the rocks became progressively more sheared, until we reached the Wester Keolka Shear Zone. This is a much more deep-seated and steeper dislocation than the Moine Thrust (which occupies an equivalent position in north-west Scotland), which separates the Sand Voe Group from the sheared orthogneisses of the Wilgi Geos Group (Lewisian). The orthogneisses were at first not very convincing due to the intense shearing, but the last outcrop of the day, on the west coast of the Fethaland peninsula, showed a less sheared and more believable Lewisian gneiss.

Thursday saw the party reunited for the long haul to Unst, which necessitated a 7 am start to catch the two ferries. The Dalradian metasediments of the Valla Field Block, which forms the west coast of Unst, were seen at Burra Firth before the party went on a good plowter through the very muddy Queyhouse talc quarry, in sheared and altered ultrabasic rocks of the lowest ophiolite nappe. The boundary of this nappe was seen at the Taing of Norwick, where hornblende schists of the Saxa Vord Block are separated from serpentinites of the ophiolite nappe by a 1-2 metre wide band of talc-schist. We then walked along the shore to try to find outcrops of the Skaw Granite, a foliated rock with 5cm phenocrysts of red microcline, and although we failed, abundant water-worn boulders were seen and a few were collected.

After lunch, the return southward was punctuated by a visit to some of the many disused chromite excavations north of Baltasound, where good specimens of chromite and kammererite (a violet chromium-bearing mica-like mineral) were collected, but the chrome garnet uvarovite proved elusive. Lack of time and deteriorating weather meant that attempts to visit the Muness

Phyllites and the gabbros and sheeted dykes of the ophiolite were abandoned in favour of a brief sightseeing stop at Muness Castle.

Friday's excursion started with a drive along the road from Bixter through Aith to Voe, mostly just east of the Walls Boundary Fault. After noting psammites of the Moine Yell Sound Division cut by monzonites of the Spiggie Complex, the party examined in detail the metamorphic aureole caused by the intrusion of a circular hornblendite/diorite plug into pelites of the Scatsa Division (Lower Dalradian).

After a stop at the craft shop in Voe, lunch was taken on the beach at Lunna House (headquarters of the "Shetland Bus" during the Second World War). The spectacular Valayre Gneiss was seen, containing prophyroblasts of red microcline 5-8cm in size. The gneiss is a marker horizon which lies close to the Moine-Dalradian boundary east of the Walls Boundary Fault. The party then visited Vidlin, where a gossan, with spectacular colours caused by iron oxide minerals, marks the outcrop of a Cu-Zn-Pb-bearing massive sulphide horizon. This provided a good sunbathing location, and the troops proved difficult to rally for the final locality of the day, just off the Vidlin-Lunning road, where large crystals of staurolite, kyanite and sillimanite in Dalradian pelites were enthused over and collected by many.

On the Friday evening the party assembled in the Hogarth chalet for a small celebration. Your correspondent was initiated into the mysteries of the Strontian Hammer by being most surprisingly presented with this trophy "at the first attempt and without even trying"! The citation included encouraging the party to reach the last and best outcrop of Lewisian on Fethaland, and research into the effect of penny whistle music on nesting fulmars (from a safe distance!).

Saturday's schedule only permitted a brief excursion because the flight from Tingwall was scheduled for lunchtime. One minibus load made the trip to Hamnavoe on West Burra, where the wide spread Spiggie Complex was seen yet again, this time in the guise of a granite with large (5cm) microcline phenocrysts. This made an interesting comparison with the Skaw granite and the Valayre Gneiss. Monzonite and hornblendite of the complex were also seen as well as another storm beach and some seals swimming in the sea. The airborne party managed to leave despite the low cloud and mist only a few miles to the east. The seafarers were able to stay on Shetland till Sunday evening, but their activities were hampered by fog and low-lying cloud for most of the time.

In all, the excursion was very successful and Andrew McMillan performed very well despite his rather sudden elevation to leadership.

Old Stone or New?

David J. Taylor
Buckstone Court, Edinburgh

Edinburgh geologists would have found much of interest in a one-day seminar in October 1988 entitled "Old Stone or New? - the availability of new and salvaged building stone in Scotland", which preceded the start of the EGS 1988/89 winter lecture season by a few days. The morning papers of this Saltire Society organised seminar, on stone extraction, working and use were of most direct geological interest. The afternoon papers covering conservation diversified into details of interior mouldings, fireplaces and railings.

Bob Heath, a consultant to both the providers and consumers of stone, gave a review of stone extraction in Scotland from historical times to the present day. The number of quarries has declined greatly during the present century, there being now about 60 left, predominantly producing roadstone. Scotland has therefore gone from being an exporter of building stone to an importer despite its reserves being far from exhausted. However, in the last fifteen years there has been a substantial revival in the use of indigenous building stones. This has resulted in the re-opening of some nine quarries specifically for building material. There has been unexpected economic success for some of these quarries; for example, some red sandstone from Corsehill Quarry, opened for restoring the National Portrait Gallery, can now be found in Dubai, Washington and Toronto. Unfortunately, the public have a conception of quarrying based on road aggregate quarrying. Building stone quarries have much less impact on the environment. Minimal blasting and output rates from only 6 lorry loads per week to as little as 2 per fortnight were quoted. Heath felt that the skills required for quarrying were still within Scotland, but that economics were the holding factor and that architects must be persuaded to use the indigenous material.

The problems of re-using stone were described from the stone-worker's point of view by Ian Ketchin. Large blocks removed from buildings may be trimmed down to a smaller size (with material waste, of course), but invisible faults can be discovered in the stone which means it has to be discarded after effort has been expended. Such faults could be weathering cracks or demolition damage. New stone has a higher quality level which can make it more cost effective, but it can be difficult to match the tool finishes on such material. Sometimes there is no choice; the 260 feet deep Craigleith quarry, as excursion regulars will know, is now filled in and is surrounded by 1930's housing, so salvage stone is the only available source.

Ian felt that architects place too much attention on colour matching when choosing a replacement material and not enough on grain, durability and weathering properties. The chemical problems of placing dissimilar stones in contact and the resultant erosion were thought to be not widely understood by architects. These points were illustrated by the next speaker, James Simpson of Simpson and Brown. Building styles have changed from a traditional solid two-foot wall, perhaps covered by harling, to today's superficial cladding. He argued that the absorption and evaporation characteristics of thicker stone, keeping the inner surface dry, differ from stone used as thin cladding which cannot absorb so much water. Slides were shown of unfortunate examples of cornices failing to shed water clear of the facade, with resultant discolouration. It seems that many architects still have something to learn.

Ballachulish quarries, once the major source of Scottish slate, are now closed and landscaped over. There is still plenty of material left and many of the delegates felt that a small working mine with a visitor centre could be a tourist attraction rather than a blot on the landscape. Must industry be incompatible with interpretive tourism? Three of the Burlington quarries are situated in the heart of the Lake District national park without creating a great outcry. Easdale was thought to be a more likely candidate for re-opening in Scotland.

The last speaker of the morning was David Wallace of Burlington Slate (a conference sponsor along with the SDA). He gave a brief history of the Cavendish family in slate production and marketing and proceeded to demonstrate his own skill in slate cleaving with a hammer and chisel! Some delegates were later to test their own skills as David had brought several thick pieces of slate up from Cumbria. His promotional film was fascinating; not only did it describe the extraction of slate from the mountain side using a variety of techniques, but allowed us to see what kind of image was being projected on behalf of this metamorphic rock! Marketing slate is not without its problems - in the USA the quality of slate is very variable, so they project a better image as "Burlington Stone". The Spanish competition was 'slated' for sometimes offering far better samples than the delivered goods!

In production, slate is separated from the base by a diamond chain saw and then split into workable pieces either by large pneumatic versions of 'hammer and chisel' or by blasting. Cumbrian slate is coarser grained and a different colour to Welsh, and is also offered in a "random" size (between set limits, I gather!) which makes best use of available material. Cumbrian grey slate is derived from volcanic ash sediments rather than the mudstone sediments that form the other varieties.

After lunch, Sigrid Nielsen, Desmond Hodges and James McCormack, discussed the problems of organising the unfortunately named 'architectural salvage', in which providers and consumers are put in touch, and important items are stored for the future. I feel that the term 'salvage' belittles the value of the items. The last speaker, Colin McPhail, moved our perspective from the indoor back to the outdoor, and partly at least, explained the reasons for Edinburgh's surfeit of bumpy roads. The Highway Department are committed to maintaining some 27 miles of 'setted' roads. One (serious) suggestion from the audience for restoring the surface roughness by dousing with hydroflouric acid, was rejected as being a little too dangerous!

The venue itself, the delightful 18th century St. Cecilia's Hall, provided architectural and historical interest during the breaks, and a number of the delegates availed themselves of the opportunity both to see Scotland's oldest concert hall and to purchase the Society's "The Building Stones of Edinburgh" as Cecilia Taylor, our publications sales officer, also attended the meeting.

Strange Earth, No. 8

Bill Baird
Royal Museum of Scotland

The roving stones of the Racetrack Playa lake, Inyo County, California have been the subject of many articles in geological journals and books. Ranging in size from pebbles to boulders several hundred pounds in weight, these stones lie at random on the surface of the playa. They leave behind them tracks on the surface of the dried up lake, showing the routes along which they have travelled. Initially falling onto the dried-up lake bed from a steep hill near its southern end, they then set off on their mysterious travels, leaving behind long shallow grooves on the clay surface. Some tracks are long, others short; they may be straight, curved or zigzag, with some even doubling back on themselves.

Although nobody has actually seen these rocks in motion at Racetrack Playa there have been several theories to account for their movement. Unconfirmed eyewitness reports from other playa lakes in the area speak of sheets of ice with stones frozen to their bases being driven across the playa surface by the wind. Strong winds combined with special low-friction conditions of the lake have been suggested and even the local Indians have been regarded with some suspicion, though there are no footprints along the trackways. Until confirmed and verified by observation of actual movement, and hopefully filmed, we cannot be certain exactly what mechanism moves the stones.

In May 1968, Dr Robert Sharp, Professor of Geology at California Institute of Technology in Pasadena marked 25 of the rocks with numbered stakes, recorded their locations, and settled down for a long wait. He was surprised to be told the very next spring that some of his rocks had moved. The heaviest of these was a rock, weighing 39 pounds, which had travelled 71 feet on a curving track. The furthest travelled was 15 pound rock which had moved 212 feet. Sharp believes that the motive force for these movements is the wind, allied to very special conditions on the lake surface.

The mechanism that he envisages requires that the top layer of the lake bed would have to be water-saturated but the underlying layers must remain firm. Winds in the area of the lake, which lies at 3,708 feet above sea level, can be strong enough to blow out car windows and force hillwalkers to their knees. Katabatic winds have been recorded elsewhere at speeds in excess of one hundred miles per hour which would seem sufficient to move even large rocks under very low friction conditions. Perhaps only by carrying out experiments in a wind tunnel with rocks sitting on low friction clay, could we find out whether this is the correct solution to the roving stones of Racetrack Playa, California.

References

STANLEY, G.M., 1955. Origin of playa stone tracks, Racetrack Playa, Inyo County, California. *Geological Society of America Bulletin*, 66, p. 1329-1350.

NATIONAL GEOGRAPHIC MAGAZINE, 1970. Vol. 137, p. 77 & 100-101.

NORRIS,R.M. and WEBB, R.W., 1976. *Geology of California* p. 119-121. John Wiley & Sons, New York.

SHARP, R. and CAREY, D.L., 1976. Sliding stones, Racetrack Playa California. *Geological Society of America Bulletin*, 87, p. 1704-1717.

Subsidence Structures of Gozo, Malta

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During the summer of 1988, I spent 7 weeks studying the geology of Gozo for my undergraduate thesis. Gozo, the second largest of the Maltese Islands, lies 96km south of Sicily and 270km north of Africa. It is composed predominantly of marine carbonate rocks deposited at depths of 5-200m and ranging in age from Chattian (Late Oligocene) to Messinian (Late Miocene). The stratigraphic sequence recognized on the island is illustrated in Figure 1.

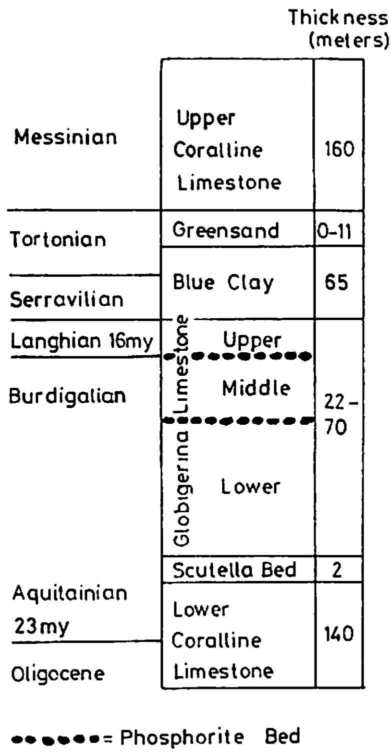


Figure 1. Late Oligocene to Lake Miocene stratigraphy of Gozo.

One of the most characteristic features of the geology of Gozo is the large number of elliptical depressions which produce a distinctive landscape. These depressions were first recognized by Spratt (1843) but it was Trechman (1938) who suggested they were formed by the collapse of cave roofs. In western Gozo seven of these features have been recognized, ranging in diameter from 30-425m, Figure 2.

Each depression contains material from the collapsed cavern roof, overlain by a layer of a coarse, unsorted biomicrite which thickens towards the edges of the depression. The biomicrite was washed into the collapse after subsidence and is distinct from micritic limestones deposited outside the subsidences, which tend to be fine-grained and homogeneous. The age of the youngest rocks within the debris of the collapsed cavern roof allows the age of subsidence to be determined. Where this collapsed rock is obscured by the deposition of later sediments, the time of collapse is difficult to ascertain. Based on the age of the youngest cavern roof collapse material, two periods of subsidence have been recognized.

(i) Oligocene - Lower Miocene phase (Scutella Bed - L Globigerina Limestone).
(ii) Upper Miocene phase.

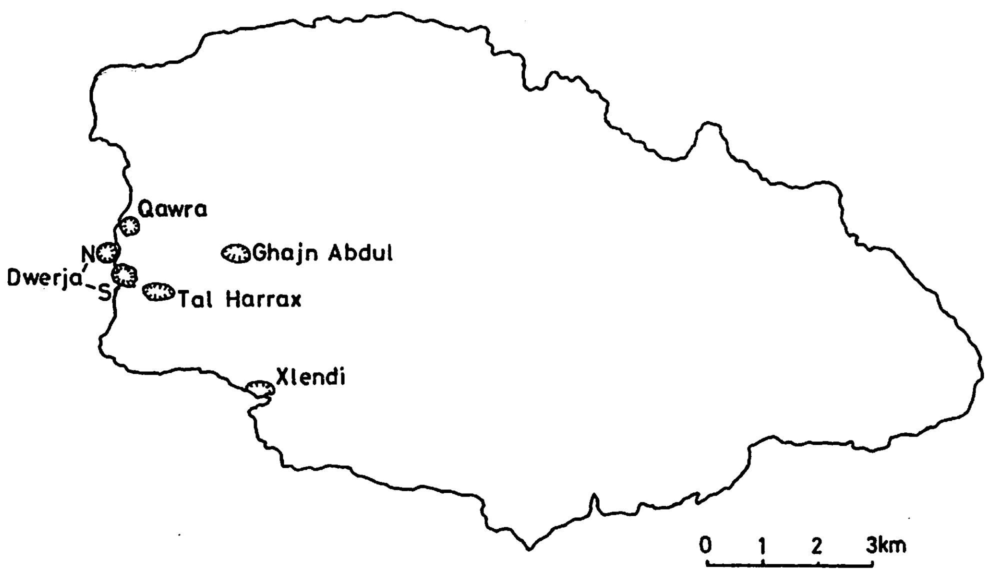


Figure 2. Location of subsidence structures in Western Gozo.

Most of the solution subsidences formed during the Oligocene-Lower Miocene Phase show evidence of renewed collapse during the Upper Miocene Phase.

Table 1. Phases of collapse

Site	Phase
Dwerja North	L. Coralline Limestone and Scutella Bed Phase
Tal Harrax	L. Coralline Limestone and Scutella Bed Phase
Qawra	L. Coralline Limestone and Scutella Bed Phase
Xlendi	L. Coralline Limestone and Scutella Bed Phase
Ghajn Abdul	Upper Miocene Phase
Dwerja South	Age unknown

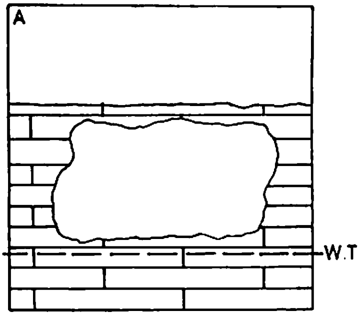
Example of a subsidence : The Xlendi structure

The village of Xlendi lies in south-west Gozo at the head of a steep narrow inlet. On the northern side of the bay one finds the Xlendi structure which collapsed during the first period of subsidence. It is approximately 200m in diameter and is bounded by vertical fracture margins. The youngest sediments contained within the collapsed cavern roof material is of L.Globerina Limestone age which allows the subsidence to be dated. This collapse debris is brown-orange, poorly sorted biomicrite containing abundant phosphorite clasts. The biomicrite is poorly fossiliferous except for occasional echinoid fragments. Scour and fill structures commonly occur. Pedley and Bennett (1985) interpreted this deposit as a calciturbidite associated with feeder channels within the depression. These sediments occupy a synsedimentary basin, formed by the mass transport of sediment towards the lowest point within the depression.

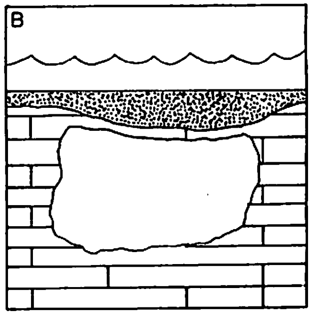
Subsidence mechanism

Evidence from a borehole at Naxxar in eastern Malta indicates that caverns are developed within much of the Pre-Miocene sequence. No evaporite horizons were recognized in this borehole. Cavern formation is therefore thought to have been due to the dissolution of limestone within the vadose zone. It is postulated that during Early Tertiary times much of Gozo was an upstanding landmass up to 50-100m in elevation, prior to its submergence in Oligo-Miocene times.

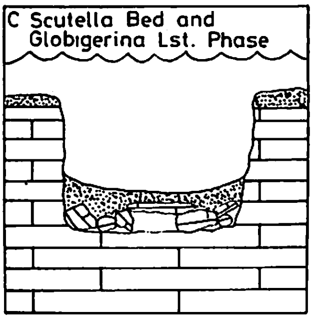
The mechanism of subsidence is summarized in Figure 3. Sagging of cavern roofs occurred due to creep. This generated tensile-stresses on the underside of each roof. Such a process is analagous to a marble bench bending downwards under its own weight. Eventually a metastable position is reached, in which the tensile strength of the rock is equal to the tensile stress. The attainment of this situation may have been enhanced by the weight of accumulating sediment above the caverns. To unbalance the equilibrium position, some input of energy was required. This may have been supplied by tectonic activity, associated with the formation of the Malta Graben which lies along the southern coast of Malta.



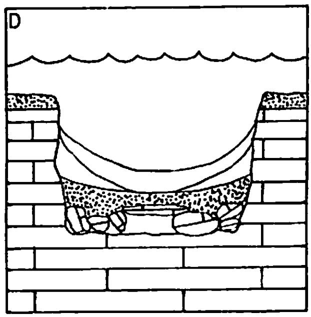
Fall in sea level. Emergence of land allowing cavern development.



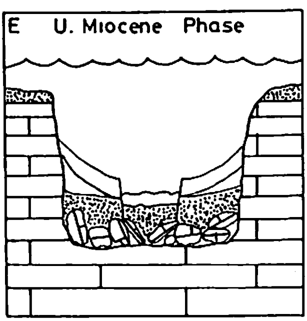
Rise in sea level. Buckling of cavern roof. Accumulation of pelagic sediment on the sea floor.



Incomplete collapse of cavern roof.



Biomicrites washed into the depression from the surrounding area.



Renewed collapse of pre-existing subsidences and formation of new ones.

Figure 3. Mechanism for solution subsidence on Gozo.

Collapse of caverns during the Scutella Bed - Globigerina Limestone Phase was incomplete and cavities were created by the foundering blocks of roof material. Some caves remained unaffected during this phase because they had not yet reached the metastable position. By Upper Miocene times however, these caverns had attained the metastable point and a second phase of tectonic activity instigated collapse. During this period, further subsidence occurred in those voids left after the first episode of collapse.

Acknowledgements

I am grateful to Dr Colin Braithwaite (Glasgow University) for his numerous constructive criticisms of the draft manuscript.

References

PEDLEY,H.M. and BENNET, S.M., 1985. Phosphorites, hardgrounds and syndepositional solution subsidence : a palaeoenvironmental model for the Miocene of the Maltese Islands. *Sedimentary Geology*. Vol.45, p. 1-34.

SPRATT, T.A.B., 1843. On the geology of the Maltese Islands, *Proc. Geol. Soc. Lond.* Vol. 4, p. 225-232.

TRENCHMAN, C.T., 1938. Quaternary conditions in Malta, *Geol. Mag.* Vol. 75, p. 1-25.

The Grant Institute Greenland Venture

Jane Foster, Rona McGill, Mark Osborne, Martin Pendlebury

The sun was shining, the brilliant blue sky was mirrored by the azure sea. We sat in shorts and t-shirts, basking in the warmth. The Costa Brava? The Caribbean? No this was Greenland! Only the flotilla of icebergs drifting slowly past in the bay below our campsite gave us the gentle reminder that we were 61° North and barely a day's walk from the largest ice-cap in the Northern Hemisphere.

We had arrived a few days earlier, flying from Glasgow to Copenhagen, and then on to Iceland where our departure was delayed by an hour due to poor visibility at Narsarsuaq*, the main airport in southern Greenland. We wondered why a little cloud should cause delay when most planes can land in anything other than thick fog, we rapidly discovered the reason. After a breathtakingly beautiful descent from 30,000ft over the ice-cap, we were skimming the cloud tops. Jagged mountains poked through the clouds as we plunged into the mist, the aircraft weaving from side to side to slow down and lose height.

As the plane dropped below the cloud base we realised that we were flying along a U-shaped valley with a meandering glacial river carrying so much suspended sediment that it resembled milk. Without warning the pilot threw the vintage 727 jet into a right turn. The whole plane was on its side! We could see the sunlight glinting on the braided outwash fan directly below us. In the plane people were screaming in terror. We straightened, nearly clipped a hilltop and fell onto the runway. Violent braking brought us to a stop 100 yards from the end of the runway, on the beach! There was thunderous applause from the local contingent at the back of the plane. Shaken, we disembarked and set foot on Greenlandic soil; we had arrived!

The whole idea of a Greenland trip was first mooted in Autumn 1988. All four of us were then honours year students at the Grant Institute. As we had enjoyed our independent mapping at the end of third year, we thought it would be fun to try something more ambitious after our finals. The idea was to go somewhere "off the beaten track" and Greenland seemed ideal - it's not the sort of place you end up by accident!

The Narsaq Region

We knew that there were many outstanding geological features in Greenland and, with the help of Brian Upton, we decided to study the Narsaq Igneous Complex because it is close to the world famous Ilimausaq intrusion and is in fact a precursor to it. Little work had been carried out in the area since

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* [Note - spelling of place-names follows the current practice in Greenland]

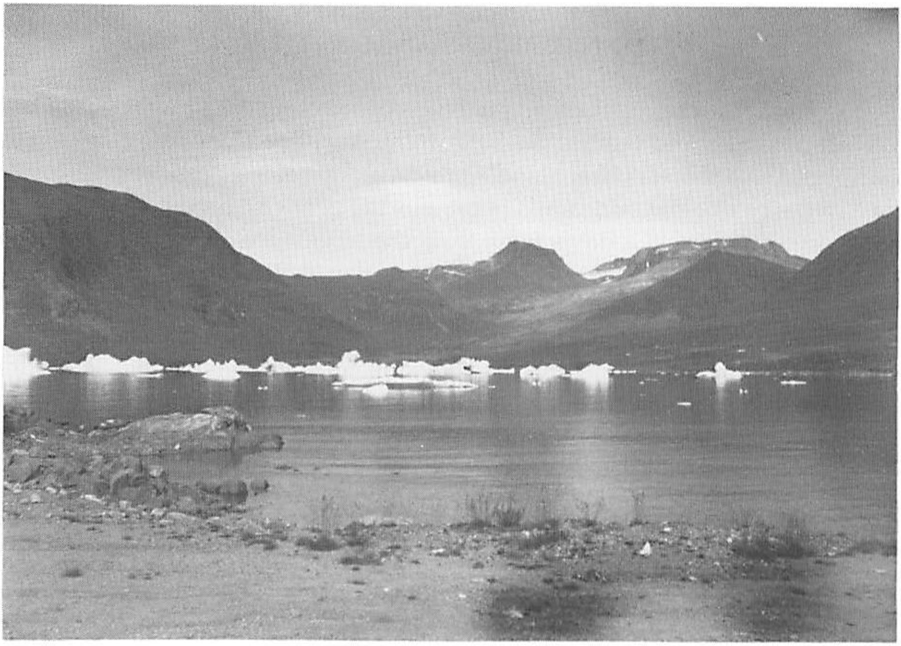

Figure 1. View of Ilimausaq Mountain from Narsaq Bay.

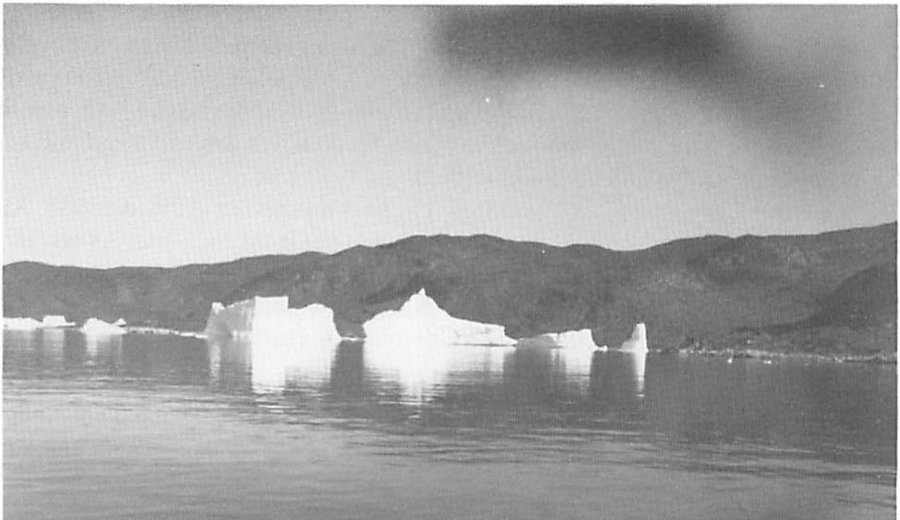

Figure 2. Icebergs in Narsaq Bay.

J.W. Stewart produced a reconnaissance map in 1961. Our objectives were to cover 15km^2 of ground and elucidate the contact relationships for the many intrusive and extrusive rock types. In order to carry out this project we received a number of generous contributions from a variety of grant-giving bodies, including the EGS Clough Fund, without which we would not have been able to attempt this trip - the undergraduate grant does not quite stretch to flights to Greenland.

Once we had arrived our initial optimism was rapidly dented. Even with superb exposure we often found it impossible to agree between ourselves as to which of two rocks preceded the other. The often imperceptable gradation of one rock type into another and the perverse ease with which one igneous melt may crystallise as a varied series of end-members led to argument. Often a bewildered Eskimo would pass by four eccentrically dressed people having heated exchanges about the relationships between rock X and rock Y and waving hammers in a dangerous manner. After several days of this we decided to go to Ilimausaq instead.

Walking 7 miles up the valley behind Narsaq we finally found a place to camp, perched above a roaring river on a gently sloping gravel terrace. It was only when we climbed into our sleeping bags that we discovered that the gentle 15° slope made it impossible to rest for more than 60 seconds without sliding down to the end of the tent. By now the mist had descended, however, and it was raining steadily, so we stayed put.

For the next two days we blundered about in the clouds, picking over the spoil heaps from a now abandoned uranium mine, and the scree slopes which make up most of the mountain-side. As we started to collect samples, half remembered mineralogy practicals floated around the back of our minds, sodalite? tugtupite? what does nepheline look like anyway? The only solution was to bring back as much as we could carry. The experts in the department managed to find minerals in our specimens that we hadn't even noticed! tiny little yellow andradite garnets, shiny diamond shaped crystals of naujakasite (only found in Ilimausaq) and the cerium-yttrium phosphate, monazite.

On our second evening as we stood around a stove waiting for the water to boil for a longed for cup of tea the dampness seemed oppressive. For 48 hours we had seldom been able to see more than 50 yards in any direction; so much for our plan to ascend the great Ilimausaq (Figure 1). Now, like a curtain rising, the mist lifted and we could just see, far down the valley, the sunshine on the icebergs in Narsaq bay (Figure 2); Ilimausaq remained doggedly obscured by the mist.

Upon our return to Narsaq we completed our observations, producing a geological map (Figure 3) which differed only slightly from J.W. Stewart's original reconnaissance map, along with a report which will be kept in the Grant Institute. From these we deduced the geological evolution of the Narsaq complex, as outlined in Figure 4. This differs from Stewart's original interpretation in some respects. We renamed the basal granite, 'Basement Granite', as we considered the contact to be intrusive rather than an unconformity between granite and quartzite.

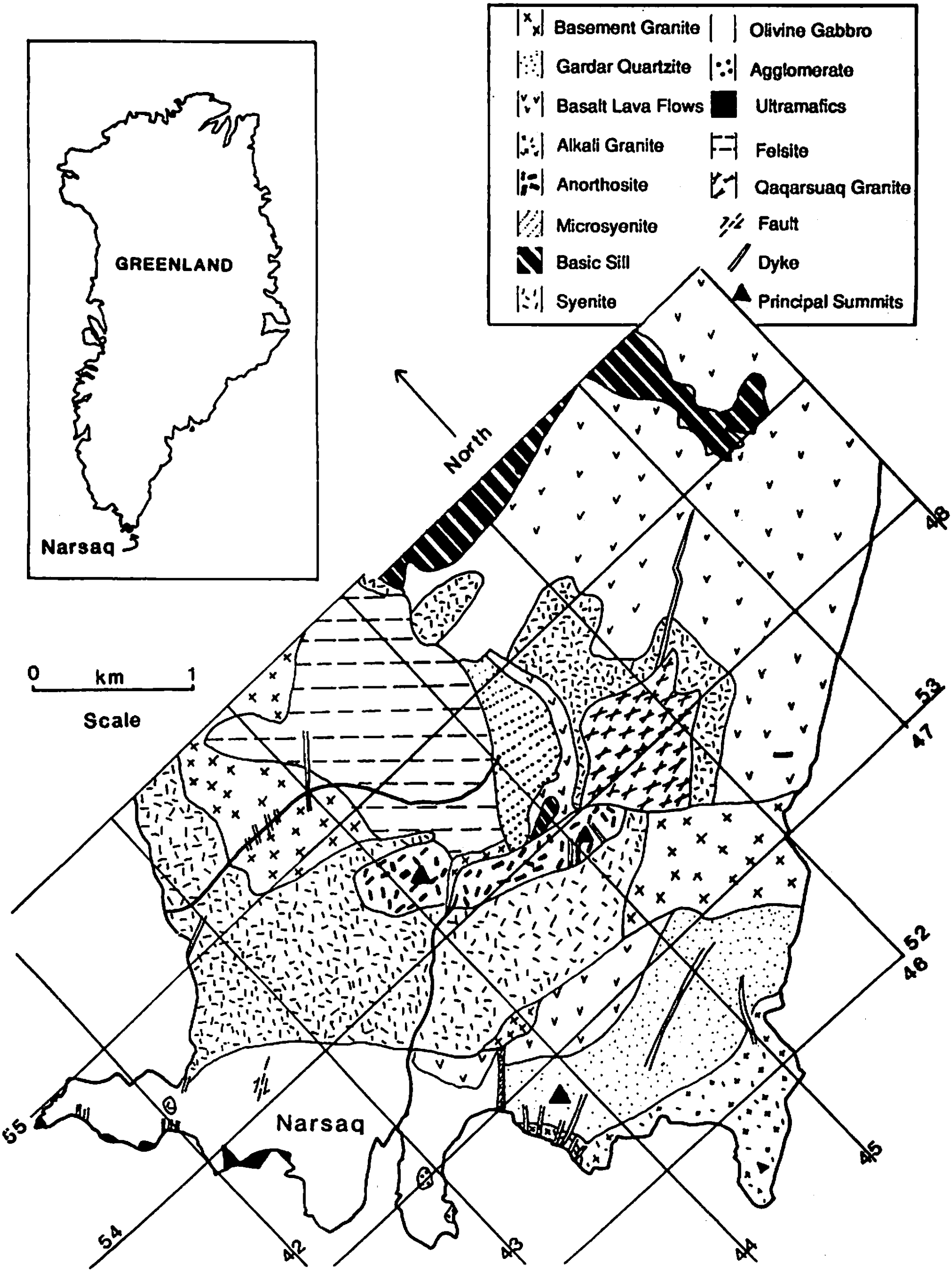

Figure 3. Geological sketch-map of the Narsaq region of SW Greenland.

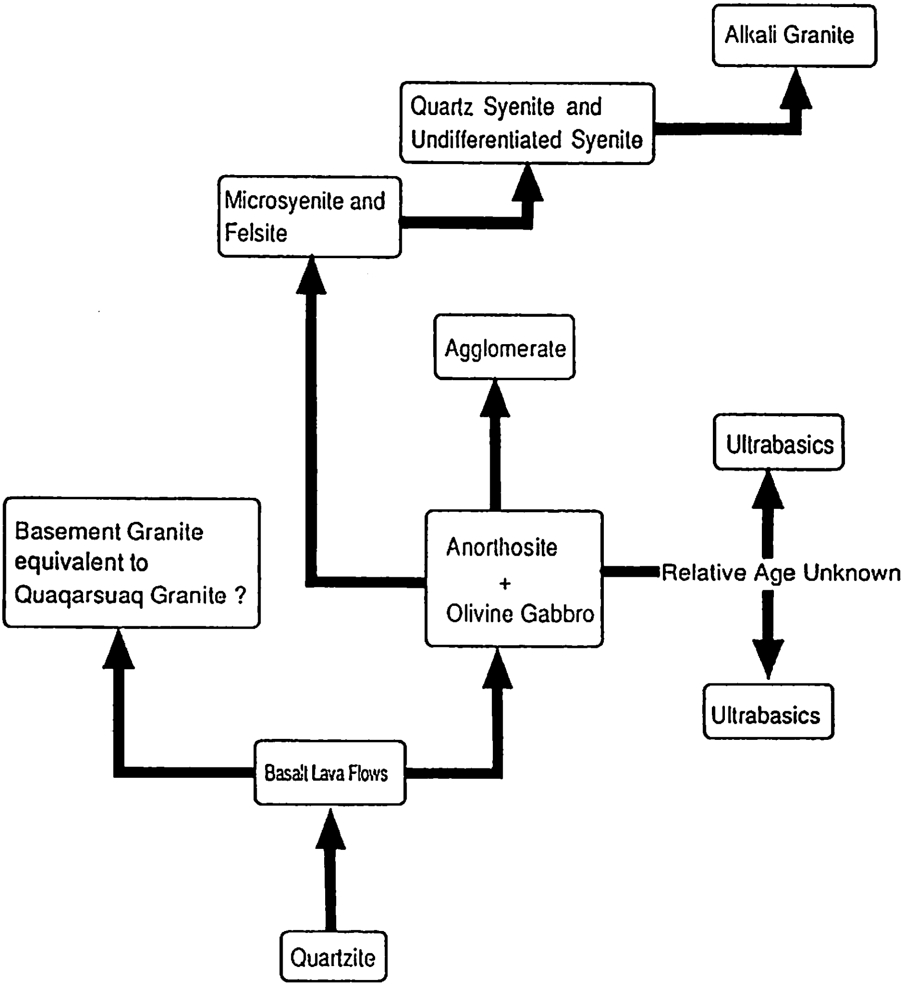

Figure 4. Geological evolution of the Narsaq Complex.

Poor exposure of contacts in some of the area meant that we also had difficulty in deciding the order of intrusion of the syenite, alkali-granite, microsyenite and felsite. Even where contacts are visible, it is still often difficult to interpret the relationships of various rock types. For example, there was a difference of opinion as to whether the ultrabasic intrusives predate or postdate the gabbro. As we found from our debates, there can often be more than one interpretation for each event.

Cultural Aspects

Along with studying the geology, we learned a little about the local people and saw some of Greenland. Narsaq, where we were based, is a largish settlement by Greenland standards, with a population of 2,000. One-fifth of these are Danish by birth, the rest being Eskimo (or Inuit as they are correctly addressed).

Most people dress in western clothes; the intricately beaded national costume is reserved for special occasions such as the first day back at school. This falls on a Saturday, allowing the parents of the youngest children to hold a party at the school.

Despite our lack of Danish we had few problems communicating, most people knowing at least numbers up to ten in English. We became expert in using sign language (of sorts), especially with regard to pointing out the largest Danish pastries in the bakery. These were relatively cheap compared to the essential foodstuffs, which cost up to three times British prices. Arctic Adventure representatives at the Hotel Perlen (we camped in it's grounds) were a great source of information and were extremely helpful throughout our stay.

We also took the opportunity to visit the nearby town of Julianehab (or Qaqortoq), the main reason for our visit being a ride in a helicopter; something none of us had ever done before. The journey provided the only reasonably priced trip. The flight lasted ten minutes and proved a worthwhile experience. The ferry ride back took two hours!

On 5th September our adventure was over. The plane left almost on time, a seemingly rare feat, and we returned with rucksacks full of rocks which we managed to pass off as "light" hand luggage, although we could hardly stand up straight. We all vowed to return, preferably with a good deal more money so we could fly the length and breadth by helicopter, eager to visit this land of ice once more.

Iceland: A Geologist's and Geographer's Paradise

J. Kenneth Oakley

Iceland is a fascinating country, where not only is geology still in the making, but what is already there is laid bare for all to see. A tour around the island, in the summer of 1988, gave me the opportunity to view many of the outstanding features of its geology and landscape, which are dominated by two contrasting geological processes; sea-floor spreading and glaciation. Iceland lies astride the Mid-Atlantic Ridge, close to the Arctic Circle and owes its existence to a mantle-plume or 'hot-spot'. As a result, the structure of the island is controlled by volcanism and rifting along the ridge-zone and much of its scenery is dominated by the erosive action of glacier ice and meltwater.

Structure and Volcanism

The island can be subdivided into three linear belts (Figure 1), symmetrically arranged about the rift zone. The oldest rocks are the central volcanoes and the Tertiary Plateau Basalts, the latter crop out along the eastern coast and in the north west. Plio-Pliestocene volcanic rocks occupy much of the ground between the two Tertiary Basalt areas and the area of active volcanism (the Neo-volcanic Zone) bisects the Plio-Pleistocene belt. A few of the volcanic eruptions have taken place sub-aerially, during relatively warm interglacial periods, but most have occurred beneath ice-sheets, which were far more extensive during the Pleistocene glacial periods.

The present-day volcanic activity, stretches from the Reykjanes peninsula in the south west of the island, north eastwards towards the Vatnajokull ice-cap and northwards towards the Myvatn area. Submarine volcanism created the islands of Vestmanneyjar and Surtsey, off the south west coast.

The Keflavik - Reykjavik Area

Views from the aircraft, as it descended towards Keflavik airport at the start of my visit, showed the graben-like structure of the south western part of the island. Rows of small volcanic cones marked the positions of past fissure-eruptions, while steam rising from the ground in many places was an equally obvious sign of geothermal activity. Reykjavik, means 'smoking bay'; a name readily appreciated no doubt, by the residents of 'Auld Reekie'.

On travelling eastwards from Reykavik, I crossed from ground underlain by rocks of Plio-Pleistocene age (3.1-0.7 million years) onto Pleistocene and Holocene rocks and back again onto Plio-Pleistocene material. This progression was repeated on crossing the more easterly branch of the Neo-volcanic zone, before reaching the classical area of Plateau Basalts, in the Eastern Fjord Region.

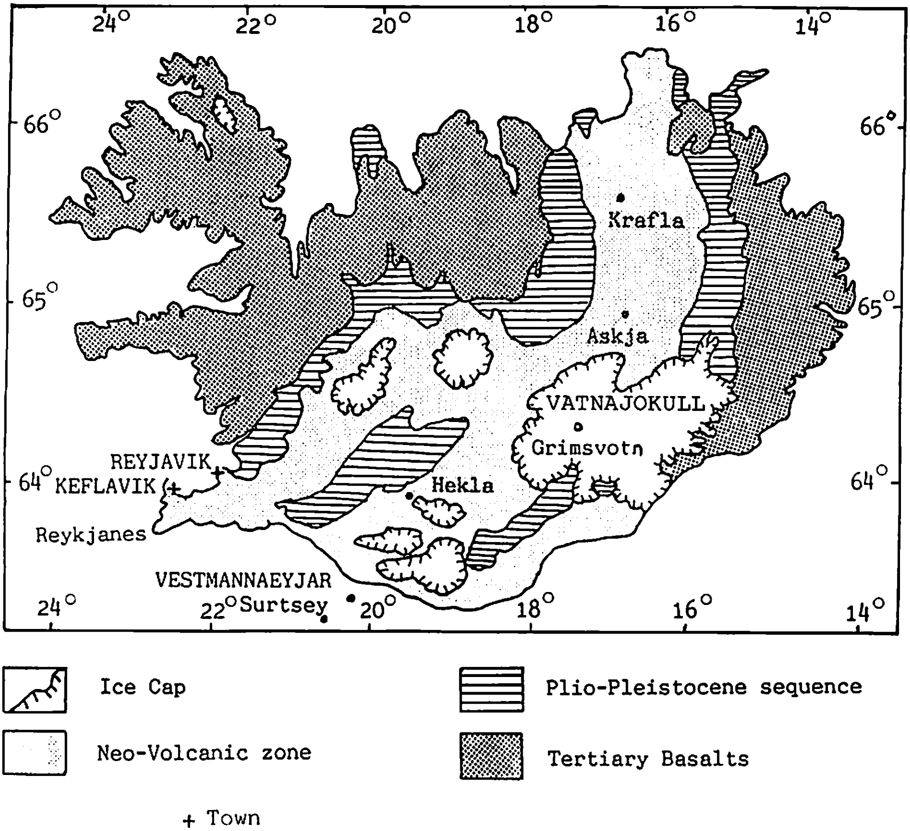

Figure 1. Sketch-map of the geology of Iceland, showing the principal ice-caps and volcanic centres.

Hekla and the South Coast

On route to the eastern fjords, a diversion was made up the valley of the Thjorsa River where a series of Plio-Pleistocene lava flows are found. Here, one is afforded fine views of one of Iceland's most famous landmarks, the active volcano Hekla, a central volcano built by Plinian eruptions of rhyolitic pumice, together with the eruption of more basic material from fissures.

Traversing the southern coastal region, one crosses a vast sandur-plain formed of outwash debris, much of which was deposited by jokulhlaups (glacier-burst floods of phenomenal magnitude). These are caused by vast quantities of meltwater, formed as a result of the eruption of subglacial volcanoes. A jokulhlaup is no doubt a spectacular sight, as long a one is well clear of its path.

The Laki Area

The fissures of Laki and Eldgja are sights not be missed. In 1783-84, the largest lava flows that have erupted in the world during historical times (in terms of both area and volume) poured from the Laki Fissure Complex. The gases, including sulphur dioxide and fluorine, emitted during the eruption caused a haze detectable as far away as the Urals. The resulting famine, due to poor crops, killed many livestock and some 20 per cent of the human population.

Many volcanic cones, aligned with Grimsvotn (a volcano beneath the Vatnajokull ice-cap) can be seen in the Laki area, while the Eldgja fissure, with the spectacular waterfall Ofaerufoss, is also a most impressive sight. Both must be reached with four-wheel drive vehicles using the "mountain roads"; the driving experience of a life-time!

Further along the south coast are cliffs of Moberg formed by sub-glacial eruption of basaltic pillow lavas and hylaclastite. The rock has a characteristic brown colour. It is formed by the subsequent hydration of basaltic glass that has been chilled by contact with ice. Moberg erodes into many weird and wonderful shapes.

The Vatnajokull Ice-cap

Apart from Antarctica and Greenland, Vatnajokull is the largest mass of land-based ice in the world. Two spectacular outlet glaciers which flow southwards from the ice-cap towards the coast are found within the Skaftafell National Park; a third, Breidamerkurjokull, is found further to the east. Each glacier occupies a valley containing fresh glaciated landforms, exhumed because the glaciers have been in retreat since about 1890.

The Eastern Fjord area

The Eastern Fjord area contains multiple sequences of basaltic lava flows; many with cross-cutting feeder dykes. The oldest exposed lavas are some 16 million years old. The lavas poured out from a central fissure zone along a former position of the Mid-Atlantic Ridge; spreading taking place at a rate of about 1cm per year. So much material has been erupted, that central volcanoes, which occasionally punched their way through the lava pile, have in turn been overwhelmed by later flows.

The Myvatn Area

On turning westward from the Tertiary Plateau Basalts of the Eastern Fjord area, I reached the Myvatn area in the Neo-volcanic Zone. The whole district is a zone of tensional fracturing, as it is situated on the Mid-Atlantic Ridge.

Myvatn itself, is an ideal centre for the geologist. Krafla is nearby where fissure eruptions have taken place regularly since the Pliestocene. The present eruption phase started in 1975. The volcanic activity is carefully monitored, both seismically and by accurate measurements of the level of the ground surface, to predict future eruptions.

Figure 2. Volcanic cones produced by fissure-eruption at Mordudalur in the northern active zone.

Geothermal energy is used for power generation, but this is fraught with difficulties. There is a geothermal power station at Krafla, but is has never produced to its expected potential. The hazards involved can be gauged by the eruption of cinders from a geothermal borehole at a nearby diatomite factory on 8th September 1977. The Iceland Power Authority is optimistic however, that one day, they will be able to export geothermally generated electricity to the United Kingdom. Hot water is piped directly to many houses in Iceland, for space-heating.

Myvatn (Midge Lake) abounds in bird life, with Barrow's Golden eye and the Harlequin Duck being well represented. The area has many examples of 'pseudo-craters' which look like normal volcanic cones, but are in fact formed by the venting of steam produced by lava flows crossing areas of damp ground.

The geothermal area of Manaskard, also near Myvatn, has many bubbling mud-pools and hot springs. Close by is a deep gorge of the Jokulsa a Fjollum, the most powerful river in the country. The gorge is young feature, cut into tills and interglacial lavas. At Mordudular, in the northern active zone, further evidence of volcanic activity can be seen. Figure 2, shows a particuarly good example of volcanic cones aligned along a fissure formed due to the tensional fracturing associated with rifting.

Figure 3. "Strokkur" (the churn) erupting; situated near "Geysir", SW Iceland.

The Geysir Area

From the north, my tour then returned westwards, across the Sprengisandur, before arriving at Iceland's main tourist attractions Gullfoss (Golden Falls); and the Geysir area. Unfortunately Geysir itself very seldom performs, but the nearby Strokkur (Churn) obliges instead (Figure 3). Amongst many unexpected sights are geothermally heated greenhouses where tomatoes and even bananas are grown!

Homeward Bound

Towards the end of my stay, I visited Thingvellir, the site of the oldest parliament in the world, which was founded in 970 A.D. I also spent some time in the wonderfully clean and tidy capital city, Reykjavik. Needless to say I am already looking forward to my next visit to this wonderful island.

Geological Heritage: Grand Opening of Birkhill Mine, Bo'ness

Mike Browne
British Geological Survey, Edinburgh

Heritage is a much abused word meaning 'anything transmitted from our ancestors or past ages'. Heritage centres have sprung up around the UK like an epidemic. Those with a geological theme are probably less common than others. However, anyone who has been underground at Beamish's coal mine (well not really), or in the slate mines of North Wales (Gloddfa Ganal, Llechwedd) will be aware of the economic, geological and archaeological heritage on display and in the surface buildings as well. In Scotland, there is the Museum of Scottish Lead Mining at Wanlockhead in the Southern Uplands. Here one can go underground in the Loch Nell Mine and walk around a variety of surface buildings and exhibitions. Locally in Edinburgh is the Coal Mining Museum at Lady Victoria Colliery and at Prestongrange but these sites only have surface displays and you cannot go underground. However, we now have Birkhill Fireclay Mine at Bo'ness open to visitors, with the emphasis clearly on the underground experience. Unlike Wanlockhead, the mine is within easy reach of all the major cities and towns in central Scotland.

The grand opening of Birkhill Clay Mine took place on the afternoon of Friday 5th May 1989. It was a gloriously sunny day, with the occasion a joint celebration between the Bo'ness Heritage Trust (owners of the mine) and the Scottish Railways Preservation Society, whose track extension to the Bo'ness and Kinneil Railway from Kinneil to Birkhill Mine was also being formally opened. The guests gathered in their best clothes (sweatshirts and jeans) at Bo'ness Station (its buildings were formerly located at Wormit in Fife and at Haymarket in Edinburgh) and the two carriage special to Birkhill station hauled by steam locomotive (ex Caley Railway No. 419) was only a few minutes late leaving. The twenty minute (3.75 mile) journey provided splendid views over the Forth estuary to the Ochil Hills and the Highlands through an almost continuous trackside avenue of trees. Landmarks along the route include the old docks of Bo'ness, a former distillery, the pithead gear of the defunct Kinneil Colliery, shadowy views of Kinneil Castle, Longannet Power Station and of course, the Grangemouth petrochemical works.

Once the train arrived at Birkhill, all of the guests gathered beside the station building (formerly sited at Monifieth, near Dundee and briefly at the Glasgow Garden Festival). A short speech of welcome was made by a representative of Central Regional Council who had bought the derelict mine from Messrs. Hurll Brothers and had given it to the Trust. The train was then backed down the track beyond the bridge at the Bo'ness end of the station and a large tape strung across the arch. The train then returned with TV personality Jimmy MacGregor (of Bonnie Prince Charlie and Spey valley fame) appropriately clad, to assist the engine in cutting the tape. Ten minutes of photocalls then followed.

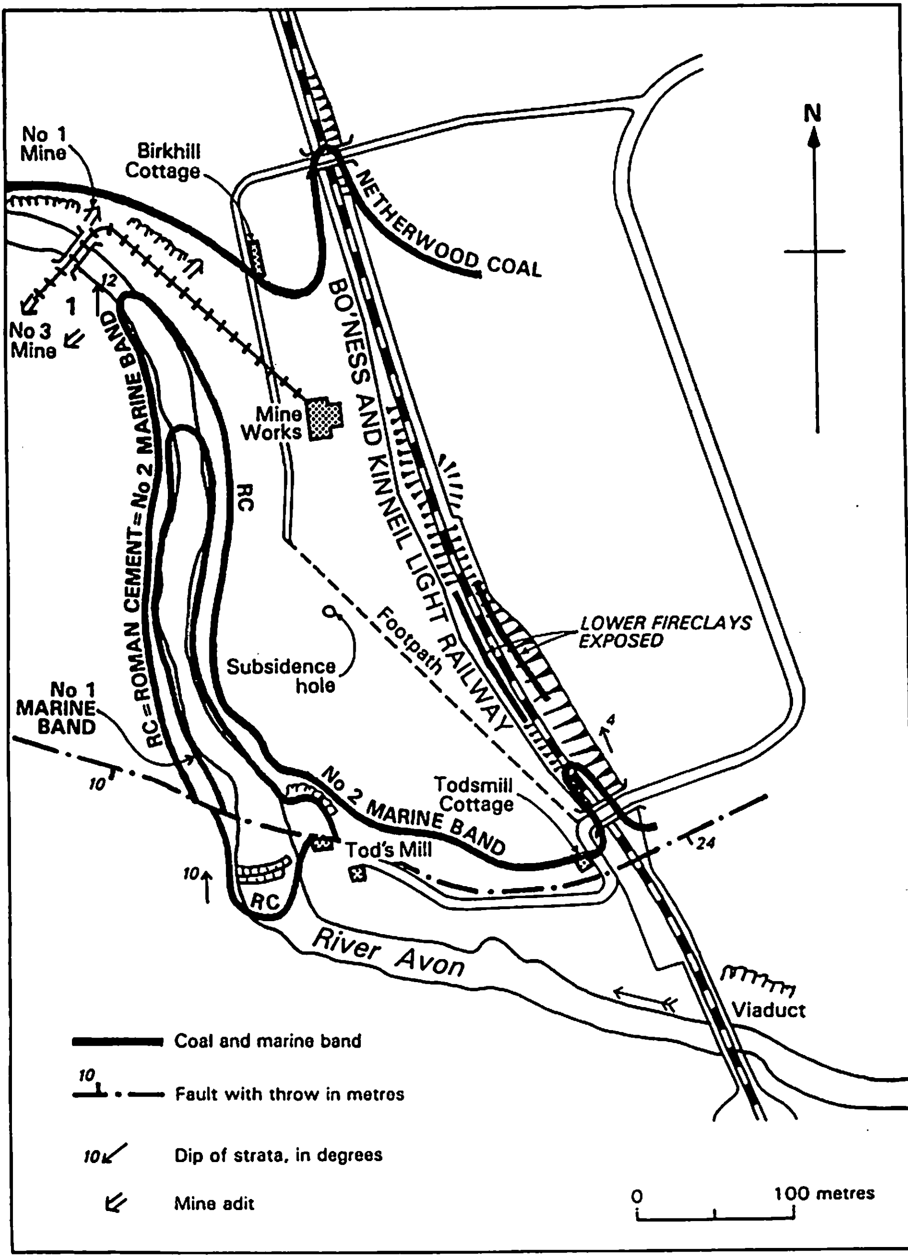

Figure 1. Location of the Birkhill Fireclay Mine; from Lothian Geology (McAdam and Clarkson, Eds.) reproduced with the permission of Scottish Academic Press.

The guests then made their way down the steep stairway, which descends the side of the wooded Avon Gorge from the mine buildings, to the bridge over the river and to the mine entrance on the opposite bank. Here Jimmy MacGregor formally opened the mine by detonating small charges of explosives and releasing hundreds of balloons. The opening ceremony was followed by a guided tour underground.

Birkhill Mine (Figure 1) is known to some members of the Society. When the Society went underground here a few years ago the trip was made by bus; there was no railway track underground, powerful torches, wellington boots and hard hats were essential. Now the mine is well-lit, conditions underfoot are dry and only the hats are required; these are provided to visitors at the mouth of the mine. To satisfy Mining Act regulations, only guided parties of up to 16 people are allowed, although more than one group can be underground at any given time. The mine is also considered to be a working operation and is managed by two former coalminers with the appropriate 'ticket'. They have to check the roof and wall conditions in the galleries on a daily basis and carry out necessary maintenance, especially in the closed season in winter.

The geology of the mine has been described in Lothian Geology (McAdam and Clarkson, Eds 1986) in chapters dealing with the geology of the River Avon area, but the experience now on offer includes audio-visual aids! The underground tour, which took 20 to 30 minutes, leaves the visitor with a vivid impression of life below ground in the rectilinear galleries and rooms mined into the fireclay. No one should go away ignorant of the meaning of the stoop (pillar) and room method of extraction. Apart from the fireclay, a fossilised wetland soil which formed on the floodplain of a major meandering river, the overlying river channel sandstones can also be seen. On your visit, look out for large tree stumps (preserved in sandstone) rooted in the top of the fireclay. Look out for fallen trees forming log-jams in the base of the overlying sandstone, small faults and the 'keel of a whale' (a small, but marked sand-filled channel cut into the fireclay). The Carboniferous stratigraphy of the site is summarised in Figure 2. Incidentally, it is unlikely that you will be suitably lubricated and fed as we were on your return to Bo'ness by train (well gratis anyway).

I am sure, unlike Princess Diana, who also visited in May, you will have the time and inclination to go underground. However, the Princess' visit was good news for sponsorship and doubled attendances instantly, even if all those policemen and bodyguards hanging around in the trees might have damaged the local woodlands, which are a botanical site of special scientific interest!

Another interesting, but little known fact, is that the underground scenes shown in Billy Kane's BBC Odyssey 3-part programme on coalmining were filmed here. Because the mine galleries are too high (3 to 4 metres) a much lower facsimile coal face was specially constructed. An advantage to the producer was that Birkhill is gas-free and electrical equipment could be used underground.

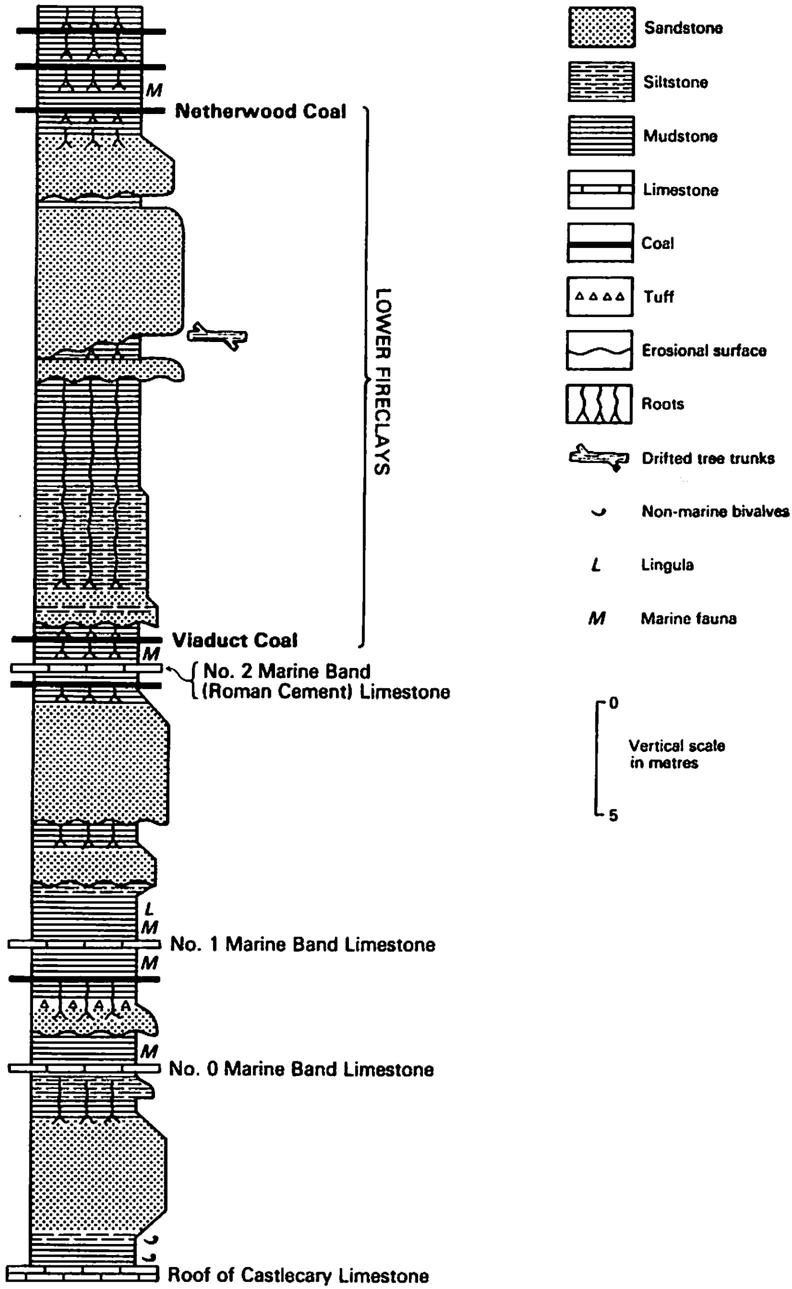

Figure 2. Namurian stratigraphy in the vicinity of the Birkhill Mine, showing the position of the Lower Fireclays; from Lothian Geology reproduced with the permission of Scottish Academic Press.

The 1989 prices of admission to the mine were £1.20 (adult) and 60p (child), rail fares are extra. The new season will start from Easter to Mid October (weekends only) in 1990, but the mine will open daily from 16th July to 31st August. School visits will take place on Wednesday to Friday 30th May - 1st June and 6th-8th June. In general the mine is open when the railway is operating, which is the preferred way of access. There is a large car park at Bo'ness station and a small one at Birkhill. Access at times other than those listed above can be arranged (Telephone Bo'ness 0506-825855). As yet there is no guide book but a school's pack is being written.

Over 8,500 people have already visited Birkhill and, even on the busiest days when several hundred customers arrived, there was little time spent in queueing. See you there this coming season.

Postscript: The Society is planning to have a commemorative plaque to C.T. Clough at Birkhill Station. He was fatally injured by a goods train in the cutting south of the present platform. The plaque would also be a warning to passengers about the dangers of railways.

Review: an Excursion Guide to The Moine Geology of The Scottish Highlands

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The Moine of Scotland has long been one of the least known areas of British geology. The term 'Unsurveyed in Detail' may no longer appear on the Geological Survey Ten Mile Map of Great Britain but there still remain many unresolved problems. These include the age of the Moine metasediments and the relationship between the Northern and Central Highlands 'Moine-like' rocks. Relationships between migmatitic and non-migmatitic rocks in the Central Highlands are also a source of controversy. At the beginning of this century, a correlation between the Torridonian sediments of the Northwest Highlands and the Moine was proposed by B.N. Peach. This was discounted on the basis of isotopic ages from the Moine, however, the validity of these ages is now being questioned.

The present state of knowledge of the Moine is outlined in 'An Excursion Guide to the Moine Geology of the Northwest Highlands' edited by I. Allison, F.May and R.A.Strachan and published recently for the Edinburgh and Glasgow Geological Societies by the Scottish Academic Press. The guide is subdivided into a summary of the geology which gives a comprehensive overview of Moine geology and a series of 12 excursions. The excursion descriptions, which are well illustrated with field sketches and maps, guide the reader through itineraries of varying lengths ranging from a few hours to several days. The descriptions of individual localities are related to both the local and regional geology. Each proposed excursion includes a preliminary page detailing the aspects of the geology that are covered, together with logistical considerations including the type of terrain to be expected, distances and time required and much other useful information (including availability of accommodation and details of land-owners or game-keepers). Shorter versions of each itinerary are also indicated for those with insufficient time to complete the full excursion. The guide also includes a summary of Gaelic placenames. For those who wish to delve deeper into Moine geology a comprehensive list of 205 references is included.

The Moine Geology Excursion Guide is a much needed guide to various aspects of the geology of the Central and Northern Highlands providing an up-to-date state of knowledge of Moine geology. Areas described include the intensively studied Moine Thrust of Assynt, perhaps one of the 'classic' and best known examples of a foreland propogating thrust belt, which is now revealed as also being in part an extensional structure. The Moine Thrust around Loch Eriboll and Ullapool is also described. Traverses across the West and Northwest Highlands from Fort William to Morar and from Glen Garry to Glen Shiel are facilitated by roadside exposures whilst the A9 provides a good section through the Central Highlands. Many of the excursions have an emphasis on structural geology, as is to be expected in this area, although other aspects of the geology are not forgotten. The longest excursion, scheduled to take up to four days, covers the north coast of Sutherland.

Criticisms of the guide are few, but there is a lack of consistency over some aspects of the terminology which could prove confusing to a newcomer to Moine geology. The Grampian Group of the Central Highlands for example, is referred to by some authors as the 'young' Moine and by others as the Grampian Division; neither should be confused with the 'old' Moine of the northern Highlands. Similarly the term 'extensional' Moine Thrust adds confusion to the terminology of the Moine Thrust. However these are minor criticisms of an excellent field guide which should be invaluable to both the informed amateur and professional geologist alike.

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Contents