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Cover illustration

Ropey flow-texture in basaltic pahoe-hoe lava,
Thingvellir, Iceland. (R.T. Wightman and I.D. Bartholomew).

EDITORIAL

Expulsion

While tidying out his office and depositing items with the Edinburgh Geological Society's archive in Edinburgh University Library, our erstwhile Secretary, Norman Butcher drew our attention to an entry in the Official Roll of Fellows (1868 to 1926). It reads 'W. Ivison Macadam, Surgeons Hall, Elected 19 December 1878' followed by the remark 'Shot by servitor in Surgeons Hall, 1902'. Perhaps some of our readers are familiar with the background to this event. We would be pleased to hear from them. Suffice it to say that we hope it had nothing to do with a contravention of the Laws of the Society for if so we feel that this was taking 'expulsion' too far. We are glad that Membership Secretaries over recent years have not needed to resort to such violent means for exacting dues.

Fifteen times Ten

On 4th December 1834 the Society was founded by Alexander Rose and during the 1984–85 session we will celebrate our 150th Anniversary. In 1835 the Geological Survey was begun under the directorship of De La Beche. To celebrate this dual anniversary the fourth meeting of European Geological Societies (MEGS IV) will take place in Edinburgh during Easter 1985. Details are being worked out by the steering committee whose members include representatives of the Society, the I.G.S., the Grant Institute of Geology and the Royal Scottish Museum.

Bicentennial

Mentioning dates, 1981 is also an important year since Alexander Rose, himself, was born exactly 200 years ago. Readers interested to learn more of this 'zealous philosophical and instructive lecturer' should refer to the *Transactions of the Edinburgh Geological Society*, Vol. XIII, 1934, pp. 191–271 and to a delightful book entitled 'Alexander Rose, Geologist and his grandson, Robert Traill Rose, Artist' by Mary Tweedie Stodart Rose. Edinburgh: C.J. Cousland & Sons Ltd.

Borehole in One

We read with great relief a recent newspaper report in which assurances are given that the Old Course at St. Andrews will not be drilled despite being included in the latest batch of areas licensed for oil and gas exploration. The very thought must send shivers up the spines of R. and A. members and vividly demonstrates our ever increasing resource demands. In any case golfers must find the 17th difficult enough with that hideous lump of modern architecture to negotiate without the prospect of having to slice around a few rigs as well.

Articles for inclusion in the Autumn '81 issue should be driven in our direction by mid-October.

Mrs Helena Butler
9 Fox Spring Crescent
Edinburgh 10

Telephone: Home: 445 3705

Mr. Andrew McMillan
Institute of Geological Sciences
Murchison House
West Mains Road
Edinburgh EH9 3LA

Telephone: Office: 667 1000

A 3–WEEK GEOLOGICAL EXCURSION TO ICELAND BY TWO RECENT EDINBURGH HONOURS GRADUATES

Roger T. Wightman
Iain D. Bartholomew
Department of Earth Sciences, The Open University, Milton Keynes

Iceland is situated on the Mid-Atlantic Ridge along which sea-floor spreading is presently occurring. We visited Iceland in the summer of 1980 for three weeks in order to study the Vidbordfjall Gabbroic Complex in the SE of Iceland (Fig. 1). This is a Tertiary complex composed of five gabbros which were intruded into basalt lavas approxmately 15 m.y. ago. Some time was also spent in studying the more recent volcanological and glacial features of Iceland.

The Vidbordfjall Complex

This gabbroic complex has already been mapped in detail by previous workers (1:25,000) (Fig. 2). However some discrepancy exists as to the order of the gabbro intrusive events. Our aim was to find the field evidence in order to solve this problem.

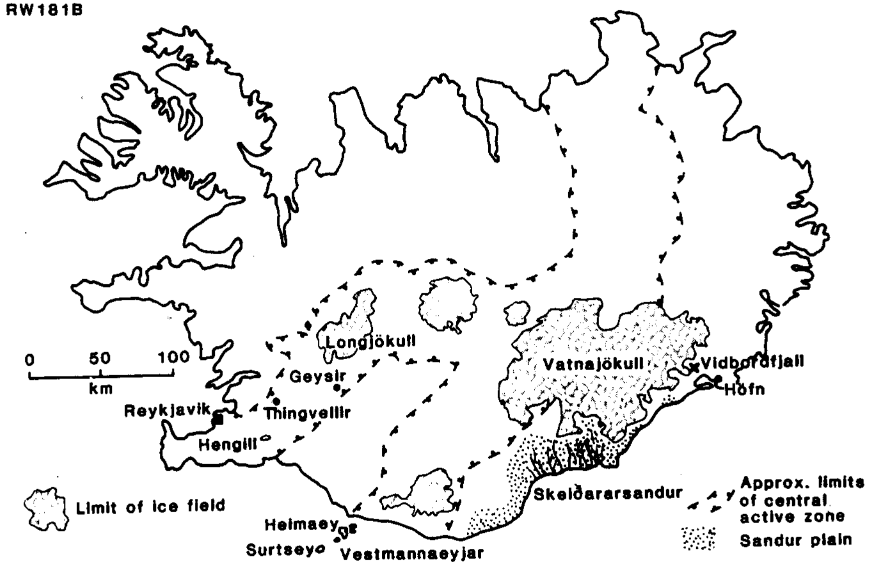

Fig. 1: General location map showing areas visited.

We concentrated on the areas of contact between the different gabbros (A', A'', B, C and D) using four different techniques to determine the intrusive history:—

1) Detailed petrographic study of the 5 gabbros.
2) Chilling and cross-cutting relationships between the gabbros.
3) Cross-cutting relationship of the major and minor intrusions.
4) Joint patterns within each of the intrusions.

1) Petrographic Study

The gabbros are mineralogically similar, composed predominantly of clinopyroxene and plagioclase feldspar. The grain-size and textures varied considerably, from pegmatitic to doleritic, both within individual gabbros and between the gabbros. It was concluded, however, that A' and A'' are two separate outcrops from the same gabbro body (Gabbro A). B is the only gabbro which contains significant amounts of olivine and this gives the gabbro an overall brown weathering colour. C and D are of similar mineralogical composition.

2) Chilling and Cross-cutting Relationships between the Gabbros.

Little information was gained from this study technique since the mapped gabbro contacts were often obscured by marginal dolerite and also by poor exposure. This was the case at the Gabbro A' – D contact where complex anatectic relationships were also present. Some contacts which had been marked on the geological map did not exist. For example, at the supposed B – C contact, lavas with vesicles and flow-tops were found between the two gabbros.

However, the contact between Gabbros C and D was well exposed and showed that D had been chilled against C. D also clearly cross-cuts C (Fig. 2). Thus Gabbro D is later than Gabbro C.

3) Cross-cutting Relationships between the Major and Minor Intrusions

On an initial reconnaissance survey of the gabbros many different dyke and sheet types were noted. These varied from thick granophyric and thin felsic to doleritic and basaltic dykes. Many of the dolerites were rich in feldspar phenocrysts and these often had chilled margins of aphyric dolerite.

By carrying out detailed studies of the cross-cutting relationships between different dykes and sheets, we were able to work out a sequence of sheet and dyke intrusions. In all, eight dyke types were distinguished.

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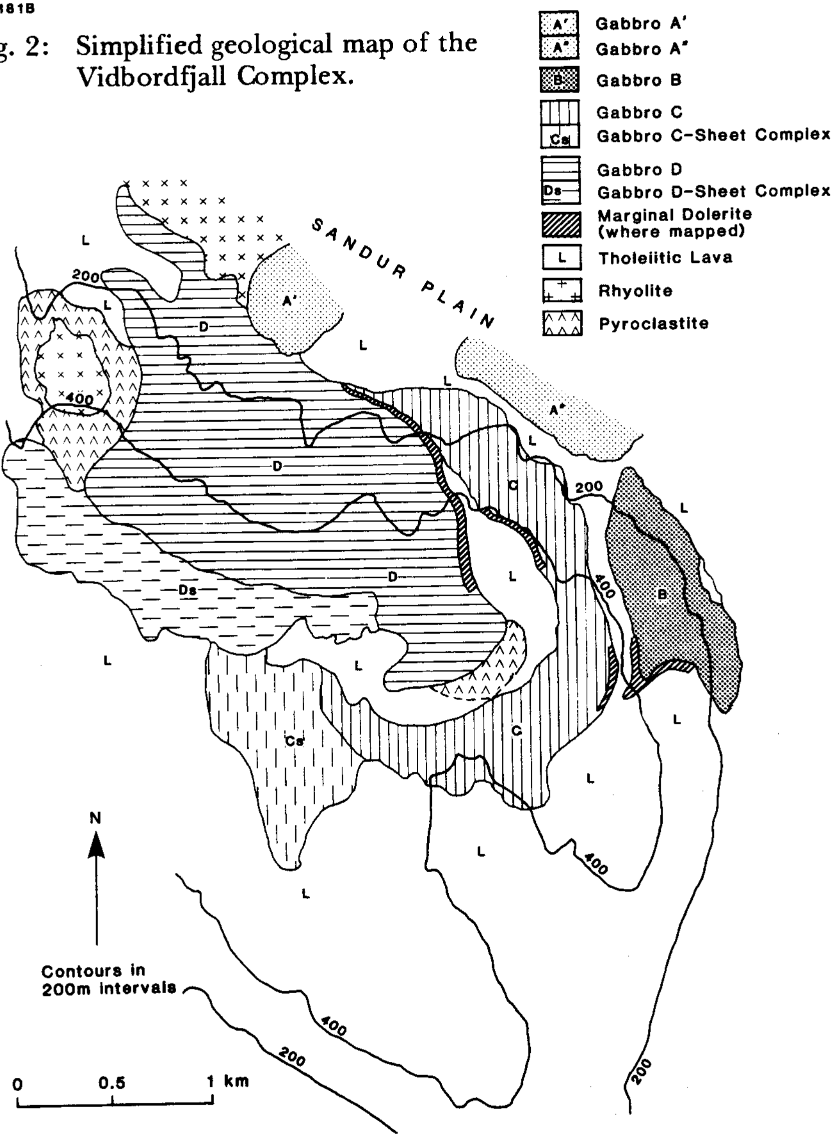
Fig. 2: Simplified geological map of the Vidbordfjall Complex.



Using the cross-cutting relationships between the different dykes and gabbros a table was constructed relating gabbro intrusive events and the dyke intrusive events (Fig. 3).

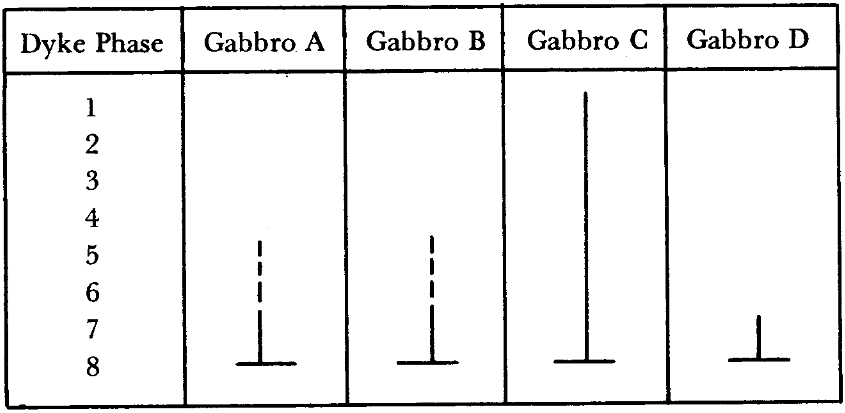


Fig. 3: Correlation of dyke phase intrusion with the gabbro bodies

As can be seen Gabbro C is clearly the oldest with A, B and D being of similar younger relative ages.

4) Joint Patterns within each of the Intrusions.

Joints were extensively measured within each of the gabbros. These were plotted stereographically and the joint patterns between the gabbros were characterised. The joints were classed into two main groups, firstly late tectonic joints which are present within all the gabbros and have formed well after the gabbro intrusion events. These have a NE–SW trend which is the general tectonic trend of the present day volcanic activity through most of Iceland (Fig. 1).

The other joints were of variable trend directions, each gabbro having its own unique joint pattern. These joints were classified as cooling joints.

By relating the joint patterns to the dyke intrusion directions it was clearly seen that the directions of dykes and joints were very similar in Gabbro C. This would imply that the joints were formed before dyke injection and subsequently dykes were injected into the lines of greatest weakness (i.e. the joints). In the other gabbros this relationship is not seen. This suggests that Gabbro C is oldest, with Gabbros A, B and D all postdating the main dyke intrusion events.

From this study we can now confidently say that Gabbro C is early, with Gabbros B and D being much younger and possibly of a contemporaneous age. All the previous workers have determined Gabbro A as the oldest. We have found no evidence for this and our fieldwork would suggest, if anything, that it is of a similar age, to Gabbros B and D. Much further work is required, however, especially on the Gabbro A' – D contact, in order to solve this problem.

Recent Volcanological and Glacial Features

After the project was completed, our return journey from Höfn to Reykjavik provided us with an excellent opportunity to study the large-scale volcanological features ranging in age from 15 m.ys. to the present, and also the effects of a recent glaciation.

To the SE tertiary volcanics are present, composed predominantly of plateau lavas and associated plutonic intrusions. Many of the lava sequences form stratified cliff faces, very similar to the Tertiary volcanics of Mull or Skye, but on a considerably larger scale.

The volcanics are capped by Vatnajökull, the largest icefield in Europe. As a result the geomorphology of SE Iceland is heavily controlled by recent glacial processes.

Frost shattering is an obvious weathering process as seen by the development of immense scree slopes, but one of the most striking results of glaciation is the presence along the coastline of vast flat 'sandur' plains. These plains, composed of black outwash sand and gravel are probably formed during periods of stability or advance of the ice fronts. In SE Iceland, the glaciers are in a continual state of fluctuation, but are presently in a phase of retreat. This can be seen at Hoffelsjökull (our project area) by the presence of terminal moraines only a few 100 m from the ice front, the intervening area being filled by a marginal lake. As a result of the retreat, there has been a decrease in the influx of clastic material and the braided outwash channels are now reworking and cutting down into the sandur plain.

The most impressive of these sandur plains is undoubtedly that of Skeidarasandur (Fig. 1) which stretches approximately 50 km across and 35 km out to sea.

On moving further west one comes to the central active zone.

It was striking to us that the topography is no longer controlled by weathering processes as in the east, but by the nature of the active volcanism itself. Several days were spent within this zone studying some of the spectacular volcanic and geothermal phenomena.

In south-west Iceland the active zone splits into two limbs (Fig. 1). One of the more recent eruptions in the south east limb was that of Heimaey, part of the Vestmannaeyjer group. This cluster of islands was formed 10–15,000 yrs ago by a series of submarine eruptions. In 1963 an eruption began which formed the island of Surtsey and this was followed in 1973 by a subaerial eruption on Heimaey. During this eruption, lava was produced which flowed over part of the town, and most of the island was covered by a blanket of tephra.

Although much of the ash has been removed, evidence of the damage to the town is still clear. At the lava flow front, derelict houses can be seen partially engulfed in lava and tephra; and the attempts of the townsfolk to halt the advance of the flow by pumping water onto it, are evident by the numerous firemans' hoses amongst the lava blocks.

The rocks themselves, are composed of interbedded olivine basalts and agglomerates(not unlike those of Arthur's Seat). The lavas are predominantly aa flows, resulting in very craggy disrupted flow tops dissected by numerous deep fissures. Another feature adding to the uncanny atmosphere is the continual presence of steam rising from the lava (due to ground water being heated at depth). This was at times a thick fog, apart from the fact that it was warm, and smelling of sulphur dioxide!

The cone of the volcano is composed of dark red agglomerates and unconsolidated ashes. Around the rim of the central crater numerous fumaroles have formed – these are small holes and cracks in the baked crusty surface through which hot, sulphurous gas is wafting. Around these, brightly coloured yellow, red and white encrusting layers of sulphurous, ferruginous and siliceous precipitates have formed.

All these features combined to make this an unforgettable experience; standing on the rim of an active volcano, at times engulfed in steam, looking down into the crater and to the lavas beyond. From this point we could clearly see the way in which the lavas had flowed out from the volcano, over the town.

Some time was also spent on the mainland, studying the geological and geothermal characteristics of the western limb of the active zone.

Between the central volcanoes of the Hengill and Langjökull (Fig. 1) fissure eruptions have led to the formation of the lava fields of Thingvellir. Since their eruption, the lavas have been downfaulted forming a 5 km wide NE trending graben, bordered to the west by an impressive 40 m fault scarp and to the east by a series of smaller step faults. Vegetation is sparse on the lavas, with the result that the graben is very easily seen. This structure has been produced as a result of the tensional stress present throughout the central active zone.

The lavas themselves, within the graben, are olivine basalts in the form of pahoe-hoe flows, exhibiting classical drape and flow structures in their ropey skin (See Front Cover).

Geothermal energy plays a large part in the economy of Iceland. Evidence for this was clear in many areas where elaborate piping systems are harnessing the supply of free energy. In Reykjavik it was a luxury to have a limitless supply of sulphurous hot water to shower under after our travels.

Solfatara areas, (regions of high geothermal activity) are characterised by hot springs, geysir and fumarolic activity. We visited two such areas:— Geysir (the location of the original Great Geysir) and a zone on the northern flanks of Hengill central volcano (the more active).

The atmosphere at Hengill is very similar to that on Heimaey. i.e. the damp warmth and sulphurous smell, but added to this is the thunder of pressurised steam roaring from blow holes and the gurgling and splattering muds in the numerous boiling mud pools and hot springs. The surrounding area is composed of a huge variety of differently coloured muds and precipitates which add to the incredible landscape.

These hot spring areas, like many of the other landscapes of

Iceland are unique and far removed from the ancient landforms of Scotland. Our trip has provided us with valuable experience in dealing with the various aspects of gabbroic complexes and has also led to our greater understanding of both volcanic and glacial surface processes. For this opportunity, we gratefully acknowledge the Weir Fund (Edinburgh University), the Clough Fund (Edinburgh Geological Society) and the Carnegie Vacation Scholarship for Scottish Universities for their financial assistance. We are also indebted to G Omar Fridleifsson for his help in devising the project and advice on logistics and methods of study.

ESSAYS FROM THE NORTH II

More extracts from the notebooks of the late Mr. Ian Sime.

SMOO CAVE December 1940

When Pat McNeil and I passed through Durness in 1923, we did not look for Smoo Cave, thinking it would be in some remote spot: little did we think that the road ran right over the cave. Bedrock and I set out one morning to the Geo of Smoo, where the Blue Dragon II once anchored, and walked up towards the cave; soon we saw the huge entrance, and scrambled down past a ruined cottage to the stepping stones which cross the stream which issues from the cave: up the other side of the burn, and into the cave we went, remarking on the water cress growing in the stream right inside the cave. Overhead was a vast dome with an air shaft; through a crevice thunders the waterfall which boils forever in a lake in the inner cave, and reaches the outer portion through an underground syphon. We have no boat to explore further so we turn our faces to the entrance with its fantastic pillar of rock, and emerge from the dripping gloom to the full light of day. We hope to return some warmer day, and work our way by boat into the inner cave.

FIRST VISIT TO THE ROCKS OF DURNESS December 1940

We were not too lucky with the weather: so only see the rocks on the way to the station. We find great slices of Dolomite, with bands of chert: one of the latter is five feet in thickness, and is probably the witness of a vast assemblage of small sea organisms with shell (or tests) of silica: sometimes the chert occurs in great sheets, and sometimes it is gathered into lenticles throughout the rock. What countless millions of small animals must have contributed to its make-up! Sponge spicules may have been represented in small quantity, but the small fry of the ocean, visible to us only under a microscope must have supplied the greater part of this huge amount of rock. The whole of the rock is shattered into small bits, pieces about 2 inches by an inch seem the largest. The chert seems to be all split up by the movement of the rock in days gone past. Below the chert is the famous 'Leopard Rock' – anyone who has heard the name would recognise the rock at once. It is very similar to the rock I once found in a bore at Meadowhead, near Forest mill; and probably tells the same tale – Worms bored up through a layer of sand, bringing with them castings of the dark mud below, the mixed sand and mud now forms the beautifully mottled rock which weathers into curious rounded shapes. We did not see the limestone beds – we shall visit Balnakiel again, that Balnakiel which has given its name to rocks found on both sides of the Atlantic – the same limestones and fossils being in the same order. In those ancient days Durness and the Western Hemisphere were one common sea floor!

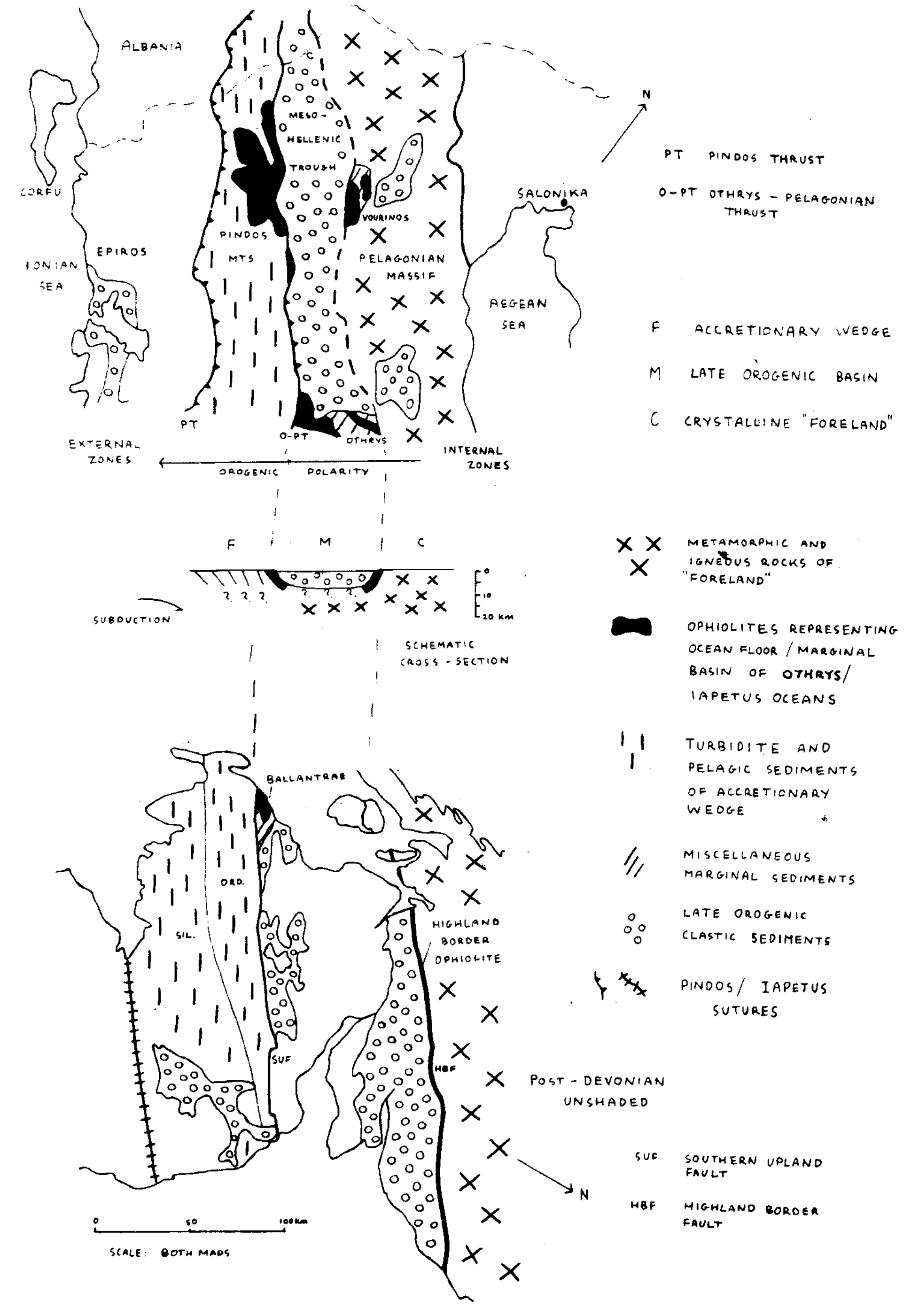
ANALOGOUS EVOLUTION OF THE NORTH WEST HELLENIDES AND THE SCOTTISH CALEDONIDES

Alan E.S. Kemp

Institute of Geological Sciences, Edinburgh

Introduction

On arrival at Murchison House fresh from three years at an English university and two summer seasons fieldwork in Greece, I found myself in the paradoxical position of being more familiar with Greek geology than that of my native Scotland. As I enthusiastically set myself to remedy this situation, broad similarities in the evolution of the two countries became apparent. Being aware of previous comparative accounts in the literature, I thought it would prove a salutory exercise to set down some brief notes on the general resemblances of Scottish and Greek geological histories.


ALBANIA
CORFU
IONIAN SEA
EPIROS
PINDOS MTS
MESO-HELLENIC TROUGH
VOURINOS
PELAGONIAN MASSIF
SALONIKA
AEGEAN SEA
N
PT
O-PT
OTHRYS
EXTERNAL ZONES
OROGENIC POLARITY
INTERNAL ZONES
PT PINDOS THRUST
O-PT OTHRYS – PELAGONIAN THRUST
F ACCRETIONARY WEDGE
M LATE OROGENIC BASIN
C CRYSTALLINE "FORELAND"
F
M
C
SUBDUCTION
0
10
20 km
SCHEMATIC CROSS-SECTION
METAMORPHIC AND IGNEOUS ROCKS OF "FORELAND"
OPHIOLITES REPRESENTING OCEAN FLOOR / MARGINAL BASIN OF OTHRYS/IAPETUS OCEANS
TURBIDITE AND PELAGIC SEDIMENTS OF ACCRETIONARY WEDGE
MISCELLANEOUS MARGINAL SEDIMENTS
LATE OROGENIC CLASTIC SEDIMENTS
PINDOS/ IAPETUS SUTURES
BALLANTRAE
ORD.
SIL.
SUF
HIGHLAND BORDER OPHIOLITE
HBF
POST-DEVONIAN UNSHADED
SUF SOUTHERN UPLAND FAULT
HBF HIGHLAND BORDER FAULT
N
0
50
100km
SCALE: BOTH MAPS

To set the scene let me first describe the two 'field' areas. In both orogenic belts, geomorphology and land use to a large extent parallel the geology. The Midland Valley and the Meso-Hellenic Trough are relatively low-lying, gently undulating tracts of fertile agricultural land while the Southern Uplands and more rugged Pindos Mountains are centres of hill sheep (and goat) farming and forestry. Conditions of fieldwork, however, are as different as the climates – the blue skies and scorching heat of the Mediterranean sun in stark contrast with the drear grey monologue of moor and mountain, rock and sky that passes for a Scottish summer scene. The main hazard encountered by the itinerant Tethyan field geologist aside the wolves, bears and soporific afternoon sun, is the Greek sheep dog. Unlike his amiable Scottish counterpart with the "honest sonsie baws'nt face" the hellenic hound is an aggressive wolf-like beast especially partial to geologist's rump – but enough digression!

The geological histories of the mainly Lower Palaeozoic Caledonides and the Mesozoic to Cainozoic Hellenides concern the rifting of a continental mass and the spreading of oceanic crust (of the Iapetus and Othrys oceans respectively). This was followed by subduction of oceanic crust at a trench and eventual continental collision. The following text should be read in conjunction with the Figure and Table which illustrate the 4–dimensional relationships between the two orogenic belts. In the Table, by subtracting 375 million years from the Caledonides dates, a time comparison may be made between the orogenic sequence of the two belts. [We have also provided a Glossary of 'difficult' terms. Eds.]

Rifting and Continental Margin Formation

In the Hellenides the Early Triassic eruption of alkaline volcanics associated with rifting was followed by the establishment of a continental margin sequence on the western edge of the Pelagonian Massif. The margin was affected by extensional faulting, throwing down to the west and by Jurassic times oceanic crust was spreading in the Othrys Zone.

Various Lower Cambrian volcanics in the Dalradian of Scotland may be comtemporaneous with the initial rifting of Iapetus. The Middle Cambrian to Lower Ordovician Durness carbonate platform of the NW Highlands [See Essays from the North II, this issue. Eds.]

CALEDONIDES

REGION	GEOLOGICAL SEQUENCE /EVENT	APPROX AGE Ma	375 ma. subtracted from Caledonide dates allowing 45 ma. Late-Orogenic sedimentation
N .W. HIGHLANDS	CONTINENTAL MARGIN SEQUENCE: Cambro-Ordovician Durness Carbonates resting on older Lewisian metamorphic basement	545–470	170–95
GRAMPIAN HIGHLANDS	CALC-ALKALINE VOLCANICS and intercalated sediments	380–375	15–0
	GRANODIORITE BATHOLITHS –	400	25
	–	460	85
	DALRADIAN COMPLEX: volcanics	570–545	195–170
	metamorphism culminated	480	105
MIDLAND VALLEY	CALC-ALKALINE VOLCANICS: andesitic lavas & tuffs and shallow intrusions	385–375	15–0
	LATE-OROGENIC SEDIMENTS: alluvial sediments of Silurian inliers and Lower Old Red Sandsone.	420–375	45–0
	TURBIDITE SEDIMENTS of Silurian inliers inliers	430–420	55–45
	TRANSGRESSIVE SEQUENCE conglomerates, sandstones and shallow water limestones passing laterally to S into redeposited limestones and turbidites	465–420	90–45
	BALLANTRAE OPHIOLITE COMPLEX Arenig sea floor 490–475 Obducted Metamorphic aureole 480	475	100
	? ? ?		
SOUTHERN UPLANDS	GRANODIORITE BATHOLITHS	410–390	35–15
	LATE-OROGENIC SEDIMENTS: Lower Old Red Sandstone alluvial sediments	385–375	20–0
	DIACHRONOUS EMERGENCE Llandovery-Ludlow	425–415	50–40
	TRENCH SEDIMENTS: Caradoc-Wenlock conglomerates, turbidite sandstones and shales and hemipelagic shales containing ophiolitic debris in Caradoc	450–415	75–40
	IAPETUS OCEAN PELAGIC SEDIMENTS: Arenig–Llandovery shales, mudstones and cherts	480–420	85–45
LAKE DISTRICT	LOWER PALAEOZOIC: Sediments and Calc-alkaline igneous rocks	–	–
	(SOUTHERN CALEDONIDES CONTINENTAL MARGIN)		

REGION	GEOLOGICAL SEQUENCE/EVENT	APPROX AGE Ma
PELAGONIAN MASSIF	CONTINENTAL MARGIN SEQUENCE: On W edge of Massif, sequence as below	220–135
	VOLCANICS: andesites and trachytes	5–0
	GRANITES and quartz porphyries	65–45
	METAMORPHIC COMPLEX: Permo Carboniferous – Early Mesozoic metamorphism culminated	110
MESO-HELLENIC TROUGH (IN OTHRYS ZONE)	VOLCANICS: isolated occurrences	0
	MOLASSE: U. Eocene-Quaternary alluvial sandstones and conglomerates, marls, limestones and lignites	45–0
	FLYSCH: U. Cretaceous – L Palaeocene turbiditic conglomerates, sandstones and shales	70–55
	TRANSGRESSIVE SEQUENCE: U. Cretaceous sandstones and conglomerates overlain by massive shallow water limestones	100–60
	PINDOS-OTHRYS-VOURINOS OPHIOLITE SHEET: U. Triassic-Jurassic sea floor 200–140; Metamorphic aureole 165; Obducted onto Continental Margin	130–110?
	CONTINENTAL MARGIN SEQUENCE: L. Triassic –L. Cretaceous platform limestone passing to SW into redeposited limestone and cherts on oceanic crust. Overlain by siliceous sediments with volcanic detritus	220–135
	VOLCANICS intercalated in Continental Margin Sequence	210
PINDOS MOUNTAINS	EMERGENCE	40
	TRENCH SEDIMENTS: Palaeocene–U. Eocene Pindos Flysch turbidite sandstones, shales and hemipelagic marls containing mainly metamorphic detritus	65–40
	EARLY FLYSCH: Turbidite sandstones, redeposited limestones with some pelagic limestone and chert containing ophiolitic debris in L. Cretaceous	135–65
	PINDOS OCEAN PELAGIC SEDIMENTS: U. Triassic-Cretaceous limestones cherts and shales	205–60
EPIROS	IONIAN ZONE: U. Triassic–Eocene platform and redeposited limestone/Oligocene – L. Miocene flysch (WESTERN HELLENIDES CONTINENTAL MARGIN)	–

records the development of the northern continental margin of Iapetus lying north of the Dalradian basin.

Subduction, Island Arcs and Ophiolites.

During Late Jurassic times an eastward-dipping subduction zone formed in the Othrys Ocean to the West of the Pelagonian Massif. Carbonate deposition at the continental margin had ceased by the earliest Cretaceous and the platform was eroded and then covered by siliceous sediments. These include volcanic material that may have been eroded from a nearby volcanic island arc which had formed above the subduction zone. The strip of ocean floor lying adjacent to the continental margin was then obducted onto the continental margin sequence during an episode of thrusting. The ophiolite and margin sequence were subsequently folded on lines which cut across the earlier thrusts and this is attributed to a period of strike slip (horizontal) fault movement contemporaneous with a pause in subduction. A marine transgression followed and shallow water limestones covered the deformed ophiolite and margin.

The Ballantrae ophiolite was deformed and obducted northwards during late-Arenig times, onto continental crust of probable Lewisian type. In the mid-to-late-Ordovician, a marine transgressive sequence then covered the ophiolite and alluvial fans interfinger to the south with marine turbidites. The latter were deposited on the continental margin and slope adjacent to a trench which was located in the area of the Southern Upland Fault. The transgressive sequence includes igneous material which indicates mid-Ordovician calc-alkaline magmatism north of Ballantrae. Subduction of Iapetus then probably started by late-Arenig times at the latest.

Whether the Ballantrae and Pindos-Othrys ophiolites represent true oceanic crust of their respective oceans is open to question. To elucidate the tectonic setting of basaltic rocks, geochemists have studied the relative concentrations of trace elements such as Zirconium and Yttrium which remain relatively stable during alteration of the rocks. This approach has been applied to both ophiolites with ambiguous results. In each case both ocean floor and island arc origins are indicated and a combination of origins is possible. If for instance a trench were initiated within oceanic crust, island arc volcanism above the subduction zone would then penetrate the strip of ocean floor adjacent to the continent, thus juxtaposing basaltic rocks of contrasting origins. The origin of the Highland Border Series ophiolite is disputed and it may represent the remnants of a separate marginal basin or alternatively an integral part of the Dalradian.

Trenches and Accretionary Wedges.

The Early Cretaceous flysch of the Pindos Mountains contains ophiolitic and calcareous detritus eroded from the ophiolite and margin sequence. By Early Tertiary times subduction had resumed and the turbidite sediments of the Pindos Flysch inundated the trench. These lack ophiolitic material and contain more mature metamorphic detritus eroded from the Pelagonian Massif. As subduction progressed successive packets of flysch and pelagic sediment were accreted to the Eastern Hellenides margin and thrust under the trailing edge of the Pindos ophiolite. The deformation of the exposed rocks in the Pindos Mountains took place relatively high in the crust and the strain associated with thrusting was mainly taken up in melange zones between thrust slices with only minor folding. This may also be a function of the rate of subduction and the degree of lithifaction of the trench and pelagic sediments. Further cross-folding in mid-Tertiary times might again be associated with strike-slip movement along the margin.

The earliest trench sediments of the Southern Uplands contain substantial quantities of ophiolitic material and acid and intermediate igneous detritus indicating erosion of the obducted ophiolite and volcanic arc rocks. Late Ordovician and Silurian trench sediments generally contain less igneous and more mature quartzose material. This has been related to the establishment of a shelf area over part of the Midland Valley supplied by sediment eroded from the metamorphic Highlands. Continued subduction led to the addition of progressively younger packets of trench and pelagic sediment to the Southern Uplands accretionary wedge and the previously accreted packets were tilted to steeper angles. The first folding episodes in the Southern Uplands are consistent with progressive accretion and thrusting within the accretionary wedge, however, later cross folding may be associated with strike-slip movement during subduction and closure of Iapetus. Observed deformation took place lower in the crust than in the Hellenides and may also relate to a greater degree of lithifaction of accreted trench sediment.

Late Orogenic Sedimentation, Calc-Alkaline Magmatism and Collision

With progressive underthrusting and accretion in the subduction complex the Pindos Flysch and pelagic sediments and trailing edge of the Pindos ophiolite became uplifted and shed detritus into the Meso-Hellenic molasse trough. The trough acted as a downfaulted basin and sediment eroded from the Pelagonian Massif to the East contributed to the rapid burial of much of the ophiolite sheet. Tertiary calc-alkaline magmatism in the Pelagonian zone was probably caused by continuing subduction. During collision, major stratal and crustal shortening took place in the Hellenides by way of low-angle East-dipping thrust faults which separate the major tectonic units.

Continued accretion and progressive tilting and uplift within the Southern Uplands accretionary wedge resulted in the emergence and erosion of accreted packets. Early Silurian marine turbidites of the Midland Valley were derived from this emergent area known as "Cockburnland". Further regional uplift and vertical movement on the Southern Upland Fault resulted in continued erosion of the Southern Uplands and alluvial sedimentation within the Midland Valley which persisted into the Devonian. The northern part of the Midland Valley was inundated with alluvial sediment derived from the Grampian Highlands in the early Devonian times in response to vertical movement on the Highland Border Fault. Strike-slip movement has also been postulated on the Highland Border Fault during this period to account for the nature of sedimentation. Faunal and stratigraphical evidence suggest that closure of Iapetus and collision with the Lake District volcanic arc occurred during Ludlovian times, at the earliest. However, subduction continuing into the Lower Devonian is suggested by the persistence of calc-alkaline magmatism north of the Iapetus Suture. On final collision the youngest accreted trench sediments of the Southern Uplands were tilted to their present near-vertical position.

Concluding Remarks

Although there are naturally some major differences in the geological histories of the two orogenic belts, the analogous evolution demonstrates the powerful and unifying nature of the "paradigm" of plate tectonics. On a more profound level perhaps it provides a lucid illustration of James Hutton's fundamental concept of uniformitarianism. Finally, I should like to apologise to all Tethyan and

Caledonian geologists whose sensitivities have been offended by the generalisations and omissions of this article which brevity has necessitated.

Suggested reading:

Hellenides: Smith, A.G., Woodcock, N.H. and Naylor, M.A., 1979. "The structural evolution of a Mesozonic continental margin, Othris Mountains, Greece" J. Geol. Soc. Lond. *136,* pp. 589–603.

Caledonides: Leggett, J.K., McKerrow, W.S., and Eales, M.H., 1979. "The Southern Uplands of Scotland: a Lower Palaeozoic accretionary prism" J. Geol. Soc. Lond. *136,* pp. 755–770.

Owen, T.R., 1976. "The Geological Evolution of the British Isles" Pergamon.

Glossary

Accretion – the addition of material to the leading edge of a continental plate when trench sediments at the subduction zone are 'scraped off' the oceanic plate during subduction.

Accretionary wedge – formed by the tectonic stacking of packets of trench sediments.

Caledonides – orogenic belt in Scotland formed during Late Precambrian and Lower Palaeozoic times, with continuation in Ireland and Newfoundland.

Crustal shortening – reduction in the amount of crust in a particular region e.g. by subduction

Flysch – marine sedimentary facies, generally composed of turbidite deposits; in the strict 'Alpine' sense, eroded from uplifted and deformed rocks and deposited before the climax of orogeny.

Hellenides – continuation of the Alpine Orogenic Belt formed during Mesozoic and Cainozoic times.

Iapetus – also called 'proto-atlantic', an ocean which spread and closed during the Caledonian orogeny

Marine transgression – invasion of a large area of land by the sea over a period of time.

Melange – a mapable unit comprising native and exotic clasts within a sheered matrix. A chaotic mixture!

Molasse – sediments derived from eroding mountain ranges after the final phase of orogeny.

Obduction – the addition of oceanic crust to the leading edge of a continental plate when part of that crust fails to be subducted. Ophiolities are characteristically preserved in this manner.

Ophiolite – a group of mafic and ultramafic rocks generally forming a layered sequence, including peridotites, gabbros, dolerites and basalts, representing ancient sea floor.

Othrys – Greek locality after which the ocean associated in the formation of the N.W. Hellenides is named.

Pelagic sediment – ocean deposit with little continental input.

Stratal shortening – shortening of a layered sequence of rocks by thrusting and /or folding.

Suture – surface lineament separating two geological sequences which originated at opposite margins of an ocean.

Turbidite -- sediment deposited by a turbidity current, normally characterised by a graded bed.

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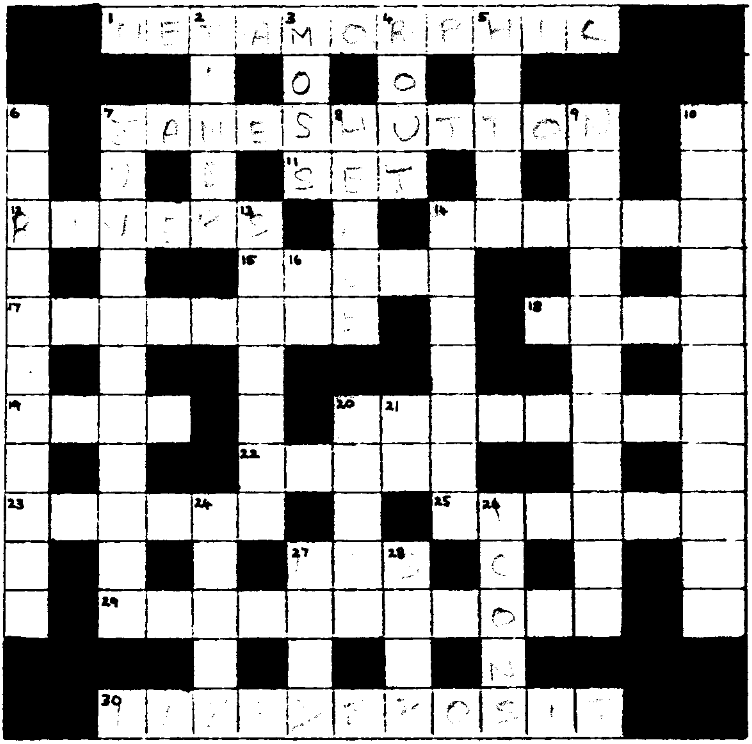
Booklet – The Elgin Reptiles		.15
Proceedings of the Edinburgh Geological Society (1–9)		free
Postcards – Hutton; Murchison & Geikie; Peach, Horne and Clough; Cadell, 1 & 2		.05
Lake District Geological Map Postcard, published by Yorkshire Geological Society		.08
Dalradian Offprints from Scottish Journal of Geology, Vol. 13, part 2, 1977.		
Introduction		out of print
1) Roseneath, Cowal		.30
2) Knapdale, North Kintyre		.20
3) Tayvallich		.30
4) Jura		.20
5) Lunga, Luing and Shuna		.20
6) Northern Loch Awe		.20
7) Loch Leven		.30
Geology of North East England, published by Natural History Society of Northumbria		£3.85

A MAINLY GEOLOGICAL CROSSWORD



Across

1. Hammer alters the topic (11)
7. Father of Geology (5,6)
11. A division of cross-bedded strata (3)
12. Streams of water (6)
14. I have run out of aluminium oxide, old boys! (6)
15. Covers a path (5)
17. An inside job, this feldspar determination (8)
18. 'Full many ____ ____ of purest ray serene
    The dark unfathomed caves of ocean bear:'
    Elegy Written in a Country Churchyard, Thomas Gray (1,3)
19. Laterite lobe (4)
20. Built as the result of an orogeny (8)
22. A hot bath (5)
23. Grouse about corals (6)

Across (continued)
25. Silica deposited by 22 across? (6)
27. Not hers (3)
29. Holey lava (11)
30. Lacustrine accumulation (4,7)

Down
2. Remit for old mineral explorer (5)
3. Peat to follow Stirling? (4)
4. Defeated trout loses its head! (4)
5. Home from home? (5)
6. Beryllium mineral found in pegmatite dykes (11)
7. Young emanation? (8,3)
8. Horizontal component of displacement (5)
9. Graptolite at the base of the Caradoc in Wales (11)
10. A product of degradation used in modelling effervescent drink! (4,7)
13. Sit on this pile of pillows (7)
14. Institutions for the blind (7)
16. Used before 'H' (2)
20. A dam that is a channel of information (5)
21. Metal mineral without end (2)
24. In store for soup (5)
26. Coins turn religious (5)
27. Sounds a dear farm worker (4)
28. American species of sea-bream (4)

A PRIZE will be presented for the correct solution or the best attempt at solving the above:

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ENTRIES TO REACH THE EDITORS BY 30th APRIL 1981.

Review

Five booklets from the Geological Museum: The Story of the Earth 1972 25p, now 55p; Volcanoes 1974 30p, now 55p; Moon, Mars and meteorites 1977 70p; Britain before Man 1978 70p; The age of the Earth 1980 90p. Published by HMSO for IGS. Each 196mm x 210 mm and of 36 pp.

Geology is neither an easy subject to teach nor to learn. One recalls the story of the eminent geophysicist who thought he would read up sufficient geology from a book in a weekend. I well remember the student at the first Durham Summer School who, when we approached the edge of the Wear gorge, asked if we were at a plate margin. The point I am making is that there can never be any real substitute for people themselves observing all the wonderful features of the Earth we are privileged to inhabit. The problem the beginner has is in knowing what it is he is seeing and, indeed, *how to observe.* De la Beche wrote a little book with that intriguing title in that marvellous period of geological development in Britain, the 1830s.

How fitting it is, then, that the Geological Survey which De la Beche first directed should make, through its Geological Museum, perhaps the single most important contribution to earth science education in Britain — the provision of modern, permanent exhibitions and a series of quite outstanding booklets. The publication at the end of October 1980 of the fifth booklet in the series provides a suitable opportunity to briefly review progress to date.

The Geological Museum was in 1935 set out in a building designed, with its lofty, light interior, to display in neat rows of cases its superb collection of gemstones and other treasures from the Earth. Following the revolution in the earth sciences in the 1960s, the museum staff achieved something of a miracle in filling in the whole of one side of the ground floor of the building with 'The Story of the Earth', a major exhibition executed by a leading designer and opened by the Queen in 1972. The accompanying booklet set the pattern for the series. Originally priced at 25p, some quarter of a million copies have since been sold!

On its cover, this first booklet has the now well-known view of the Earth from Apollo 10 and its 36 pages have 71 illustrations, all in colour, interspersed with text. Many of the illustrations are beautifully done, e.g. no. 29, a section across a typical continent. The text follows the thread of the exhibition in the museum, considering first the Earth in space, then Earth structure, Geological time and processes. Together with the Geological Map postcard also produced by the museum and the Manchester Museum's Geological Column, we have had now for some years the 'best buys' for anyone interested in geology.

The Story of the Earth touched briefly on volcanoes at the end and these were the subject of the second booklet published in 1974. With 116 illustrations, *Volcanoes* gave ample vent to the artistic skill of the production team, e.g. no. 55, showing magma genesis in relation to plate boundaries. On p. 27 there is the now well-known reconstruction of the Arthur's Seat volcano.

Understandably, in view of the Apollo programme, the third booklet in 1977 dealt with *Moon, Mars and meteorites.* With 78 illustrations, much of the booklet deals with the six Apollo landings from 1969 to 1972, but there are short sections on Mars and meteorites, including those enigmatic glassy objects, the tektites.

1977 saw the second major permanent exhibition mounted in the Geological Museum, that dealing with 'Britain before Man'. The accompanying booklet, published the following year, has as many as 122 illustrations which include a new simplified version of the Geological Map of Britain and Ireland, available separately as a postcard. Beginning with the Earth's crust under Britain showing a north-south section based on the LISPB profile, the text deals successively with the sequence of geological periods in the evolution of Britain.

The latest booklet in the series deals with *The age of the Earth* and contains 69 illustrations. Notable among these is a full-page reproduction of a portion of William Smith's great map of 1815, appropriately that part around Bath. A portion of this marvellous map was published some years ago in *The Penrose Annual* and the present reproduction does justice to Smith's beautiful map. The text deals with the technique of dating rocks, whether in layers or otherwise and unfolds the evolution of life in the major eras of geological time. Curiously, though William Smith, Charles Lyell, Lord Kelvin and Arthur Holmes are all included, there is no mention of James Hutton.

Together, these five booklets form an excellent introduction to modern geology, dealing concisely with the present state of the art as well as tracing its historical development. Everyone can profit from them and it will be interesting to see if HMSO now offer the five as a set at a reduced price, as they have with the six Science Museum booklets in the same format on the theme of Exploration.

In any case, we can all eagerly look forward to the next in the series which I understand is to be on Earthquakes. May the Geological Museum long continue to shake us all up.

Norman E. Butcher.

Review

SARJEANT, William A.S.: Geologists and the history of geology; an international bibliography from the origins to 1978. London: Macmillan Press, 1980. 5 vols., £250, ISBN 0–333–29393–2

These volumes, the fruits of twenty years of careful bibliographical work carried out as a part of the author's geological researches, are "a compilation of detailed bibliographic information on the works . . . which tell of the origin and growth of geology, of its societies, associations and collections . . . and of the lives of the men and women whose endeavours have built the science of geology".

Histories of geology, its sub-divisions, related subjects, societies and museums, are listed in volume 1. Volumes 2 and 3 contain the references to biographies of individual geologists. Volume 4 indexes the biographies of speciality, by country of birth, and by the countries worked in by those geologists. Volume 5 consists of an alphabetical index of authors, editors and translators.

Different sciences have different attitudes to their own pasts. Thus in electronics, works over 10 years old are fairly dated, and are seldom consulted. In chemistry there is a small but significant minority interest in the history of the subject. Most geological practitioners, on the other hand, tend to delve very deeply into historical works, as an integral part of current research. It may then seem surprising that before this current bibliography no one had attempted such a major undertaking on geologists and the history of geology. Writers on geological history have had to search through sources scattered widely throughout the geological literature. Now for the first time we have a reference source which is accurate, definitive, and, within limits, comprehensive. Sarjeant claims a coverage of 85% for English language publications, and an overall coverage of 50–60% for all Latin alphabet sources. Having found biographies of several early Scottish geologists, I see no reason to doubt these figures.

There are 28,000 subject and reference entries; 25,000 entries in the author index; 28,000 entries in the geographical indexes; and 21,000 entries in the "Speciality" index. Such numbers would seem to belong more to the world of the Library catalogue than to the reference index of a single individual. The answer lies in Sarjeant's use of a computer to manipulate the data collected manually over a twenty year period. The bibliographical uses of computers are many, and this field is rapidly expanding throughout the world, but they depend finally on the meticulous work of the dedicated human being who records the data in the first place. All those geologists who carry around little boxes of reference cards should look at Sarjeant's bibliography to see how potentially useful to others their own efforts could become, given twenty years, inexhaustible patience, and a good geological library or two.

Edinburgh geologists should note that copies of this immensely useful reference tool are held in the libraries of IGS and the University, and geologists throughout the world will have reason to be grateful to the author for many years to come.

C.D. Will.