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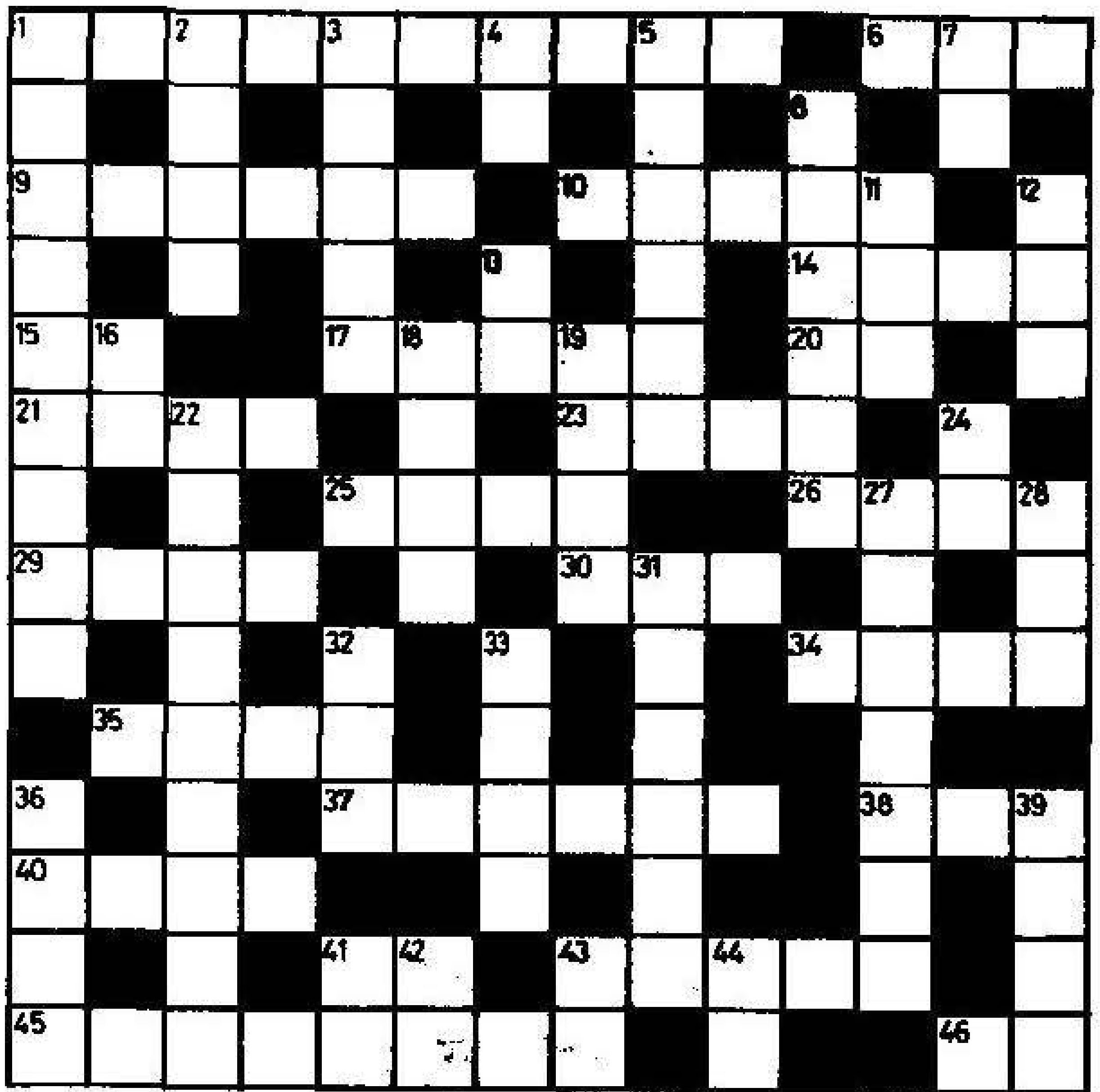
Cross Bedding

Crossword with a geological bias set by Catherine Francis. All correct entries submitted to the **Editor by 1st June** will be put into a Prize Draw at the Summer Social.



CLUES ACROSS

1. Medical Centre for the single person?
6. Continent for Socialists?
9. Top Town of the Silures?
10. First stirrings in the "Primordial Soup"?
14. Fifty five to aa obtains itself.
15. Magnetic reversals?
17. Cleric's pay cut keeps colony afloat.
20. *In reverse, quite rare, but down to earth.*
21. Examination for a sea-urchin?
23. The . . . . .lady is not for smelting!
25. Unquiet town in Yugoslavia.
26. A granitic detective?
29. Was it a fiery embrace at Arthur's seat?
30. Winged gods of the planets.
34. Fifty in volcanic subsidence.
35. Some muscle left in weakened workers co-operative.
37. A fossil alive and well in China.
38. Not the crystal to wear for long.
40. Untruthful clays?
41. Radioactive Egyptian god.
43. Not the sort of cavity which requires a dentist's attention.
45. The devil take it!
46. In pyrites all that glisters is not gold.

CLUES DOWN

1. One sick saint in a thousand grates on others.
2. The built-in sound effect in Carboniferous trees.
3. Right angry bedding!
4. The hottest planetary property in our Solar System.
5. *A geological layabout.*
7. Are you into Heavy Metal?
8. Miners would give it almost a glance.
11. A confused geological time unit.
12. "Skate's off" but we have a near relation.
13. An extremely sociable element.
16. City lights not on.
18. So soft and gentle to the hands!
19. Part of the pit has been found in the coal.
22. P.S. Minerals.
24. An element that gets to the heart of the matter.
27. It sounds like a hundred in limelight.
28. The . . . . . star, brightest in the animal world.
31. Watch your language! Without the aluminium it is mixed-up rubbish.
32. Bellamy's natural environment.
33. A singular KZCSD.
36. Apatriotic paving.
39. Agnostids lacked these.
41. A shortened form of heat control.
42. Hawaiian baby's first sounds?
43. The rare element that is half in its dotage.
44. Mappable metal?

Cover illustration by Paul Olver

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Vulcano in History and in Eruption

Paul Olver

In April 1981, a group of Society members visited the Aeolian archipelago in the Southern Tyrrhenian Sea, one of the two active volcanic arcs in the Mediterranean. This report concentrates on the magmatic evolution of the 'ancestral volcano', namely Vulcano, the southernmost of the islands and still one of the most active.

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1. Introduction

The Aeolian Islands consist of seven inhabited major islands, namely Lipari, Vulcano, Salina, Panarea, Stromboli, Filicudi and Alicudi together with several scattered islets notably around Panarea. The group as a whole lies about 40 km from the north-east Sicilian coast in the Southern Tyrrhenian Sea (FIG. 1). All the islands are totally volcanic in origin although only two, Vulcano and Stromboli, show present day activity. The contrasting topography and vegetative cover of the islands can be directly related to their volcanic constitution. The more base-rich volcanics produce the extremely fertile soils and gentle slopes of Salina and the forested terraces of Panarea while most of the more craggy slopes of Lipari and Vulcano are either barren or at most covered only with sparse scrub and prickly-pear cactus, witness to the predominantly acid volcanic rocks of these southernmost islands.

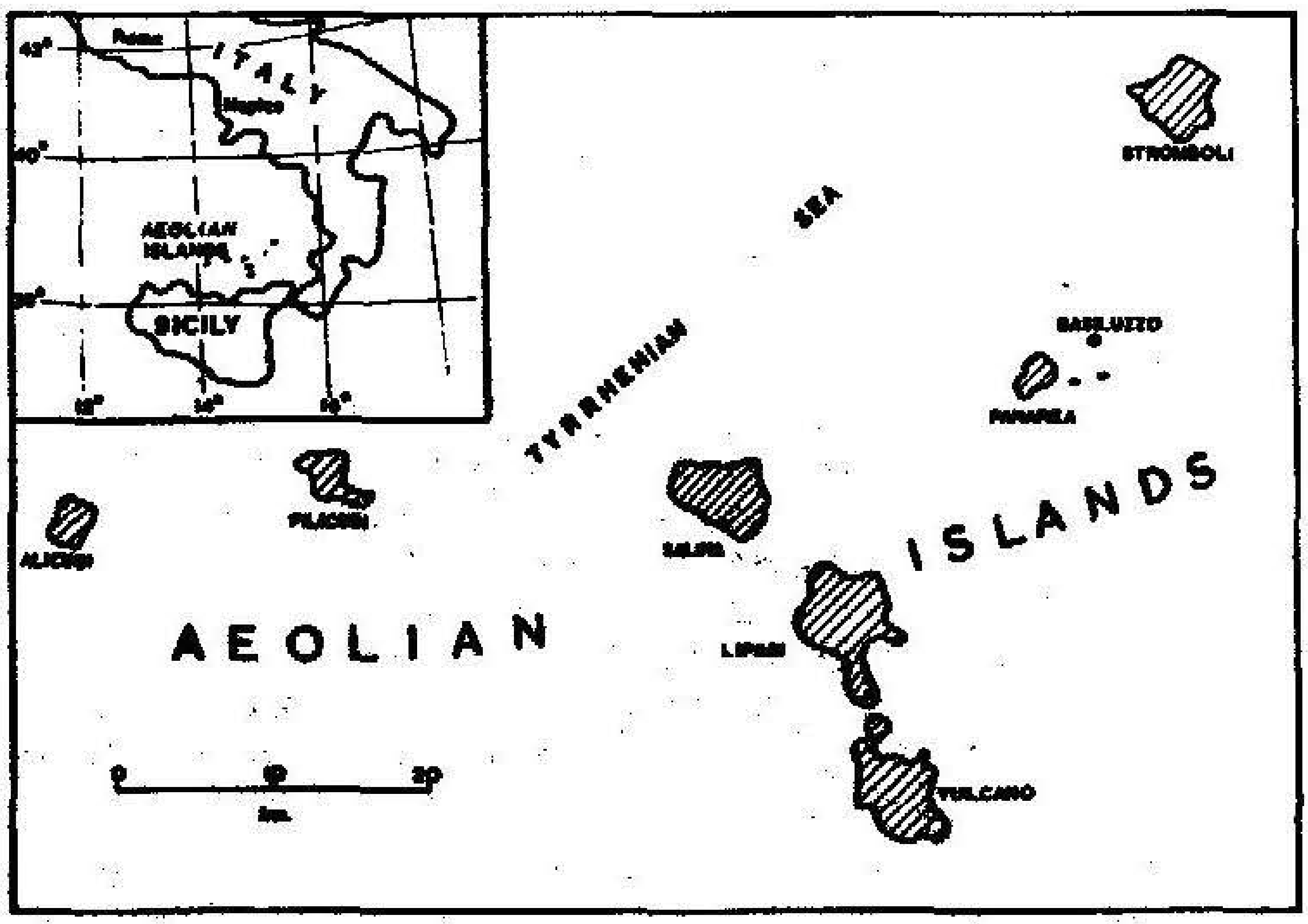

FIG. 1 Map showing the Aeolian archipelago and its relationship to the southern Italian mainland.

2. Volcanic History

The earliest volcanic centre on Vulcano has been almost completely eroded away and is now represented solely by the Eastern Faraglione, a steep-sided cliff which overlooks the Porto di Levante (FIG. 2). Despite intense solfataric alteration due to present day activity in the area and the 19th century excavations for alum, submarine pillow lavas can still be recognised whose orientation suggests that the centre perhaps lay to the east within the bay itself.

The southernmost part of Vulcano is a fertile, well-farmed plateau rising to 500 m at Monte Aria in the south-east sector. This is all that remains of the second basaltic phase in which there were many eruptive craters collectively called Vulcano del Piano. The present day plateau represents the floor of a huge caldera, the highest points such as Monte Saraceno being the craters which remained active after its subsidence. Among the products were olivine trachybasalts and trachyandesites (Baldanza 1961) which now form the highest point on the caldera rim at Monte Aria and Monte Saraceno and also the steep crags to the north that separate this area from the present day active centre of Vulcano della Fossa (FIG. 2).

The next stage in the volcanic evolution of the island occurred at the end of the Tertiary when an extensive series of acid volcanic rocks, consisting of liparite and obsidian lavas together with their associated pyroclastics, was deposited. The sole remnant of this third salic phase is now seen in the Monte Lentia region in the north-west part of the island (FIG. 2). These deposits have been studied both petrographically and geochemically by the author in order to elucidate the evolution of the Vulcanian magmas just prior to the development of the present centre at Vulcano della Fossa. The detailed results of this research are presented later in this paper.

The Monte Lentia acid volcanics and the second phase basaltic lavas form a caldera wall around the most recent, and still active, volcanic centre of Vulcano della Fossa. La Fossa lies directly on a prominent north-south lineament which can be traced from the volcanic centres of north-east Lipari, centred on Monte Pelato, through fumarolic zones in western Lipari and across to the island of Vulcano. Little is known about the early history of La Fossa except that its formation was heralded either by the cataclysmic destruction of the earlier volcanic edifice or, more likely, by a period of cauldron subsidence during which time La Fossa centre was initiated within the downfaulted region.

There is much evidence from the writings of the Romans including Pliny, Obsequens, Orosius and Eutropius that after the initiation of La Fossa in prehistoric times, the next major volcanological event was the formation of the then separate islet of Vulcanello, lying on the same important lineament, but to the north of La Fossa (FIG. 2). From their writings the date for its apperance can be confirmed as 183 B.C. Keller (1970a) places the two most easterly craters of Vulcanello, designated I and II, as part of this initial phase. These early structures have now been heavily eroded by the sea, especially on the north-east side where a transverse section through Cone I, showing quaquaversal stratified ash layers, is seen. Among the eruptive products of the early Vulcanello is a prominent leucite tephrite lava flow which forms a near-horizontal lava field around the volcanic centre. The lava is highly vesicular in nature and shows well developed pahoehoe structures on most surfaces. This uppermost crust of the lava is now heavily stained with ferric oxide due to weathering effects.

Another feature is a localised trachyte lava flow originating from Centre II and forming the headland at Punta Roveto. Similar trachytic lava flows outcropping at Punta Nere on the north-eastern side of La Fossa are correlated with this Vulcanello phase of volcanicity.

Presumably they represent a concurrent, or nearly concurrent, eruption of similar lavas at the early Fossa centre. De Fiore (1922), from the study of ancient texts, tentatively suggests that the main Vulcanello eruptions of this period, after its initiation in 183 B.C., were 126 B.C. and 91 B.C.

Sometime in the 6th century A.D. the terminal eruptions of the Monte Pelato (N.E. Lipari) centre took place. These highly explosive eruptions laid down thick pyroclastic fall deposits in Lipari and thinner representative in the islands of Vulcanello and Vulcano to the south. A 10 cm thick layer of this Monte Pelato pumise if found on both islands and can be used as an important datum line. At Vulcanello, the deposits of Crater III, the most westerly of the three craters, overlie this pumice layer and are thought to have been erupted in the late 6th century A.D. On Vulcano, scattered pyroclastic fall deposits, with a characteristic reddish tinge, are found in small outcrops around the present day centre. These are the eruptive products of the Fossa II volcano whose centre lay just to the east of the present Vulcano della Fossa. These well-bedded tuffs are prominently exposed inside the present crater walls, beneath a cover of later pyroclastics, and show variegated colours and highly developed cross bedding. Parasitic cones built up on the Fossa II edifice and are still clearly seen as the double crater of Forgia Vecchia on the northern flanks. The last activity of these parasitic vents can be attributed to around 1727 when D'Orvilles reported seeing a small active crater near the main centre.

FIG. 2 Map of the island of Vulcano showing the active La Fossa centre and the older Monte Lentia centre to the north-west.

In 1739, an extemely viscous trachytic magma produced the spectacular Pietre Cotte on the north-west slopes of La Fossa.This narrow, steep sided flow of trachytic obsidian, which probably originated near the southern crater wall of Fossa II before its eventual destruction, extends for only one kilometre towards Porto de Levante. Obsidian fragments from the same eruption also tend to be common on the southern slopes of La Fossa intermixed with 'breadcrust' bombs of the 1888 - 1890 eruption. The Pietre Cotte is characterised by progressive degassing along selected planes within the obsidian to form discrete pumiceous layers. The obsidian is also highly affected by the present day fumarolic activity on this north-west slope and contains areas rich in ammonium chloride sublimate.

The early development of the present day Vulcano della Fossa, to the west of Fossa II, is largely undocumented. Presumably the active magma chambers, associated with the north-south Tyrrhenian fracture referred to earlier, slightly changed their conduits and gave rise to small eruptions in the 17th and 18th centuries which eventually destroyed most of the structure of the earlier Fossa centre.

The 1888 - 1890 eruption is the only recorded high explosive event of Vulcano della Fossa in historic times. No pumice was ejected with the dark eruptive cloud although broken fragments of already partially solidified and extremely viscous lava showered over the island. These produced the characteristic spindle-shaped 'breadcrust' bombs which still litter the slopes of the volcano and which at maximum can measure 270 x 180 x 180 cm although, in most cases, fragmentation due to impact on the volcanic slopes has occurred. The fine, black, cinderitic ash which coats most of the northern half of the island is associated with the products of the 1888 - 1890 eruption and with a similar less well documented eruption in 1786. It is especially prominent to the west and north-west where the Monte Lentia (FIG. 2) formations are totally concealed on their eastern side by ea thick deposit.

3. Vulcano Today

At present, Vulcanello is joined to mainland Vulcano by a narrow isthmus formed from its last eruption, originating from Crater III, in 1550 (FIG. 2). Volcanic activity in the area is restricted to fumaroles associated with Vulcano della Fossa and also at Porto di Levante. Fumaroles on La Fossa tend to be concentrated in straight lines, along the eastern edge of the crater and on the northern edge of the cone close to the older Forgia Vecchia centre, now reduced to a heavily eroded amphitheatre breaking the otherwise smooth lines of the main volcano. These alignments are the present day manifestations of the Tyrrhenian fault lines that control the volcanism of the island.

The fumaroles tend to be 'cool' in that the temperature seldom exceeds 101°C. At Forgia Vecchia the air is heavily laden with sulphur dioxide and carbon dioxide although water vapour constitutes 80% of the fumarolic gases. Reaction with the air at these relatively low temperatures produces droplets of sulphuric acid - a fact brought home to the Society party by the relentless disintegration of their clothes and rucksacks! Some of the fumaroles are of the higher temperature and produce colourful sublimates of white ammonium chloride, reddish realgar (AsS) and ferric chloride close to their orifices. Further away from these fumaroles, cavities in the surrounding pyroclastic fall deposits are crowded with mats of delicate sulphur crystals. Both monoclinic and rhombic forms occur indicating temperature fluctuations around 95.6°C, the transition point.

Further active fumaroles occur on the beach and above low water mark near the Eastern Faraglione of Porto di Levante (FIG.2). Those covered by high water produce a myriad of bubbles on the water surface giving the appearance of a 'boiling sea'. A characteristic milky appearance to the water is also seen due to an abundance of colloidal sulphur. Other fumaroles on the beach are associated with small, hot circular areas of water which rise and fall with the tides. They are surrounded by variegated sublimates and an atmosphere highly charged with sulphuretted hydrogen.

The island, therefore, shows a generally intermediate to acid volcanism both at the present day and in the recent past. This volcanism is characterised by regularly spaced but rare Vulcanian eruptions of varying intensity. The crucial period in the evolution of Vulcano is marked by the changeover from the basic Strombolian activity at Vulcano del Piano to the more violent northern events at Monte Lentia and at La Fossa. Study of the Monte Lentia successions by the author covers this important time interval and it is these early acid volcanic rocks that are now described in some detail.

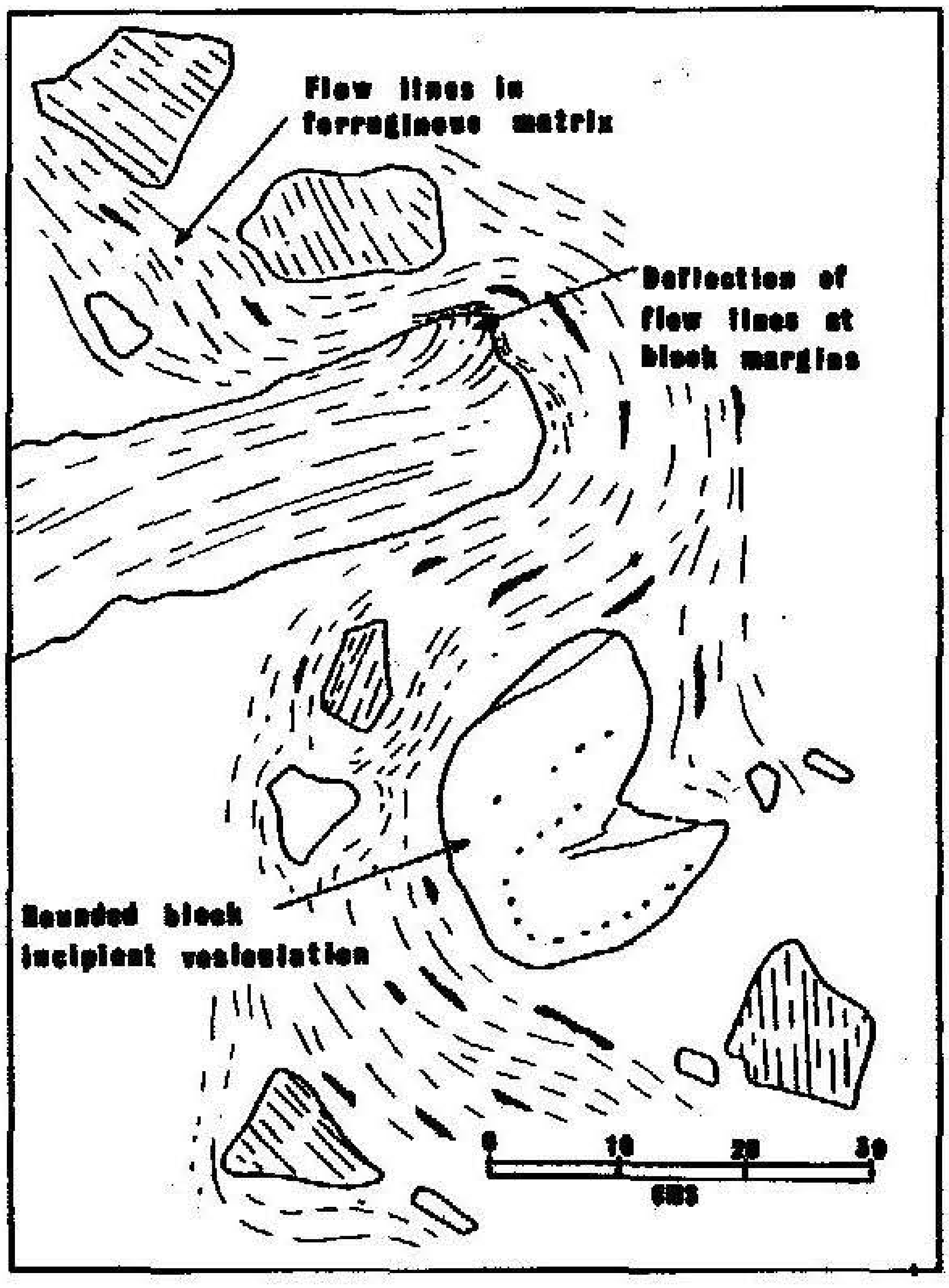

FIG. 3
Detailed structure within a pyroclastic flow breccia at Capo Grosso, near Monte Lentia, Vulcano.

4. Monte Lentia Volcanism

The volcanic suite at Monte Lentia consists of alternations of coarse to fine bedded tuffs, coarse to fine breccias, occasional obsidians and black banded liparites. All these volcanic units are gradational into each other. The term 'liparite', first defined in the Aeolian Islands by Roth (1860), is synonomous with rhyolite but is used in this paper on the grounds of its historical association with the area.

The bay of Cala di Mastro Minico (FIG.2) displays a typical succession of volcanic units in its cliff face. To the north, the coarse breccias of Capo Grosso pass south-eastwards into bedded tuffs which underlie a partially vesiculated and heavily flow contorted liparite lava. Above this lava, the succession repeats itself until a further liparite outcrops to form the next headland to the south.

The breccia horizons, of various size grades, consist of fragments of highly vesiculated pumice, black weathering liparite lava, semi-degassed obsidian and occasional fragments showing fiamme of obsidian set in a fine rhyolitic matrix.

At Capo Grosso, the junction between one of these breccias and the succeeding liparite lava is marked by a transitional breccia horizon displaying a red ferruginous cement in contrast to the normal white dusty pumice matrix. Here, random angular to subrounded liparite blocks are set in a flow textured groundmass (FIG.3). The ferruginous cement accentuates small obsidian fiamme whose flowage texture, frayed margins and flattened appearance closely resemble that of pumice clasts in a typical ignimbrite horizon. The subrounded nature of some blocks and the occasional block showing upturned flow banding at its margin (FIG.3) strongly indicate high levels of retained heat within this system during deposition. This is in accord with a pyroclastic flow origin for this particular horizon.

The prominent liparite lava at Cala di Mastro Minico is typical of these units at Monte Lentia. It shows irregular incipient vesiculation along selected planes which when carried to its conclusion produces a characteristic cinderitic texture. All grades of vesiculation can occur between these two extremes. The rocks is alternately banded in black and light grey, the latter areas representing the more heavily degassed zones. The lava is highly flow-contorted in places with prominent folds plunging at shallow angles to the north. These areas disturb an otherwise uniform stratification in the lavas.

Obsidian in the form of vitreous black, flow-contorted, thin flows outcrops at Capo Grosso and south of Monte Lentia at Testa Grossa. The lavas at both localities form steeply dipping 'walls' whose surfaces display refolded fold patterns, an extreme form of flow contortion. These localised flows represent a highly chilled, glassy form of the surrounding liparite lavas and have an almost identical major element composition (see Section 6).

5. Geochemistry of the Lavas

The volcanic rocks of Monte Lentia can all be classified as rhyolites and possess Rittmann salic indices ranging from 2.791 to 3.503 within the average Pacific field. Their silica contents range from 68.61 to 61.54 wt % and the analyses indicate that, unlike the second phase rhyodacites and third phase dome lavas of Lipari to the north, there is no excess alumina and corundum is therefore absent from the norm. (TABLE 1).

The Monte Lentia suite as a whole shows significant rubidium enrichment with K/Rb ratios averaging 138. This is intermediate in value between the Central Lipari rhyodacites and the Southern Lipari dome lavas and may indicate a chronological difference. Unlike their Lipari counterparts, the Monte Lentia rhyolites are rich in Ca and Sr (average 450 ppm) and display low Ca/Sr ratios averaging 46. The higher content of andesine - oligoclase within the rhyolites is the main cause of this concentration and may have caused the depletion of these elements in the succeeding Southern Lipari dome lavas. There are several indications, beside the Rb contents, that these acid magmas have undergone fractionation from an original anatectic melt. These include the high thorium, lead, rare earth and chlorine contents compared to the Central Lipari rhyodacites although, as in Southern Lipari, the La/Y ratios remain anomalously low if such fractionation processes have been operative.

TABLE 1: MONTE LENTIA VOLCANIC SUITE CHEMICAL ANALYSES

Element wt %	1	2	3
SiO_2	66.52	67.76	65.40
TiO_2	0.25	0.25	0.28
Al_2O_3	14.59	14.91	14.16
Fe_2O_3	1.59	2.51	4.33
FeO	1.96	1.22	nd
MnO	0.08	0.06	0.08
MgO	0.76	0.79	1.41
CaO	2.50	2.39	3.63
Na_2O	3.93	3.84	3.51
K_2O	4.63	4.74	4.46
P_2O_5	0.10	0.11	0.11

Trace Element ppm	1	2	3
S	58	54	18
Cl	969	454	1022
Cr	20	23	49
Ni	8	11	15
Zn	51	50	50
Ga	10	12	10
Rb	289	288	266
Sr	451	461	526
Y	35	38	33
Zr	246	247	221
Ba	nd	520	560
La	65	63	56
Ce	116	111	99
Pb	29	30	34
Th	50	44	42

All major and trace element analyses by X-Ray Fluorescence techniques.
Ferrous iron determinations by titration using N/20 ceric sulphate.
Analysis 1. Obsidian lava flow, Capo Grosso. Pellet No. 7086.
Analysis 2. Liparite lava flow, Capo Grosso. Pellet No. 7088.
Analysis 3. Breccia block, Cala di Mastro Minico. Pellet No. 7084.

A statistical analysis of the geochemical results obtained at Monte Lentia produced an anomalously low correlation between potash and rubidium but a high correlation between the latter element and thorium. The small number of samples might possibly cause this anomaly although it could indicate that the two trace elements are being preferentially concentrated in the vitric matrices rather than in the sanidine microlites. The strong positive correlation between CaO and P_2O_5 confirms the presence of minute apatite needles although the expected correlation between chlorine and these elements is not apparent. The chlorine, therefore, appears to be concentrated within the volcanic glasses, a feature not uncommon in other natural silicic glasses (Noble *et al* 1967). Minor correlations of Pb, Zn and Fe_2O_3 with sulphur suggest that these glasses are probably saturated with sulphides as indicated by the specs of pyrite observed in thin section under reflected light. Zirconium shows none of its expected correlations with lanthanum,cerium or yttrium confirming the absence of zircon accessory.It does, however, show a very strong correlation with soda.As zirconium does not enter feldspar lattices, this correlation may indicate its presence,alongside soda, in the silicic glass matrices.This element is known to have a high solubility in peralkaline liquids(Carmichael & McDonald 1961, Sceal & Weaver 1971).

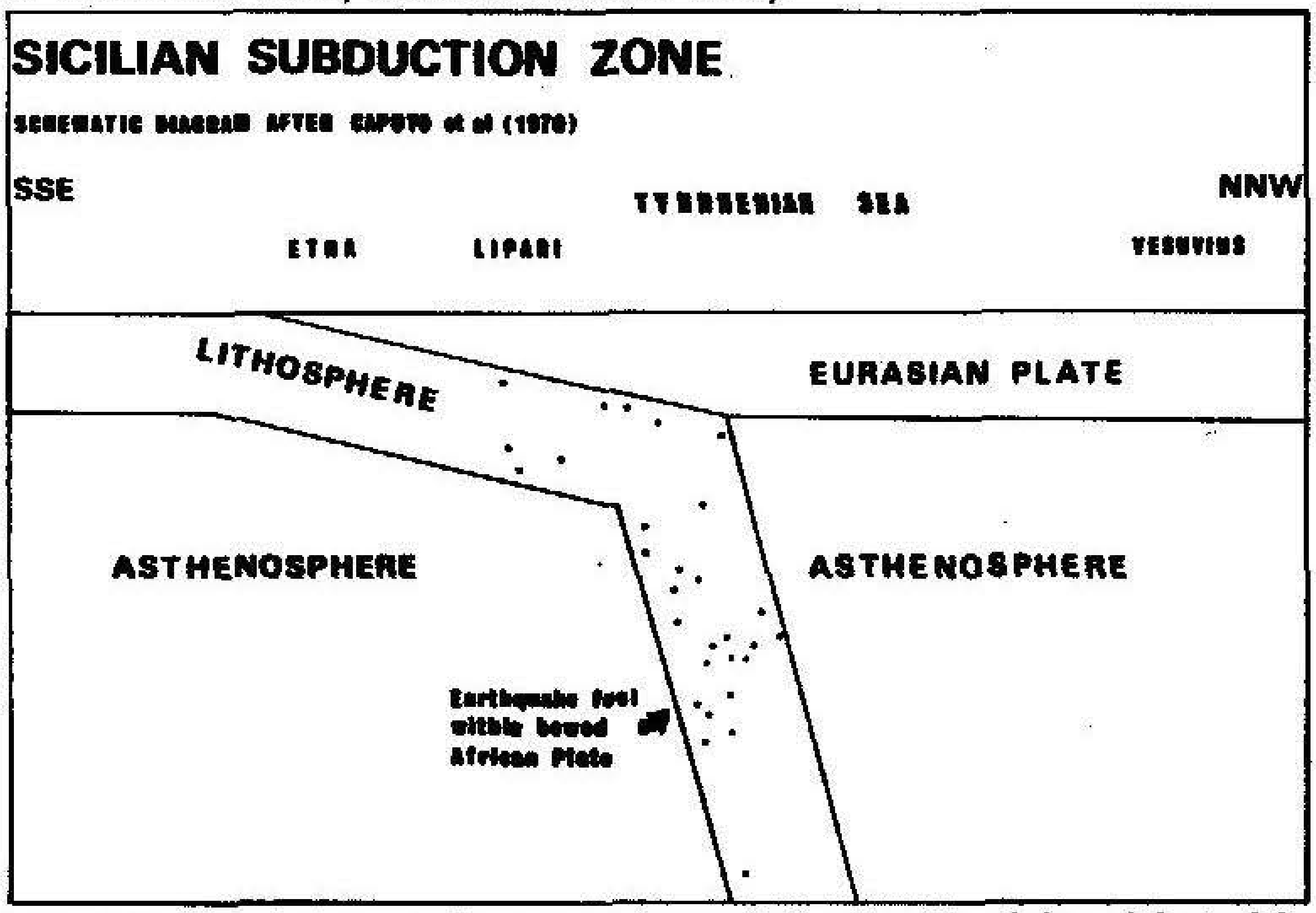

FIG. 4 Proposed plate configurations beneath Aeolian Island Arc. Adapted from Caputo et al (1970).

6. Petrogenesis of the Lavas

The development of the potash-rich rhyolite magmas of Monte Lentia involves a complex interaction of both petrological and structural factors. The petrogenesis of this suite, therefore, will be discussed under two separate sub-sections concerned with:-

(a) The development of the extensional features that allowed calc-alkaline magmas access to the surface.

(b) The petrological evolution of these rhyolitic magmas beneath the island of Vulcano.

(a) Magmatic Access

The present day south-east Tyrrhenian Sea, over 3500 m deep on average, is floored by the remnants of a former orogenic belt which has gradually subsided to oceanic levels (Pannekoek 1969). North-south trending compressional ridges characterise this metamorphic basement and form the shallowest regions of the present Tyrrhenian Sea.

These ridges are associated with a set of compressional strike-slip faults trending NW - SE. The islands of Vulcano and Lipari have been constructed on a ridge of north-south trending matamorphic basement (Morelli 1970) and are flanked on their western side by a major dextral strike-slip fault (Grindley 1973).

Further important structures were initiated during the Tyrrhenian subsidence of mid-Pliocene times. This foundering of the Tyrrhenian orogenic belt caused the production of two sets of fractures. The first set was essentially concentric to the surrounding continental slopes of Italy and Sicily while the second was aligned approximately at right angles to the main ESE - WNW direction of maximum extension. The combined effect of these two fracture systems is to produce a gridiron pattern in the region of Vulcano and Lipari whose intersections provide adequate pathways for the ascent of calc-alkaline magmas.

These north-east to north trending second set of fractures are at present undergoing further extension due to the general SSE migration of the Eurasian continental plate over the downgoing African plate (FIG.4). The configuration of this subduction zone beneath the Aeolian arc has been found by plotting the foci of intermediate to deep focus earthquakes, 200 - 350 km below the Tyrrhenian Sea (Caputo *et al* 1970, Blot 1976).

Results indicate a maximum compression plane dipping at 60° to the WNW (FIG.4) and that the plane may be deformed, bowed or even fragmented to account for the various volcanic alignments in the area. Thus it is both the continued subsidence of the Tyrrhenian plus recent continental plate interaction that provide the fractures and, therefore, access for magmas to move towards the surface.

(b) Development of the Acid Magmas

Whereas the rise of the magmas can be associated with both subsidence and plate interaction, the actual origin of the calcalkaline melts can be directly attributed to the downgoing African lithospheric plate. Oceanic crust associated with this lithospheric slab is likely to have been converted into quartz-eclogite at depths of 100 - 150 km beneath the Aeolian Island Arc (Ringwood 1974). A partial melting of this quartz-eclogite can produce the required rhyodacitic-rhyolitic magmas characteristic of the later volcanism on Vulcano. These magmas, if they reached the surface, would be characterised by low Na/K ratios, high abundances of Ba, La, Ce, Th and Zr and strongly fractionated rare earth elements linked to high La/Y ratios.

However, these magmatic characteristics are probably inherited by the calc-alkaline magmas by a different, more indirect process. It is more likely that these initial rhyodacitic-rhyolitic liquids react with the overlying mantle pyrolite to produce diapirs of hydrous pyroxenite which detach themselves from the Benioff Zone and undergo partial melting as they rise from depths between 100 - 150 km. The magmas that separate from these rising diapirs will inherit the geochemical characteristics of the initial rhyodacitic-rhyolitic melts and will fractionate to produce the varied orogenic-type magmas found within the Aeolian Island Arc.

Brown & Schairer (1968) and Yoder (1969) presented a case for distinguishing between calc-alkaline circum-oceanic arc volcanism and calc-alkaline continental margin volcanism. The latter lavas are predominantly andesitic as expected but are characterised by more abundant dacite and rhyolite representatives. These acid products either occur as broad plateaux or as rhyolite flows and domes. Forbes *et al* (1968) noted that such continental calc-alkaline lavas were generally more potassic and show less of an increase in Fe:Mg ratio with increased silica contents. The characteristically high potash contents of the Vulcanian magmas and the presence of abundant acid volcanic rocks on the island would seem to confirm its relationship to the continental margin calc-alkaline suites and the existence of continental crust beneath the Tyrrhenian Sea.

Direct interaction with this continental crust, through contact anatexis, can be ruled out in the case of the Monte Lentia magmas. Their chemistry indicates (TABLE 1) that, although they are potash-rich, they are not peraluminous. They do, however, display all the chemical characteristics required of the continental margin suites and were probably derived directly from pockets of calc-alkaline magmas by processes of fractionation. A probable model would be a deep permanent basaltic-andesitic magma evolving as a closed system and feeding, through successive magmatic pulses, one or several superficial magma chambers under Vulcano where the main fractionation processes would take place. In this way, the alkali rhyolites of Monte Lentia and the later magmas of La Fossa Centre could successfully develop.

7. Acknowledgements

This paper forms part of a research programme at the University of Birmingham financed by the Natural Environment Research Council whose support is gratefully acknowledged. I am particularly indebted to Dr. E. Lo Guidice and Dr. Jean-Paul Blot for introducing me to the fascinating geology of Vulcano and also to Dr. G. L. Hendry whose help with the chemical analyses is very much appreciated.

Finally I would like to thank the Society members who accompanied me on my return visit. Their tremendous enthusiasm in blistering temperatures made it all worthwhile and prompted me to put pen to paper.

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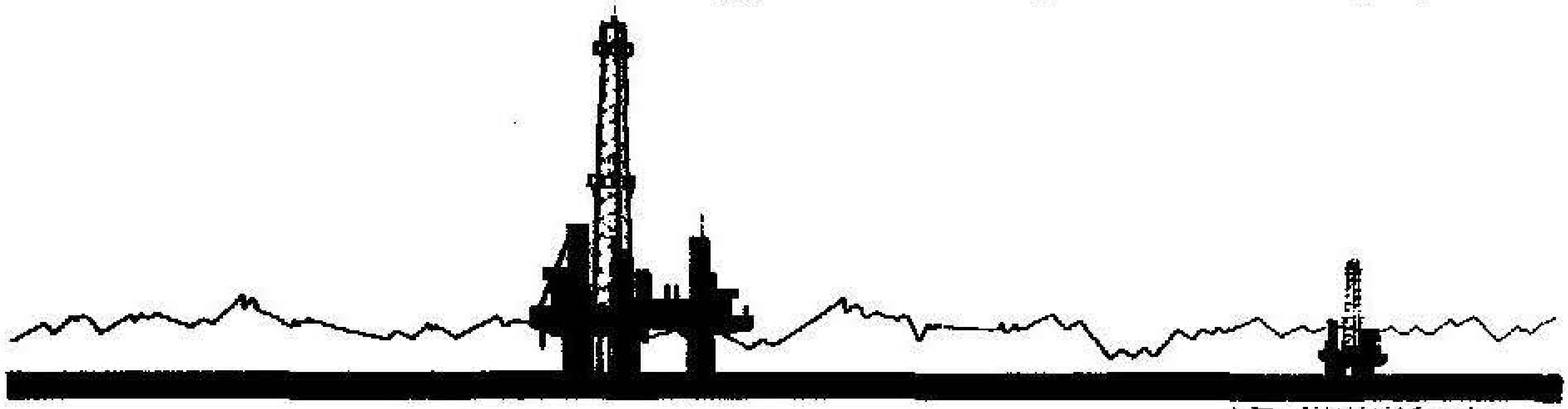
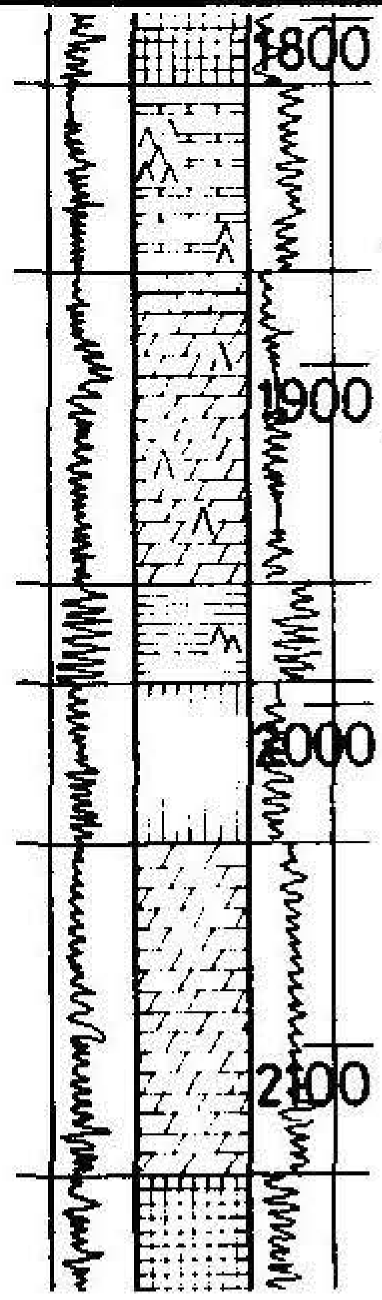


BORING

Homeless rig that squats alone,
Sentenced for its life to roam,
Blind but strong it gropes below,
Searching for a pay or show.
Men that waste here, men that toil,
Most that never see the oil,
Few that love it, none that say,
Some that never see the day.
Sun that blisters overhead,
Sea that often plays at dead,
A long, hot shower at the end of the day,
See a dolphin (miles away).
Lazy fish that eat too much,
Soaring birds that never touch.
Helideck walking, round and round,
Power failures, not a sound.
Stoning fish, eating steak,
Nuts and bolts, what shall I make?
Running up the metal stairs,
Getting mail, stealing spares.
Time that staggers, time that flies;
Heavy boots and empty skies.
Help the sun rise, wish it set,
Cross the day off, don't forget,
Men at work but one at play,
Joy of Joys............... Home today.   **Richard Kerr**



CONGRATULATIONS

We are very pleased to announce the award to David Taylor, our former Secretary, of a B.Sc. degree from Birkbeck College, University of London.
Well done, Dave and good luck with your Master's degree!

Tunnelling at Redcar

David and Shirley Stephens

The building of tunnels is fraught with problems for the engineering geologist. David Stephens outlines below how some of these problems were successfully resolved in a major project in the North-East of England.

1. Introduction

An outfall tunnel was built for the British Steel Corporation as part of the new £500 million Ironworks, incorporating the largest blast furnace in Europe, which first went into production in October, 1979. The outfall discharges the cooling water 1 km offshore and 2 km south of the mouth of the River Tees, the site being chosen chiefly for environmental reasons. The cooling water intake is from the estuary of the River Tees.

2. Site Investigation

The site investigation was made by sinking boreholes offset to the line of the proposed tunnel, those offshore being drilled from a moored platform. The section on the centreline of the tunnel (Fig.1) shows a succession which includes tipped slag, sands, gravels and glacial clays overlying a bedrock of Bunter Sandstone and Keuper Marl series dipping between 3° and 15°at a bearing of 165°. The thickness of the Keuper Marl was found to be considerably less than expected, hence the tunnel under the sea was driven through the underlying Bunter sandstone and mudstone strata instead of the Keuper Marl, as originally planned.

Towards the end of the site investigation a depression, caused by erosion and filled with gravel, was discovered offshore. This meant that the whole tunnel had to be driven 15 m lower than planned, at 65 m below sea level, in order to pass at a safe depth below this low point.

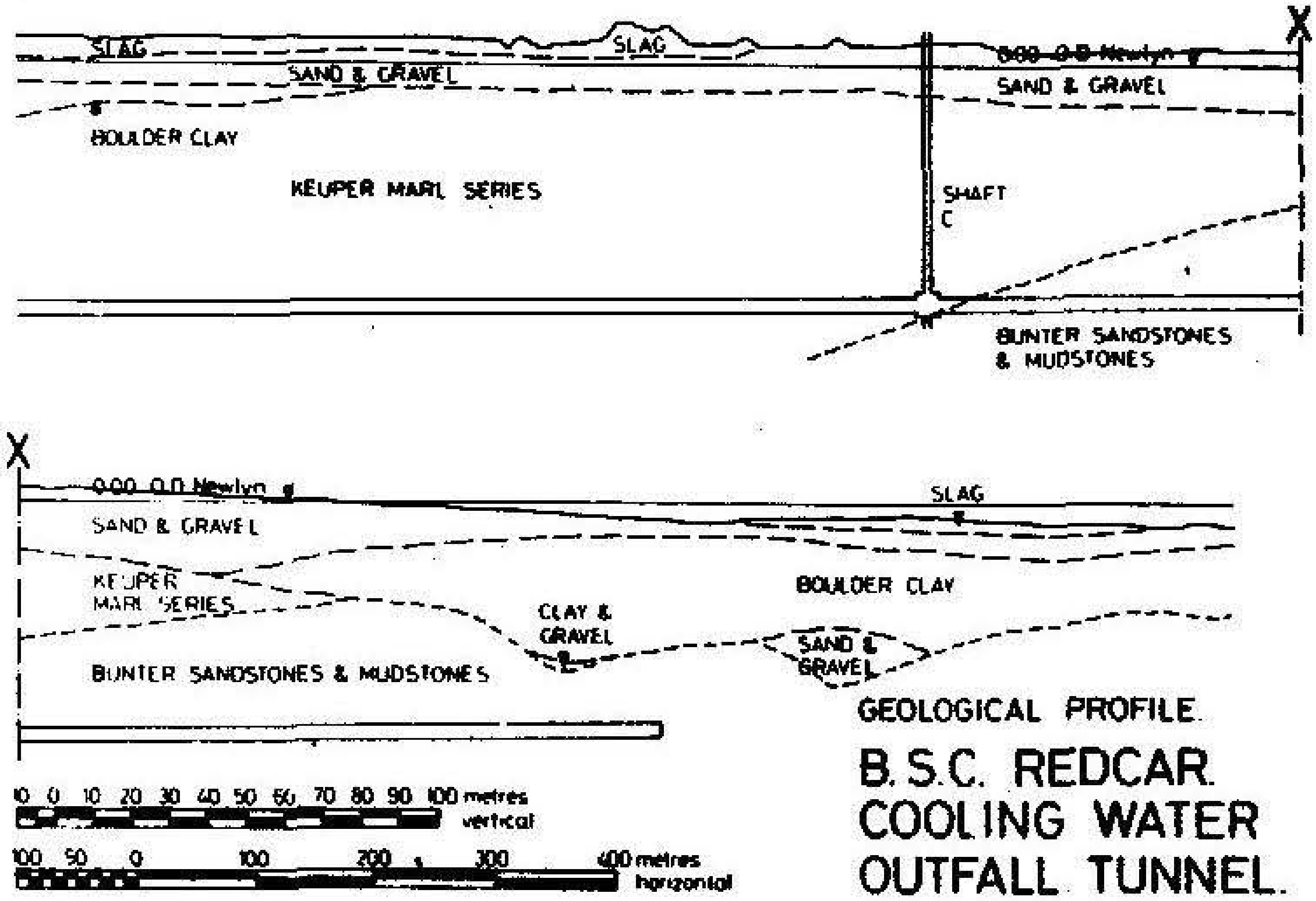


FIG. 1 Geological cross section showing line of the British Steel Corporation Outfall Tunnel, Redcar.

3. The Tunnel

The tunnel was driven by face-header machines in two directions from a shaft (NZ 263567) sunk 70 m deep in sand-dunes, near to the shoreline. The junction of the Keuper and Bunter beds was found to be near the base of this shaft.

The landward drive of the tunnel was driven, almost level, in Keuper Marl at a bearing of about 15°from the dip of the beds. At the base of the Keuper Marl a particularly hard layer of quartzitic sandstone was met, which had a maximum thickness of 1.5 m. (The only borehole to indicate this stratum had shown it to be 200mm thick.) This slowed the rate of tunnel advance considerably for the first 100 m; thereafter, hard layers, generally of siltstone or mudstone, sometimes associated with anhydrite, were seldom greater than 0.2 m thick. Generally the strata were closely banded in colours from dark red to green and included many veins of gypsum.

The seaward drive was driven almost entirely in alternating layers of Bunter sandstone and mudstone, both of which have the strength designation of a moderately weak rock. Over part of this drive the dip of the beds changed from 12° to 3° and, associated with this change of dip, was a zone of extensive fissuring, notorious for its sudden and unwanted leakages of sea water into the tunnel. Over this length more than a third of the time available for driving the tunnel was spent grouting these fissures in order to reduce the inrush of water which, at times, was as much as 1500 gallons a minute. The absence of a cover of boulder clay over the tunnel, had produced a short flow-path to the water entering the tunnel from the sea.

4. Behaviour of Triassic Rocks when Exposed

The Keuper Marl became stronger with depth as the weathering became less, the top 10 metres being particularly weathered. Thus the landward face was more difficult to drive than expected because it had to be driven deeper than originally planned and hence in stronger rock than the machine was designed to cut. However, this material rapidly lost strength when mixed with water and, in this state, quickly became a slurry when rehandled. If the face was left exposed for more than 3 days the mudstone tended to swell and peel off due to the pressure of groundwater flowing to the exposed face. The tunnel was lined with precast concrete segments as the face was advanced in order to provide immediate support to the ground.

The Bunter mudstones and sandstones also disintegrated quickly when exposed to water, creating a highly abrasive mixture due to the high silica content. The depth of highly weathered strata at the top of this series was seldom more than 5 m. The sandstones were generally highly porous, allowing water to enter the tunnel, but the interbedded mudstones were almost impermeable, reducing the vertical movement of water.

5. Rhaetic Bone Bed

Immediately south of the tunnel, about 0.7 km inshore, boreholes for the area of the main foundations of the Ironworks found a Rhaetic layer about 200-400 mm thick across some of the site overlying the Keuper strata, but buried by recent deposits.

6. A Site Visit from the Angle of a Wife and Daughter

In March 1978, during construction of the tunnel, Claire and I donned waterproofs, hard hats and size 8 wellingtons, descended the shaft in the man-hoist, and waded uphill for half a mile to the seaward face in a depth of 150-250 mm of rushing water! We were actually there for a "shove" of the tunnel shield, after the miners had excavated for one ring of the tunnel lining. During the excavation of the Bunter sandstone the face could not be seen for dust - we should have been wearing face masks as the miners were! However, the filter fan system collected the dust efficiently from the face, the "muck" being removed by a conveyor system and taken to the shaft in skips. We were also interested to see the laser beam which defined the line of drive.

7. Achnowledgment

The authors would like to thank Dr. L. M. Lake of Messrs. Mott, Hay and Anderson for permission to publish this report.

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Epitaph for the Lake District Meteorite

The mysterious nodule found near Keswick, variously identified as a diagenetic melt, an intrusive igneous rock and even meteoritic, has finally been deciphered as a slag derived from the smelting of iron ore (British Museum, Dept. of Mineralogy,1982).Despite its humble origins, its beauty is without question and specimens are still available from Lothar Neubert!

TREKKING ACROSS ICELAND

Jean Bulley

A personal account of a holiday undertaken by a Society member to some of the most active and inhospitable areas of volcanic Iceland. Her account provides an interesting comparison for all those who ventured on the Southern Italian expedition in April, 1981.

1. Our Arrival in Iceland

It was already dark when we took off from Heathrow, but we flew back into the sunset already past. First a hairline of grey across the cabin window, then a wider lighter streak that became suffused with rose and gold, so that when we landed at Keflavik at midnight, it was lighter than when we started on our journey.

At Reykjavik our tents were already erected and we were supplied with inflatable mattresses. I had managed to borrow an army sleeping bag, but those of our party who had hired bags in Iceland did better; they were given two down bags each. "You will be here in September, you will need two," they were told. "It will be cold." It was!

Although Iceland is only about the same size as Ireland, the difference in temperature between the north and south of the island is several degrees. The Mid-Atlantic ridge runs from Bouvet Island, 1800 Km. off the coast of Antarctica, up through Iceland in the north. It is not one continuous mountain chain, but is split by deep canyons which run in an east to west direction, and by ridges which rise about 2000m. above the surrounding ocean floor. The Walvis Rise and the Rio Grande Rise are the best known of these, but there is also a rise from north of Scotland to Greenland on which both Iceland and The Faroes outcrop. It is this ridge, holding back the freezing cold water from the depths of the Norwegian Sea and preventing it from flowing around the southern side of the island which causes the temperature variation.

It was the first time that I have ever been on a camping holiday, but there is nothing like jumping in at the deep end. There were eleven of us in the party altogether including Steve Penn, the leader, and his assistant, Anne. The trip was originally planned for students of the Open University, but the cost, at £400 per person, limited the number of applicants, so it was made available to the public and by lucky chance I saw it advertised. Camping was not as uncivilised as it might have been. Some of the sites are provided with naturally heated water, and the loos were all scrupulously clean. At Heirdubreid they were all supplied with deodorisers, but it is a bit disconcerting and chilly to find oneself sitting over a fast flowing stream. Our bus had a double seat for each of us so that we could spread out with our gear, and we were accompanied by a kitchen wagon which provided adequate basic meals and one or two rather odd surprises. Apricot soup and tinned fruit salad in mayonnaise being examples!

2. Heimaey

The first day we were without transport, so we were up at six a.m. to fly to Heimaey. (Fig. 1) This is the small island off the South Coast of Iceland that had an eruption in 1973 which caused the evacuation of most of the inhabitants. The lava flowed down the edge of the town overwhelming some of the houses, destroying the fish processing factory, and partly filling the harbour. Hekla, on the mainland, had started to erupt the week before we came away, and we hoped to see something of its activity from the air. We were like children on Guy Fawkes night eagerly waiting for the fireworks, but all we could discern were four thin separate columns of smoke.

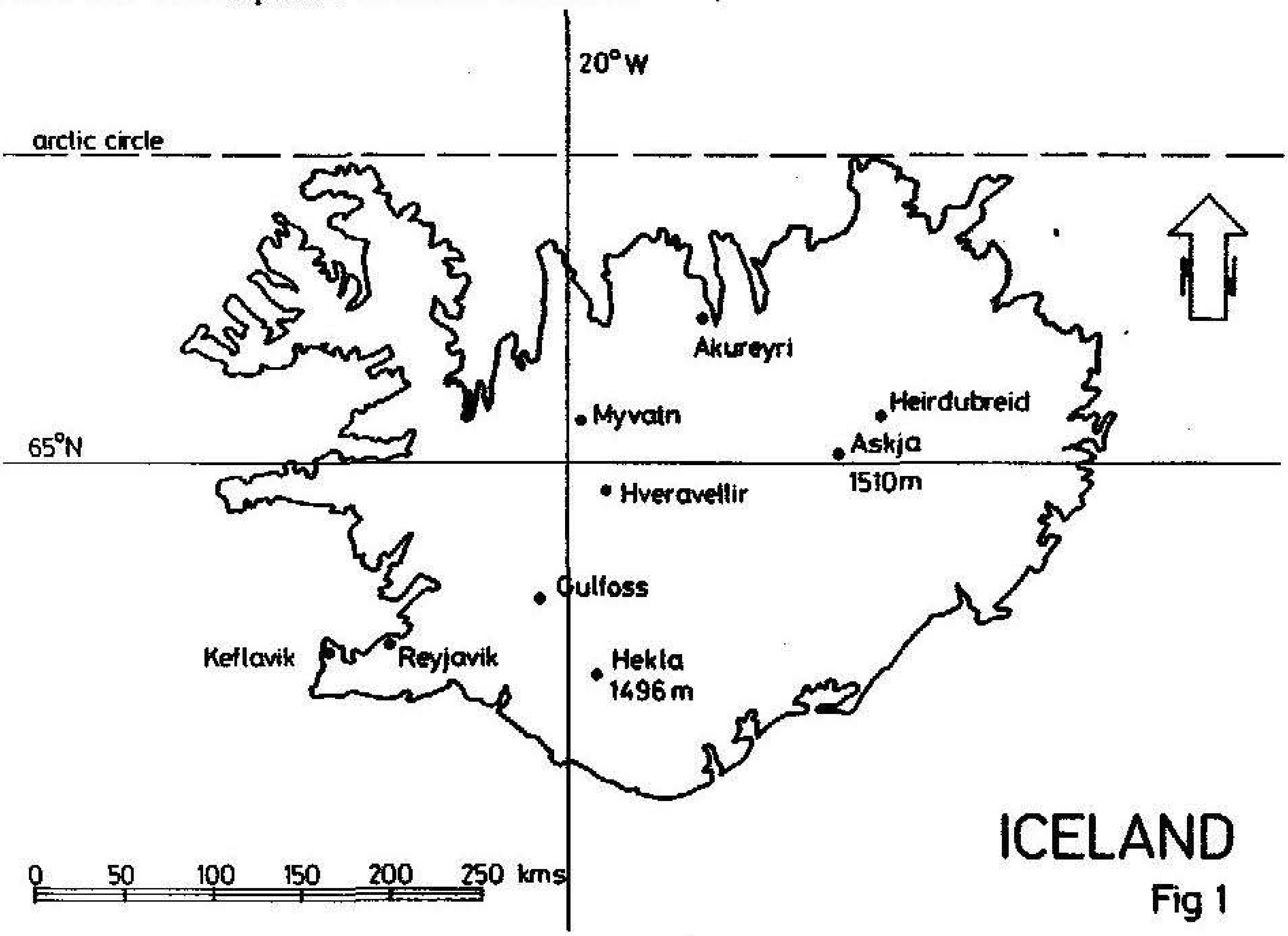

Fig 1

Heimaey airfield is a well-rolled black cinder strip, and we walked straight out over the dark scoria towards Helgafel, which we climbed. This is another older volcano formed under glacial conditions, and which created an island out of what had been a series of sub-glacial eruptions, uniting them into a whole. At the base of the cone are traces of crude fragmented pillow lavas. The climb was strenuous as the loose ash and cinders made walking heavy going, and some of the gradients simply ignored the rules relating to natural angles of slope. There is little difference between sub-glacial and submarine eruptions, since the heat melts the ice; the result being a heap of unsorted pyroclastic and scoriaceous material.

The new volcano, Kirkjufell, which erupted in 1973, has a horseshoe shape, and has been built up from the products of two main fissure eruptions. The ashes contain volcanic bombs of up to 50 cm. across, each sitting in its own little impact crater. The contorted mass of fine grained basaltic lava broke down the crater wall to the south. This is a ropy lava containing phenocrysts of sodic plagioclase, the massive chilled edge made by water from hoses played on the lava by the townsmen in an attempt to hold back the flow and save their homes. We climbed up the steep side of the volcano and around the ridge, where many small fumaroles emit gas and heat. We lit paper by holding it over the vents and watched the evil-smelling sulphur forming all the time around the rims, its bright yellow contrasting strongly with the dark background. It was a terrifying thought that the heat from the rocks on which we sat while we ate our lunch came, not from the sun above us, but from the fiery cauldron below.

On Heimaey we saw a quarry which had snow lenses in it, the ashes acting as insulation. The material is used for road building and as a component of the dark cement from which the houses are built.

3. On Iceland

Although Iceland lies halfway between Norway and Greenland, which both share the same geological features, it bears little or no relation to either of these countries.

It is the newest country in the world. The oldest rocks are scarcely more than 16 million years old, and Surtsey was only born in 1963. Essentially, Iceland is made up of a series of basaltic lava flows, the oldest of which are tilted slightly to the east, while later flows are horizontal. In earlier time it was well wooded, but now there are only vestigial plantations of small straggly birches. The Danish settlers chopped down the trees for their huts and fuel, and overgrazing of the land has prevented their regrowth. All timber has to be imported, as do almost all foodstuffs, except for dairy produce and, of course, fish. There are no clays for brickmaking and no deposits of limestone. Lime has to be obtained by dredging up seashells and crushing them.

The buildings are all constructed from dark cement. To compensate for the drabness, the houses all seem to have brightly coloured rooftops so that from the air the effect is of a child's toy town. Many of the thermally heated greenhouses are given over to the cultivation of flowers and pot plants, and in Reykjavik a lot of rowan trees are to be seen cowering in the shelter of the houses. Main roads are very good, as are those in the towns, but for many months of the year a lot of the island is inacccessible; the roads being continually swept away by meltwater floods and other natural hazards.

In character, the Icelandic people seem to be in direct contrast to their environment. While the scenery is harsh with a terrible beauty of its own, awe inspiring and inhospitable, the people are gentle, polite and friendly. The tradition of the sagas is still alive, and relatively, there must be more good bookshops in Iceland than anywhere else in the world. They have a small but creative theatrical movement, and a surprisingly large number of good sculptors. Icelanders must be fatalistic in their attitude to disasters, or just plain foolhardy. In Heimaey we saw the houses which had been devastated being rebuilt on exactly the same spot.

Iceland is not only liable to direct volcanic action; tremendous floods can occur as a result of sub-glacial eruptions. Fortunately, these have so far been confined to uninhabited areas. The country is also, quite literally, falling apart at the seams. The plate margin runs through Iceland in a south-east to north-west direction.Dilation fissures form almost a herring bone pattern along it, particularly aroundThingvellir in the south-east, where the fissure swarms take a north-west to south-east trend, and at Myvatn where they run from north to south.

These dilation fissure swarms are not volcanic, but form part of a world wide rift system which takes place for the most part under the oceans. It has been thought that dykes which fail to reach the surface may be responsible for them, but there is movement along the rifts varying from one centimetre to one metre a year. We walked along the sides of some of the rifts at Thingvellir where we saw reindeer moss, but no reindeer, although there are some wild ones in the east introduced from Norway in the 18th century.

4. Geysers and Waterfalls

The first part of our tour took us from Reykjavik up to the northernmost town of Akureyri, where we stopped for a couple of hours, and to Myvatn in the north-west (FIG.1). On the way we stopped at Geysir, the place which gave its name to intermittent boiling water spouts. The great geyser which blew a fountain of about 20m. is now dormant, but a smaller, very active geyser of about half that height gave a wonderful display. The streams of hot water deposit silica in beautiful botryoidal cryptocrystalline masses, the colour varying from milky blue-white through to deep yellow and orange. Another geothermal region, Hveravellir, is very different. Here, the deposits are of iron compounds which give strong red and brown staining. There is also a deep blue pool and much gurgling from the gulping mud pools.

ICELANDIC VOLCANIC TOPOGRAPHY

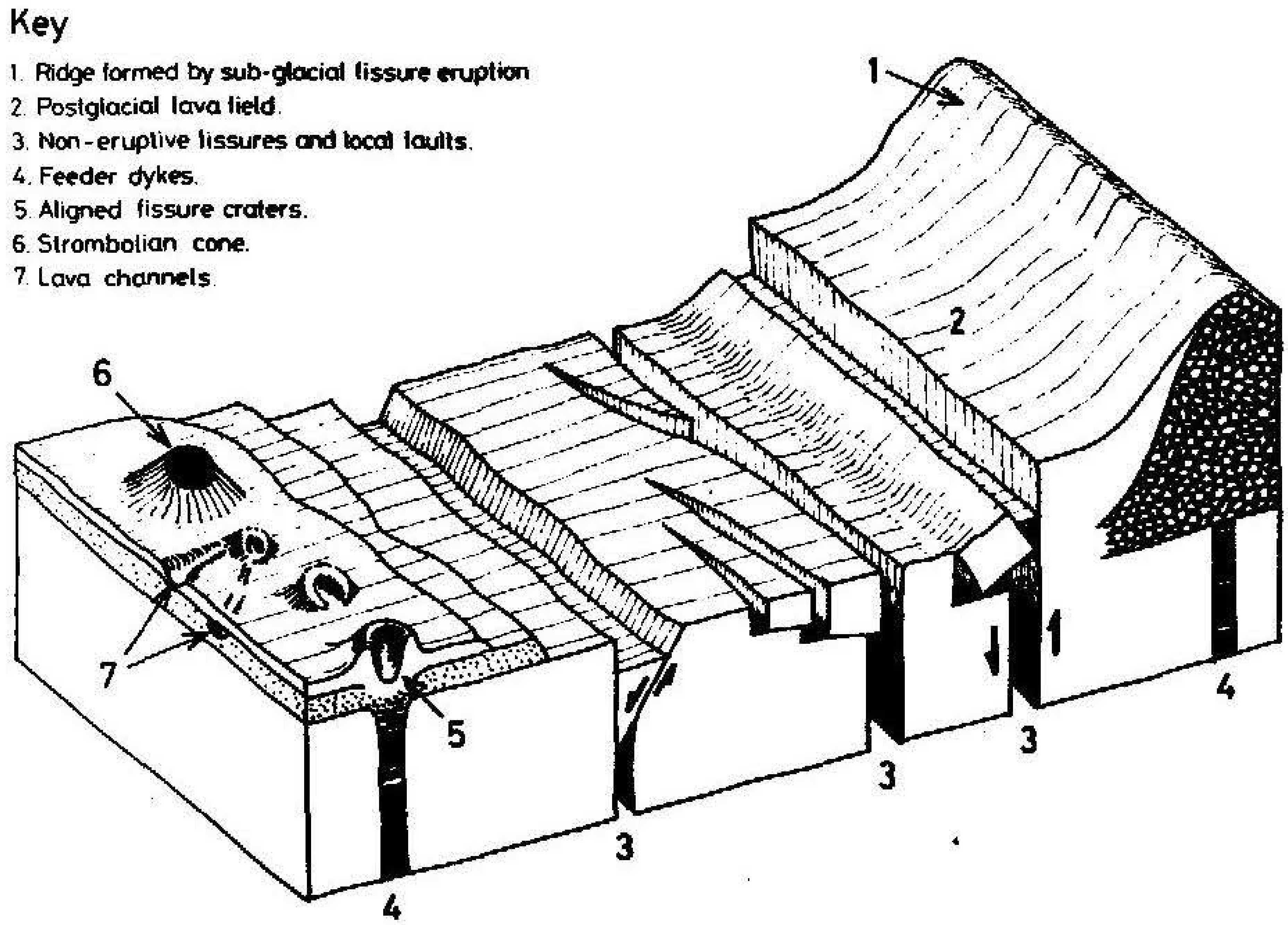

Diagram adapted from Walker, 1965

Fig 2

These geysers are the result of ground water being heated by the rocks below. When they reach boiling point or over, they explode up through the surface carrying minerals picked up both from the surface rocks through which they have flowed, and from the magma beneath. Gases from the magma also add to the explosive force.

We gazed in awe at waterfalls of a beauty and magnitude only to be wondered at. The gorges cut by the fast flowing rivers exposed the different lava layers which average about ten metres each in thickness. The oldest of these layers is Tertiary, and they comprise a mixture of columnar basalts and hyaloclastites from sub-glacial eruptions with some glacial till. The very names of these waterfalls are magic: Gulfoss (the golden waterfall) and Godafoss (the waterfall of the gods); both are really a number of falls occurring together, and at Gulfoss the basaltic columns have an unusual curved appearance.

We camped in the midst of desolation at Hefavatn and scrambled over scree in the rain to see icebergs floating in the lake. The glacier snout which we walked up to, but could not climb, was contorted and crevassed with a capping of last year's snow. Steve and Anne, who had both been there the previous year, were surprised at the change in the glacier. Last year it had been quite smooth and they climbed on to it with ease.

5. Myvatn

We soon became adept at erecting and dismantling our tents. At Myvatn we were lucky for we camped for two nights. There were hot water taps on the camp site for washing and in the fissures are caverns which form natural hot swimming pools. The Myvatn area is one of the most beautiful in Iceland. The name means Midge Lake, but fortunately it was too late in the year for any insects, although spiders which crept into our tents to keep warm kept me busy as chief spider evictor. It was too late also for the famous ducks which breed on the lake in enormous numbers, some species being very rare.

To the north of the lake are great glacio-fluvial hillocks formed by moraine from the edge of the ice sheet. The post-glacial soil is loessic and contains layers of ash, some of these layers being light rhyolitic ash from Hekla in the south. The great explosion crater volcano of Ludent is to the east, but the geology and scenery of the area is dominated by the two Laxa lavas. The older Laxa lava dates from about 4000 years ago. It came from the summit crater of the shield volcano Ketildyngaand damming the valley to form the present lake. The lava has been recognised as having flowed only 2.5 Km. within already existing channels. Most of the other lavas have emanated from fissure volcanoes which can be seen forming lines of craters and pseudo-craters. The latter craters were formed by layers of very fluid lava trapping groundwater beneath themselves, which has then explosively escaped as steam, leaving behind the characteristic rows of small craters.

The chief tourist attraction is the Dimmuborgur, or Lava Castles, a field of gigantic and weird lava piles. It is also an area of serious geophysical research and abounds in monitoring stations. One of these measuring points is in a well on a local farm; this and the neighbouring lake margin act as tiltmeters. As the magma chamber fills up, the pressure causes the land on the north side of the lake to rise. When the well dries up an eruption is imminent. The water of the lake is full of diatoms which precipitate out at the side so that any fall in the level of the lake is visible. We measured the amount of lake margin now above the water level and made it 20 cm. The thermally heated water in the caves below the fissures also gives warning of expected activity. Many of the pools north of Myvatn are now too hot for people to swim in.

6. The Central Plateau

Near Krafla, a volcano which erupts frequently, a diatomaceous earth plant which extracts silica from slurry is found immediately over the plate margin. Low dykes of earth are built to stop any thin lava flows, but there is constant fear of eruption or movement severing the pipes. This is another solfatara area with vast streams of boiling water; one of the few places where one can get scalded and frostbitten simultaneously!

We climbed Askjya; camped at Heirdubreid under the beautiful table mountain; crossed the stony desert where every particle of soil is blown away by the biting winds; travelled down valleys which could serve as a text book on geomorphology. In spring, the whole of the valley floor would be a mass of swirling melt water, but by late August and early September, there were braided channel systems; meanders; near cut-offs; as well as corries, hanging valleys and stepped terraces.

Most of Iceland is a plateau some 600 to 800 m. above sea level from which volcanic peaks rise to altitudes of approximately 1600 m. Every type of volcano is represented: the largest number, however, are of the linear fissure type. The flow of lava from these eruptions is often not uniform, but can alternate between several related fissures in one line. (FIG. 2 & 3).

A TYPICAL FISSURE ERUPTION

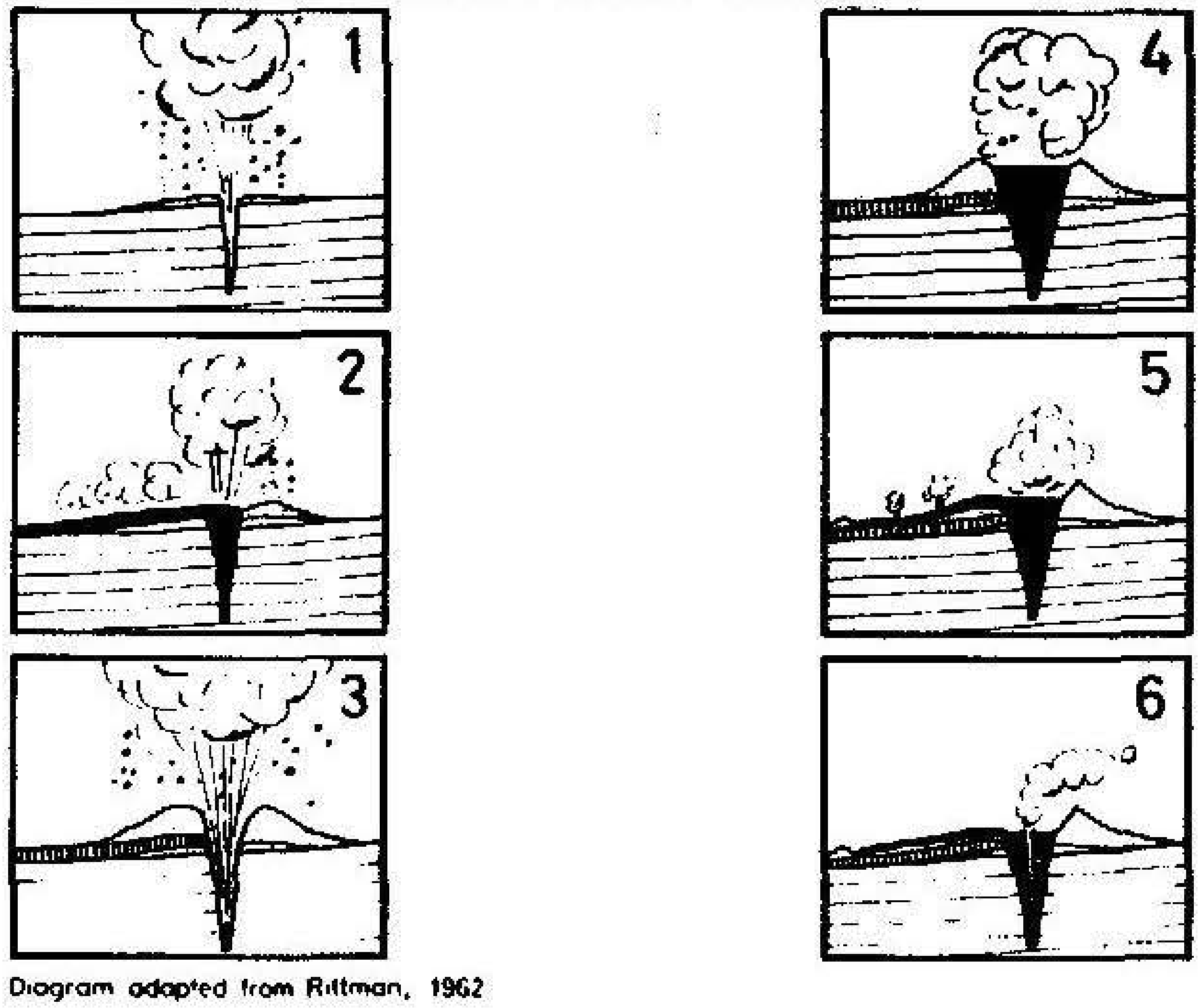

FIG. 3 Sequence of events during a typical Icelandic fissure eruption. Stage 1: Fissure opens and is cleared and widened by explosive activity. Stage 2: Eruption of large quantities of gas-rich, fluid basalt magma. Stage 3: Ejected scoriae and clots of lava construct a row of cones. Stage 4: Lava lakes form in the craters of the cones. Stage 5: Very hot and largely devolatilized basalt lavas break through the crater walls and solidify as pahoehoe flows. Stage 6: Eruptive episode wanes and is replaced by fumarolic activity. After Williams & McBirney (1979).

In the south, rhyolitic lavas are common. Both Askjya and Hekla produce either basaltic or rhyolitic lavas depending on the period that has elapsed between eruptions. The longer the period between eruptions, the more acid the lava. It often changes its composition in the course of one eruption. It used to be thought that this was due to fractional differentiation, but it is now believed that the changes are brought about by partially melted material from the surface mixing with the magma.

7. Hekla

We visited Hekla on the last leg of our trip. This had not been on our original itinerary. Fortunately, it had rained during the last two days and this had laid the ashes. Visitors who had tried to get near earlier in the week were unable to see anything for the clouds of choking dust. We drove until all traces of the road were obliterated by a thick layer of ash. It was like an Arctic scene in negative, the crisp surface layer of ash gave under our feet and we sank into it like soft snow; a black tongue of lava licked the landscape like a slowly creeping glacier.

For miles we trekked over fields covered with anything from 7 to 30 cm. of ash and saw bales of hay put out by farmers for the sheep which had survived. We were able to follow a wire fence marking a farm boundary, then skirted an older lava field and followed a small stream before walking up a dry river bed. At last, across more fields of ash, we could see the new lava still smoking and steaming in the driving rain. We came up to the edge of the lava flow, but did not venture too far on it for fear of methane gas which had killed some of the sheep. It is heartbreaking to see the desolation. We came hoping to see the earth giving birth to new land, but it is not the rocks that feel the pain of labour, but the people who see their homes and livelihood destroyed.

This is just the barest outline of some of the things we saw and did. The trip was not without its incidents. Jill fell in the water as we crossed a stream on stepping stones and injured her arm. Muriel twisted her knee at the same spot. We lost Doris in the Dimmuborgur, and she twisted an ankle. At Krafla some boiling water splashed over my boot and slightly scalded an ankle; but none of these things deterred us or dampened our enthusiasm. We came to Iceland to look at rocks and scenery, but I hope that at the end of the trip, we had also learned more about its people.

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A Special Mention

The Editor and all the contributing authors for this second issue would like to thank Peter Bower, a long serving Society member, for all his efforts in producing the final artwork and diagrams. Without Peter's overtime working, this *Journal* would never have surfaced.

COPPER AND ITS MINERALS

Colin Wilson

This paper is intended to give a brief introduction to copper and some of the more interesting copper minerals. Man's use of the metal together with the formation of some minerals are considered and the more physical characteristics and points of identification are enumerated.

1. Copper in History

Copper in its native form was one of the earliest metals known to Man, and due in part to the ease with which it can be worked, it was probably being fashioned into simple implements as early as the late Stone Age. At the same time its distinctive colour, ranging from salmon-pink when pure to reddish bronze when contaminated, made it particularly attractive for purely decorative and ornamental work. By about 5000 BC the techniques of work hardening, annealing and casting had become well developed and the range of articles being produced had expanded to include more imaginative tools, weapons, nails, tubes, ornaments and statues. Soon after this time, smelting of copper minerals to give relatively pure metal had been established and the amount of available workable material thereby increased. The process was probably discovered by accident during the glazing of ceramics using oxidised copper deposits at high temperature.

Copper combines easily with a number of other metals to form a series of different alloys. One such is bronze, and whilst the earliest examples occurred naturally in Middle Eastern mineral deposits, by 3500 BC a standard tin/copper alloy had been developed. This was both harder than copper and easier to cast, leading to improved weapons and finer ornamental items. Whilst the Romans were spreading these techniques and ideas throughout their Empire, similar usage of these materials was being made in Britain, China and South America. During the millenium following the end of the Bronze Age and the start of the Iron Age, copper and its alloys continued to be used wherever a combination of strength and durability was required. Typical applications would be the casting of bronze church bells, doors, and latterly cannon, and of copper-based wire, pins, printing plates and sheathing for ships..

At the end of the 18th century, the Industrial Revolution gave an upsurge to demand for coal and iron as the machine age began and this led to a corresponding rise in demand for copper. For a short period, Great Britain was the world's largest producer until the high grade deposits of Cornwall and North Wales were exhausted, after which production in North and South America became dominant. The rapid development of the Electrical Engineering Industry over the last one hundred and fifty years has had by far the greatest influence on the increase in demand for copper. The chief use is as an electrical conductor and this accounts for roughly half the total consumption. Other industrial users include the building and construction industry, the car and agricultural industries.

2. The name - 'Copper' and its symbol

The Ancient Romans obtained suplies of copper from Cyprus where it was known as 'aes cyprium'. From this the latin name Cyprus was derived, hence the word copper and chemical formula 'Cu'. The copper symbol is taken from the Egyptian hieroglyph for both copper and eternal life, the ankh. As desirability is a major feature of copper the symbol is used for the metal itself.

3. Copper ore and their occurrence

Copper ore bodies are widely, though not uniformly, distributed throughout the world. They are found in practically every type of ore deposit and are associated with every metallic and rock forming mineral. There are five major mining areas for copper and its ores - the Rocky Mountains and Great Basin area of the USA; the Western slopes of the Andes in Chile and Peru; Central Africa; Central Canada and Northern Michigan; and the Soviet Union.

Many mineral deposits are found as tabular or sheet-like bodies intruded into joints or fissures in the host rock. The physical characteristics of these veins are dependent upon the type of fissure and surrounding rock. This mineralization is generally the result of deposition from a hydrothermal process associated with igneous activity. High temperature solutions containing sulphur and copper intrude into the fissures in the host rock, or in some cases, replace the rock completely. On cooling, the minerals are deposited out as vein-stuff. Butte, in Montana, one of the most productive regions in the world, has such well defined veins. The only native copper deposits of note are found in the Lake Superior district. The ores are either amygdaloid or conglomerate containing copper grains ranging in size up to large nuggets and beyond. The largest recorded single mass of metal weighed 420 tons.

The most extensive deposits worked in the present day are colloquially known as 'porphyry coppers', these are low-grade disseminated sulphide ores containing usually not more than one or two per cent of the metal. Such deposits are found in the South Western United States and in Chile and Peru. The copperbelt deposits of Central Africa resemble the porphyry coppers except that these bedded ore deposits are usually sharply delimited by barren rock walls and are of a much higher grade. In Zambia, for example, oxide mineralization extends down to a depth of some 50 m, below which the leached secondary oxide changes to widespread high grade sulphide mineralization.

With few exceptions, copper-bearing veins (see FIG.1/2) are economically interesting only if the ore has been concentrated by secondary or supergene enrichment. The level of the water table is significant, as above it oxidation and below it secondary enrichment are the dominant processes. The primary copper minerals are oxidised and leached out near the surface by the action of low temperature meteoric water. The sulphides are converted to soluble sulphates and a residual limonite is left on the surface, in the form of a reddish brown gossan or 'iron hat'. Lower down in the oxidised enrichment zone, the descending sulphate solutions react with the original ores to form the two carbonates, malachite and azurite; cuprite and native copper. Below the water table, the reaction between the oxysalts and primary ores gives a deposition of minerals with a greatly increased mineral content. For example, a vein containing chalcopyrite (34.5% Cu) may be enriched by either deposition of bornite, or by more chalcopyrite and even by the conversion of the latter mineral to chalcocite (79.8% Cu).

Beneath this secondary sulphide enrichment (or 'chalcocite') zone, the vein is in its primary condition where the mineral content is usually at too low a concentration to allow economic working. In arid regions with a maritime climate, wind-blown sodium chloride may combine with the copper to form atacamite and brochantite, both important sources of ore at Chuquicamota, Chile.

4. Some Common Copper Minerals

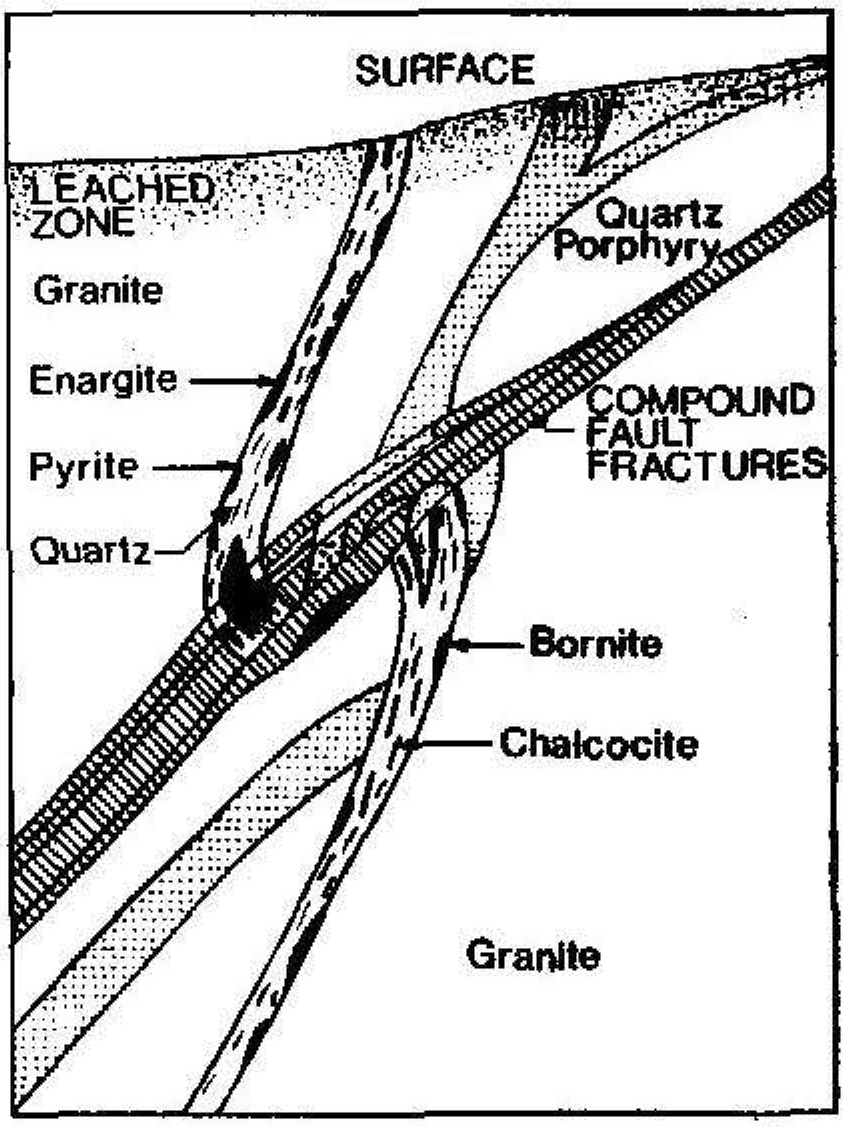
In the following section, a brief descriptive narrative is given for chalcopyrite, the chief primary ore of copper. Also included are malachite, an important and decorative carbonate and cuprite, a copper-rich oxide ore. The three sulphides bornite, covellite and dioptase complete the range of major copper minerals, the last named being particularly decorative.

(a) Chalcopyrite (Copper pyrites or 'Fools' gold) $CuFeS_2$

Geographically the most widely distributed copper mineral, this sulphide of copper and iron is one of the most important sources of the metal. It occurs as a primary mineral in hydrothermal vein and replacement deposits and is associated with pyrites, cassiterite, sphalerite, galena and various gangue materials. In the porphyry copper deposits it is disseminated with bornite and pyrites, and is also found in pegmatite dykes and contact metamorphic deposits.

The common form is usually in compact masses. Occasionally it is found in small tetrahedral crystals of the tetragonal system, resembling cubes or wedges, which may be twinned. The distinctive features of chalcopyrite, include its brass yellow colour (often tarnished to bronze or iridescence), metallic lustre, and greenish black streak. It is distinguished from pyrites by its deeper yellow colour and inferior hardness (H $3^1/_2$ - 4); and from gold by its superior hardness and brittleness. It is soluble in nitric acid, and of medium weight (SG 4.1 - 4.3).

The theoretical composition is about 34.6% copper but this figure may be as low as 2% or less in terms of rock concentration. Even such low grade ores can be recovered economically under favourable conditions.The mineral is unsuitable for cutting. The name is derived from the Greek word meaning brass and from pyrites.



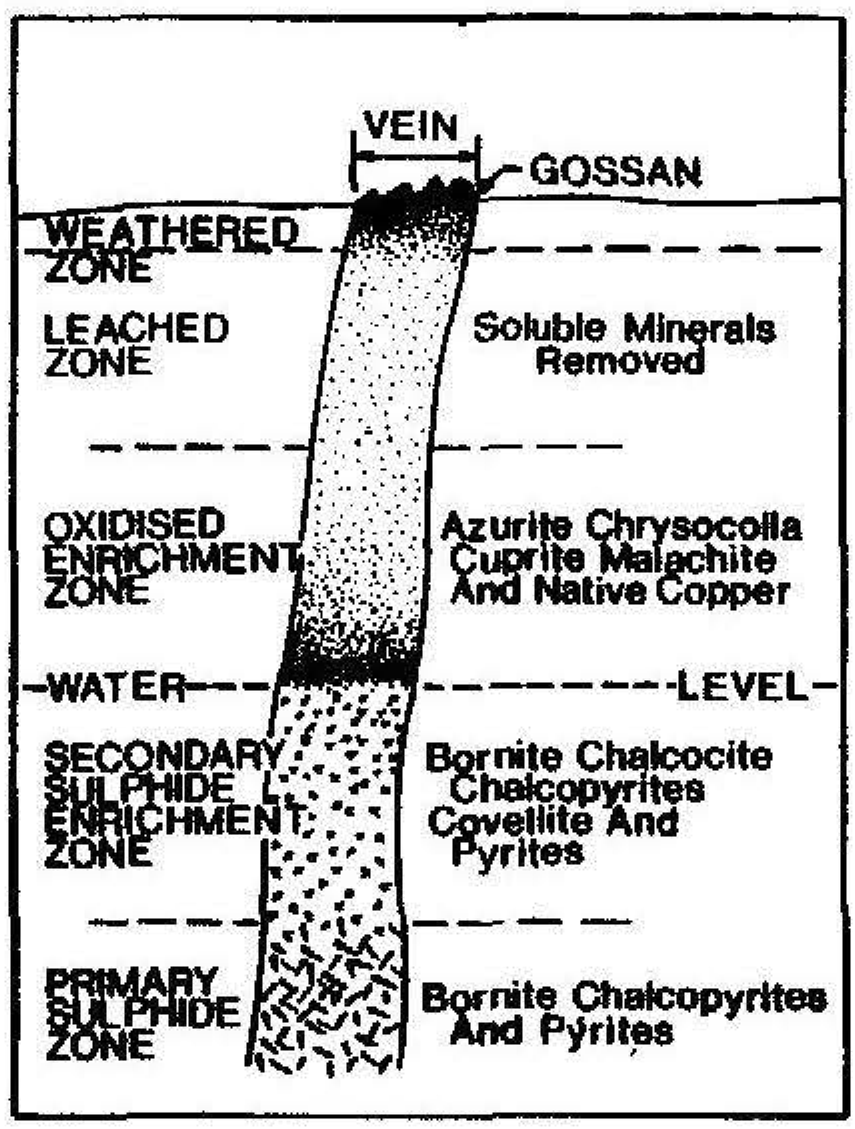


FIG. 1 Diagrammatic cross section through the Anaconda (Butte, Montana) copper deposit. Adapted from CDA publication No. 46 (1967).

FIG. 2 Supergene enrichment in a typical copper lode.

(b) Malachite $Cu_2CO_3(OH)_2$

The most abundant oxidised copper ore, this hydrated carbonate usually occurs in copper veins associated with limestone. Although crystallizing in the monoclinic system, it commonly occurs as radiating aggregates with botryoidal surfaces and may sometimes be pseudomorphic after azurite. On cutting and polishing, the characteristic concentric bands of blackish green colour are particularly distinctive. It possesses a medium hardness and weight (H $3^1/_2$ - 4; SG 4) and displays a light green streak with a variable lustre.

It was the source of much of the copper mined in ancient times, probably because of its conspicuous appearance in outcrops. The pure mineral contains 57.7% copper but because of its high colouring power and solubility it often stains and encrusts large areas of worthless rock disguising it as a valuable mineral. When found in large solid masses its worth is not only as a mineral ore, but also as a semi-precious stone taking a high polish. It is used for jewellery, table top veneers, vases and other works of art - particularly in the U.S.S.R. In smaller pieces, cutting is generally as a cabochon, beads or in flat pieces. The name is derived from the Greek word for mallows, a wild green plant of the genus *Malva*.

(c) Cuprite (Red Oxide of copper) (Cu_20)

Cuprite, a cuprous oxide, is rarer than the other oxidised ores but because of its high copper content (88.8%), it is of greater value. It occurs as a supergene mineral in the upper zones of more oxidised copper ore deposits and is assocated with limonite, native copper, malachite, azurite and chrysocolla.

This cubic mineral crystallizes as eight or twelve-sided crystals, but can occasionally occur in a reddish brown fibrous habit, know as chalcotrichite ('plush copper'). The colour varies from shades of deep red through brownish red and purple to almost black, and in the translucent crystal form shows a ruby red colour for which it is called 'ruby ore'. It is hard and heavy (H $3^1/^2$ to 4; SG 5).

Cuprite is distinguished by its crystal form, high submetallic to adamantine lustre, brownish red streak and association with limonite. It is used as a minor ore of copper, is unsuitable for cutting and is named after the Latin for copper - *cuprum*.

(d) Bornite (erubescite) Cu_5FeS_4

Bornite is a sulphide of copper and iron with a variable copper content, say 55.5%. It is fairly common but occurs usually in subordinate amounts, in association with other sulphides in hypogene deposits. Less frequently, it is found as a supergene mineral in the upper zones of the copper vein. It crystallizes in the cubic system, commonly as cubes or eight-sided octohedra, but is usually in a massive form. It is heavy and of medium hardness ($H^1/_2$ to 2, SG 4.5 - 4.76), the freshly broken surface has a copper-red to bluish-brown colour (horseflesh ore) which tarnishes to variegated blues and purples. This accounts for its name of 'peacock ore'.

It has a metallic lustre and greyish-black streak. Bornite is distinguished by its characteristic bronze colour on a fresh fracture and by its purplish tarnish. It is altered readily to chalcocite and covellite. Although an important ore of copper, it is not suitable for cutting. Bornite was named after the German mineralogist Von Born (1742-1791).

(e) Covellite (Covelline) (CuS)

The cupric sulphide (66.4% copper) is chemically less stable than the cuprous sulphide chalcocite. Whilst found in hydrothermal veins, it is more common in the secondary enrichment zone in association with other copper minerals, primarily chalcocite, bornite, chalcopyrite, enargite, from which it is derived by alteration. Primary covellite is known but uncommon.

Although a hexagonal crystal, the tabular crystals are rare and it usually occurs as flexible plates or foliated massive in the form of coatings or disseminations through other copper minerals. The stiking deep indigo to blue-black colour, which when moistened turns to an easily recognisable purple, is characteristic. Its streak is lead grey to black, hardness $1^1/_2$ - 2 and specific gravity 4.6 - 4.76. It is distinguished from bornite by its cleavage and from chalcocite by its colour. A relatively rare ore mineral, except at Butte, Montana, it is used as a minor ore of copper and was named after N. Covelli (1790-1829), the discoverer of the Vesuvian covellite.

(f) Dioptase (Emerald Copper) $Cu_6(Si_6O_{18})6H_2O$

An uncommon mineral found in the oxidised parts of copper sulphide deposits, in calcite veins and druses. Dioptase is a rhombohedral cyclosilicate occurring in well-defined short prismatic crystals of the trigonal system, in crystalline aggregates, or massive form. Its distinguishing features are an emerald green colour, translucent crystals and association with copper minerals. Hardness and weight are medium (H. 5.0; SG 3.3), its lustre vitreous, and its streak green to greyish blue.

This mineral is too rare to be of use as a copper ore, and it is valued as a semi-precious stone. The best specimens are found in the Tsumeb Mine, South West Africa. It may be faceted, cabochon-cut or tumbled. The name is derived from the Greek words meaning 'through' and 'to see', since the cleavage was first observed by looking through the crystals.

5. A Last Word

Copper minerals have always been much valued by mineral collectors and lapidarists for their colourful beauty. Their bright colours belie their crucial economic value to many Third World countries today. Copper has so many uses in modern industry that its future on the world metal markets seems assured.

6. Acknowledgements

The author would like to express his appreciation for all the assistance provided by Mr C. Lunt (Copper Development Association), Mr. R. Hobson (Zambia Appointments Ltd) and Mr. J. Hughes (Rio Tinto Zinc Services Ltd).

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The Language of Rocks

Peggy Innes

Drawing on her long experience as a language teacher, Peggy Innes explains the sometimes tortured origins of those geological terms we use so often.

We consider geological terms from different points of view. For the experienced geologist, words and meanings are so closely associated that he may not consider breaking down words as he would break down rocks. The novice may, by knowledge of languages, be able to deduce the meaning of a term otherwise incomprehensible.

What are the main origins of geological terms? Obviously some are based on names of places and early discoverers. Andesite is derived from the Andes, sillimanite from Dr. Silliman the American chemist and dolomite from Dolomieu, the famous eighteenth century French mineralogist; but anorthosite does not come from the North, nor did Dr. Olver discover olivine.

Frequently the basis of these words is from Greek, Latin and old European languages such as Old Teutonic - many of these having already been derived from the original Sanskrit. Some words are from other languages such as the Hawaiian word Aa for a certain type of lava or the word basalt itself which, according to Pliny, comes from the Ethiopian *Basal* meaning ferruginous rock. Even a thorough knowledge of Sanskrit is unlikely to be of much use to us as many terms are derived from a mixture of sources. For example, diorite, a hybrid igneous rock, derives from the Greek *Di* meaning two and the Sanskrit *Ayos* meaning metal, the latter word appearing again as the Latin *Aes*, the Old English *Ora* and eventually into modern geological terminology as Ore.

Then too, some names have been given as a result of errors made centuries ago. According to Pliny, it was not Obsidais who was the discoverer of obsidian but Obsais. The mineral group name pyroxene (Greek *Piur* - fire plus Greek *xenos* -foreigner) was based on the mistaken belief that pyroxenes were supposedly foreign to igneous rocks.

Obviously in such a welter of geological nomenclature, one needs to be selective in order to illustrate these various lines of derivation. Accordingly, I have concentrated solely on the geological words associated with igneous and metamorphic processes, a list of which appears overleaf.

Geological Word	Derivation
Igneous	Latin Ignis - fire
Mantle	Latin Mantellum - cloak
Magma	Greek Masso (root Mag -) - to knead - a reference to the viscosity of such melts.
Plutonic	Pluto - Greek god of the underworld
Batholith	Greek Bathos - depth & Litho - stone
Hypabyssal	Greek Hupo - under & Abussos - depths
Sill	Old English Sylle - shelf
Dyke	Old English Dich - ditch
Vein	Latin Vena - vein
Granite	Latin Granum - grain and later Italian Granito - grained : alludes to the coarse grained crystalline appearance.
Tor	Gaelic Torr - bulging hill
Phenocryst	Greek Pheno - shining & Krustallos - crystal
Porphyritic	Roman mythical giant - Porphyrion: a reference to the large phenocrysts seen in such rocks.
Matrix	Latin Mater - mother or womb
Volcanic	Vulcan - Roman god of fire: Vulcanic was the spelling up to this century.
Lava	Italian Lava - stream
Vesicle	Italian Vessica - blister
Amygdale	Latin Amygdalus - almond
Scoria	Latin Skoria - refuse from Greek Skor meaning 'dung'.
Pyroclastic	Greek Piur - fire and Klastos - break
Lapilli	Italian Lapilli - walnut
Rhyolite	Greek Rheo - I flow
Ignimbrite	Latin Ignis - fire & Nimbus - cloud
Tachylyte	Greek Tachys - swift & Lytos - fusible: the common spelling of 'tachylite' is therefore strictly incorrect.
Plagioclase	Greek Plagio - oblique & Klastos - break
Orthoclase	Greek Ortho - conventional & Klastos - break
Anorthosite	Greek An - not & Greek Ortho - conventional
Syenite	Egyptian town Syene now Aswan
Pyrite	Greek Piur - fire: alludes to the sparks given off when pyrites is struck.
Ilmenite	Russian Ilmen Mountains
Kaolinite	Chinese Kao - high & Ling - hill hence Kao-ling mountain where first substantial deposits were found.
Cataclastic	Greek Kata - down & Klastos - break
Mylonite	Greek Mylon - grinding mill
Andalusite	Spanish province Andalusia
Cordierite	Named after Dr. P.L.A. Cordier - a French geologist.
Schist	French Schiste but originally from Greek Skhistos - split
Porphyroblast	Roman giant Porphyrion & Greek Blastos - growth.

These terms I have selected are important for a full understanding of the definitions and processes involved in the genesis of igneous and metamorphic rocks. They may not all be accurate as there are often alternative etymological possibilities. Once one starts to search out the origins of words, still older languages and interpretations begin to appear. As in all search for knowledge, the more that is discovered, the more is shown as yet to be discovered.

Fossil Sites in and around Alton

Cyril Potton

An outline account of some fossiliferous localities within the local Upper Greensand and Chalk outcrops all of which can readily be visited on a single day excursion.

1. Introduction.

Atherfield, Ludlow and Lyme Regis all feature prominently in a geologist's thinking as being areas where fossils are readily collected. The present writer, however has found that the Alton area can, with patience, yield faunas equalling those of such classic localities. The advantage of local collecting sites is that they can be revisited without vast expense and in this way a varied and thus representative fossil fauna is soon discovered.

2. Geological Structure

Alton lies at the north-western extremity of the Wealden anticline (I.G.S. sheet no. 300). To the east, towards Farnham and Guildford, the varied Cretaceous and Tertiary strata dip steeply northwards under the London Basin whilst to the south, the beds plunge westwards at very low angles beneath a broad expanse of chalk downland. This shallow westerly dip produces the characteristic north-south strike of the Gault Clay, Upper Greensand and Chalk through villages such as Oakhanger, West Worldham, Selborne and Hawkley.

3. Sedimentary Environments

The two sedimentary horizons mentioned in this account are the Upper Greensand and the Chalk both of which have extensive and important outcrops within the Alton area. The changing environments of deposition during this period of Cretaceous history had a marked effect of the faunal assemblages and ultimately, after selective preservation, on the types of fossils now found in the Alton area.

Our story begins 100 Ma ago when over much of southern and south-eastern England, Lower Greensand deposition was terminated by the extensive Albian marine transgression. The associated deepening of the seas at this period led to a change from dominantly arenaceous Folkestone Beds to the basinal marine mudstones of the Gault Clay. Initially, this clay facies covered the Alton area and is well exposed at the Honey Lane Brickworks, east of Selborne (SU 767343).

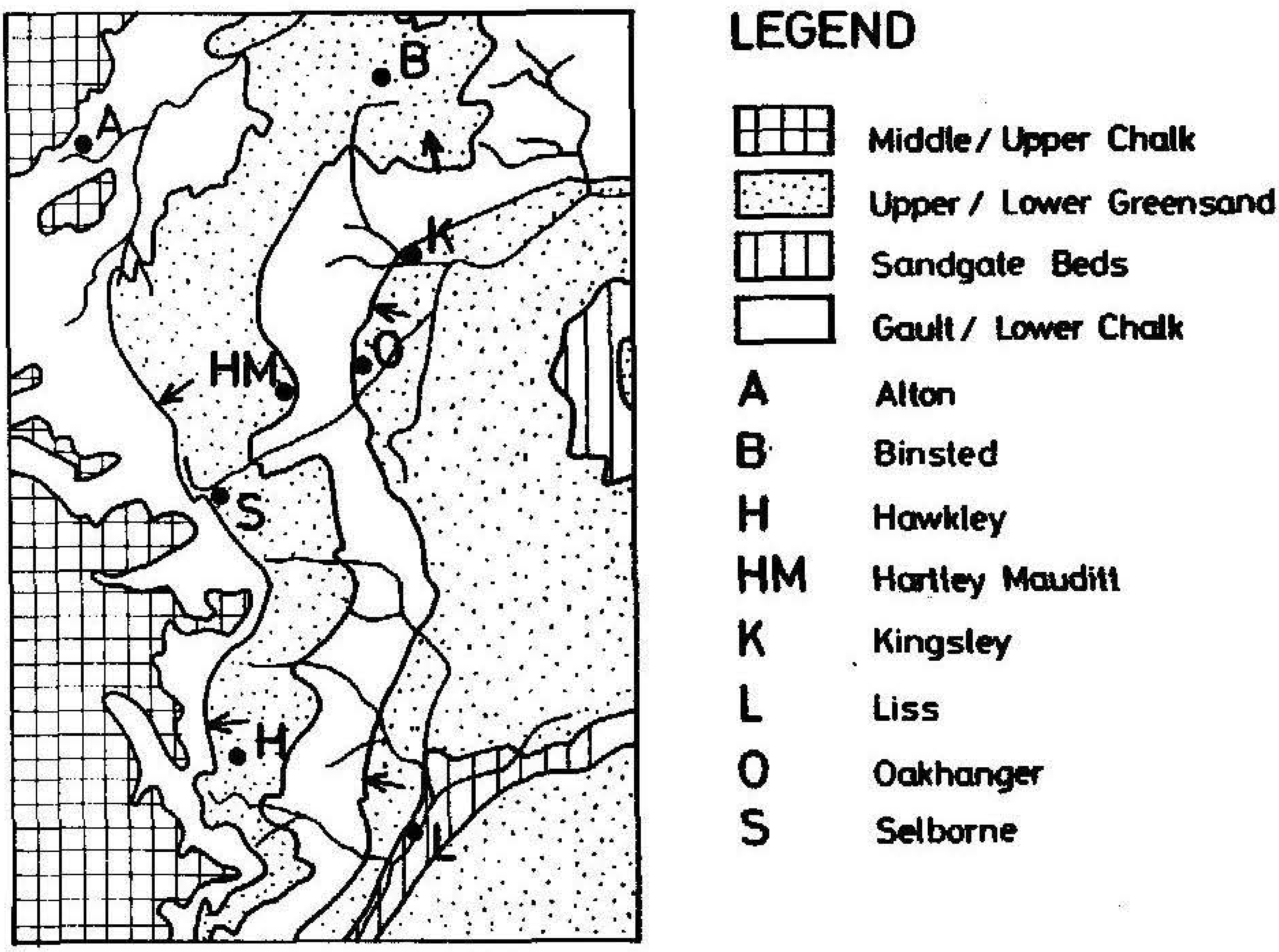
However, to the west, the Gault clay facies is laterally replaced by glauconitic sands of the Upper Greensand Formation. This coarser clastic material was being derived from western source areas of mainly Upper Palaeozoic age in Devon and Cornwall. Later, these continental shelf sands prograded eastwards as far as Sevenoaks during a minor regression of the Gault Clay sea. In the Alton area, therefore, Upper Greensand was deposited on top of the deeper water Gault Clay facies. The contact between these two Albian horizons is not exposed in the area although the Gault Clay at Selborne is noticeably silty in its uppermost layers.

In the Alton area, the Upper Greensand contains little glauconite and is largely represented by a pale coloured sandstone mostly cemented by silica but also containing small amounts of clay, calcareous matter and flakes of mica. The abundant, though often poorly preserved, fauna of bivalves and sponges together with the occasional ammonite is in keeping with a shallow water environment at the edge of a shelving landmass.

The late Cretaceous period in the Alton area is dominated by the gradual transgression of the Chalk sea towards the north and west. At its contact with the Upper Greensand, a glauconitic sandy marl indicates the proximity of landmasses to the west. However, this so-called Chloritic Marl soon gives way to the familiar soft, friable white limestones whose initial grey tint, due to minor mud content, is progressively diluted upwards through the succession.

The fossil faunas of the local Chalk are strong indicators of the environments within this unique Chalk sea. Most of the microfossils within the Chalk consist of coccoliths, a variety of planktonic algae now found in clear tropical seas at depths of 50 - 200 metres (Hancock 1975). Within these warm shallow waters, normal salinities are indicated by the presence of echinoids, brachiopods and ammonites. The accumulation of thixotropic calcareous ooze on the Chalk sea bottom severely restricted the variety of bivalve genera although certain taxa such as *Inoceramus, Pycnodonte* and *Spondylus* solved the problem by "ooze floating" on their inflated left valves. Intense bioturbation found in many local chalks, for example at Lower Froyle Quarry (SU 762447), supports these soft substrate conditions.

ALTON AREA GEOLOGY



4. Upper Greensand localities

(a) Sunken lane at Hartley Mauditt (SU 751360)

A good exposure of white, strongly jointed, calcareous malmstone is seen at the top of this typical Hampshire sunken lane. Exposures occur on both sides of the lane which cuts down through the Upper Greensand scarp. At the base of the scarp. undulating topography has resulted from the extensive landslipping of the sandstone over the underlying Gault Clay.

With patience and minimal hammering as the rock is exceptionally friable, good specimens of zonal ammonites *Mortoniceras inflatum* and *M. commune* (FIG.1) have been extracted. Over several visits, these important finds have beem supplemented by bivalves, often fragmentary although occasionally perfect, of genera such as *Chlamys*, *Entolium* and oyster *Exogyra*.

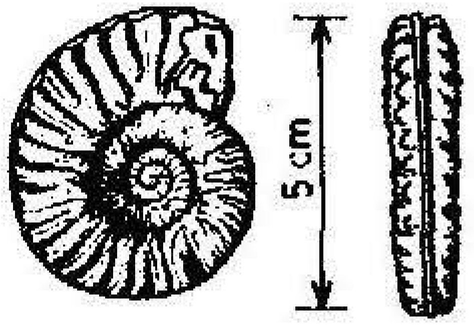


Fig 1

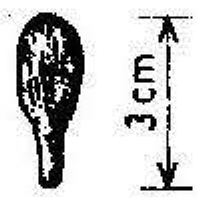


Fig 2

FIG. 1 ***Mortoniceras commune*** *from the Upper Greensand, Hartley Mauditt.*

FIG. 2 ***Tylocidaris clavigera*** *from the Upper Chalk, Anstey.*

(b) Minor cutting S.E. of Rhode Farm (SU 759340)

Close to the road from the Brickworks to Selborne village on a sharp bend there occurs a minor exposure of Upper Greensand above an extensive scree fall. This is close to the Gault Clay - Upper Greensand contact and the nearby farm track is probably cut into the clays.

Upper Greensand is commonly confused with the local Chalk facies but is readily distinguished by its sandy texture in the hand and the absence of any major effervescence with cold dilute hydrochloric acid.

This small locality has yielded a perfect specimen of *Acanthoceras rhotomagense* measuring 20 cm across as well as small siliceous sponges such as *Doryderma* sp. and *Hallirhora* sp.

(c) Other localities

The Upper Greensand is well in several sunken lanes in the Selborne district notably in the Blackmoor road just east of Selborne (SU 745334) and south of Hawkley Church at SU 746288. The village of Binsted, in the northern sector of the area, has several scattered outcrops along the Blacknest road to the east at SU 791411 and again, further into the village, at SU 784411. At all these additional localities bivalves of the types already mentioned predominate although rare sponges and even rarer gastropods have been found by the writer.

5. Chalk localities

Good exposures of Middle Chalk are already well known to Society members at Lower Froyle Quarry (SU 762447) where further research work is now in progress. Palaeontological work is already supporting the view that the upper part of the Lower Chalk is also exposed within these quarry workings. The author, therefore, has decided to concentrate on the less familiar exposures of Upper Chalk within the Alton area.

(a) The Flint Line at Anstey

This linear outcrop of Cretaceous flint nodules has been exposed in two ploughed fields between SU 716411 and SU 721417. Best visited after ploughing, the fossils occur as isolated flints or enclosed within large irregular flint nodules cleaved apart by the constant ploughing. The flint concentration is noticeably aligned along the southern boundary of the periglacial drift deposits marked on the Alresford I.G.S. Sheet 300. Presumably, many of the flints have accumulated at the foot of the Holybourne Downs by solifluction processes already well documented at Lower Froyle Quarry to the east (Carolan *et al* 1981).

The Upper Cretaceous fauna derived from the flints at Anstey is exceptional in its variety of echinoids. Both Senonian zonal echinoids, *Micraster cortestudinarium* and *M. coranguinum*, have been found as well as good specimens of the regular echinoid *Tylocidaris clavigera* (FIG.2) and irregular echinoids *Conulus albogalerus* (FIG.3) and *Echinocorys Scutata*.

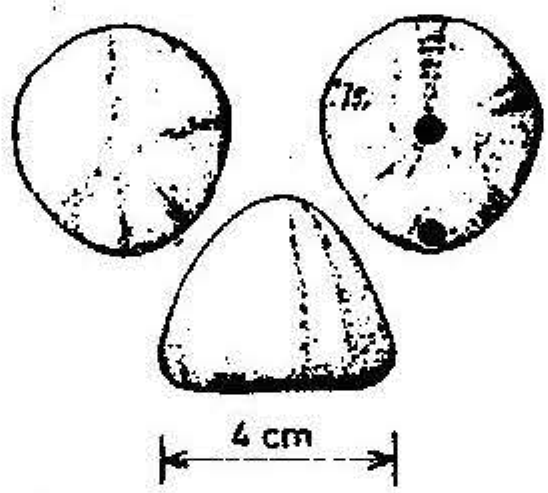


Fig 3

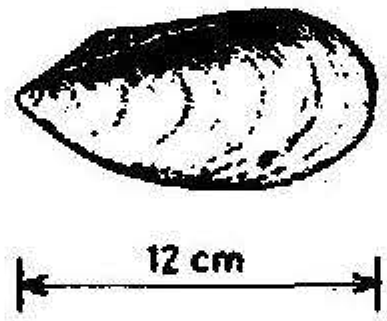


Fig 4

FIG. 3 ***Conulus albogalerus*** *from the Upper Chalk, Anstey.*

FIG. 4 ***Inoceramus labiatus*** *from the Upper Chalk, Four Marks Railway Cutting.*

(b) Railway Cutting at Four Marks

This location is situated between the bridge at SU 673354 and Medstead & Four Marks Station on the now preserved Mid-Hants Railway or "Watercress Line". The cutting is 400 m. long, 20 m high and wide enough to accommodate two standard gauge tracks. At the time of writing, prior to the proposed re-opening of the line to Alton, the floor of the cutting is littered with an extensive fall of Chalk blocks throughout its length. It is from these blocks that the fauna has been collected and no climbing up the cutting sides has been found necessary.

The most important finds so far include the zonal echinoid *Micraster cortestudinarium* and abundant well preserved specimens of the bivalve *Inoceramus labiatus* (FIG.4). Further investigation of the prominent flint horizons in the cutting sides and of the isolated nodules on the former trackbed may yield an even richer fauna.

This location is now actively undergoing renovation in preparation for the extension of the "Watercress Line" to Alton by 1984. Casual visits, therefore, are now being restricted and permission must be sought from the Winchester & Alton Railway Co. Ltd. at Alresford Station.

6. Acknowledgments

The author would like to express his appreciation to all those who have helped in the preparation of this paper. Particular thanks are due to Stephen Froud for the use of his car, Lothar Neubert for advice on the preparation of the transcript and Tony Cross at the Curtis Museum, Alton for his assistance with the fossil identification.

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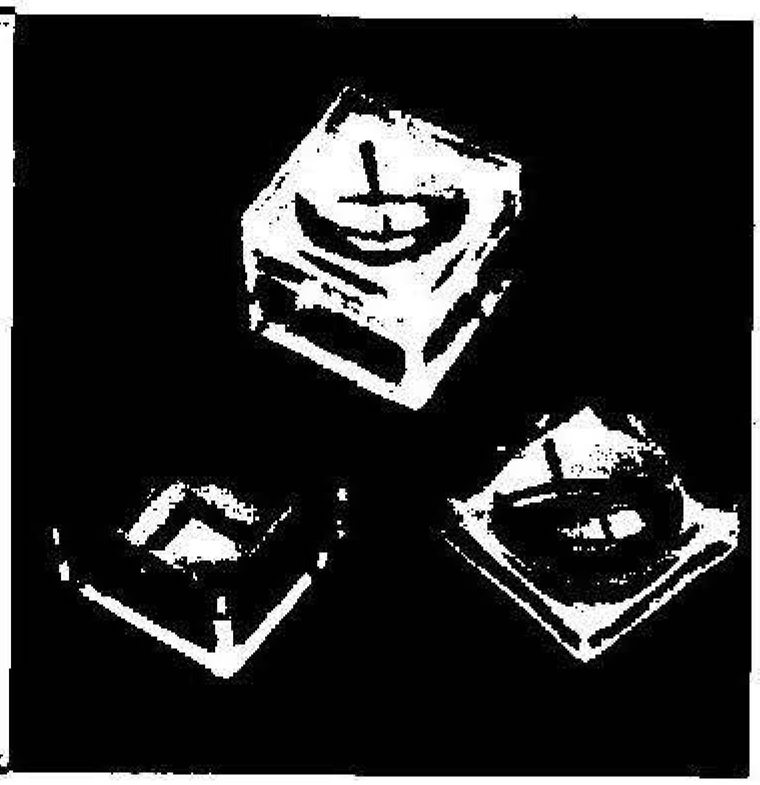
1. Limestone 2. Plutonic 3. Bristle Cone Pine 4. Detrital, Chemical/Organic 5. Leonardo da Vinci 6. Syncline 7. Jurassic 8. Gastroliths, Stomachs 9. Goniatites 10. *Lepidodendron, Calamites* 11. *Lingula* 12. Remanié 13. Bajocian, Callovian, Kimmeridgian 14. Crinoidea 15. Mountain Building 16. Dunes 17. Low Tide, Continental Shelf 18. Schist, amphibolite and serpentine-gabbro 19. Silurian inliers 20. Dreikanter, desert 21. Loess, Brickearth 22. Continental Drift 23. Gondwanaland 24. *Didymograptus extensus* - Arenig, *Didymograptus bifidus* - Llanvirn, *Dicranograptus clingani* -Caradoc, *Dicellograptus anceps* - Ashgill. 25. Orthoclase, Oligocene, Andesite, Phyllite, Bytownite, Muschelkalk.



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