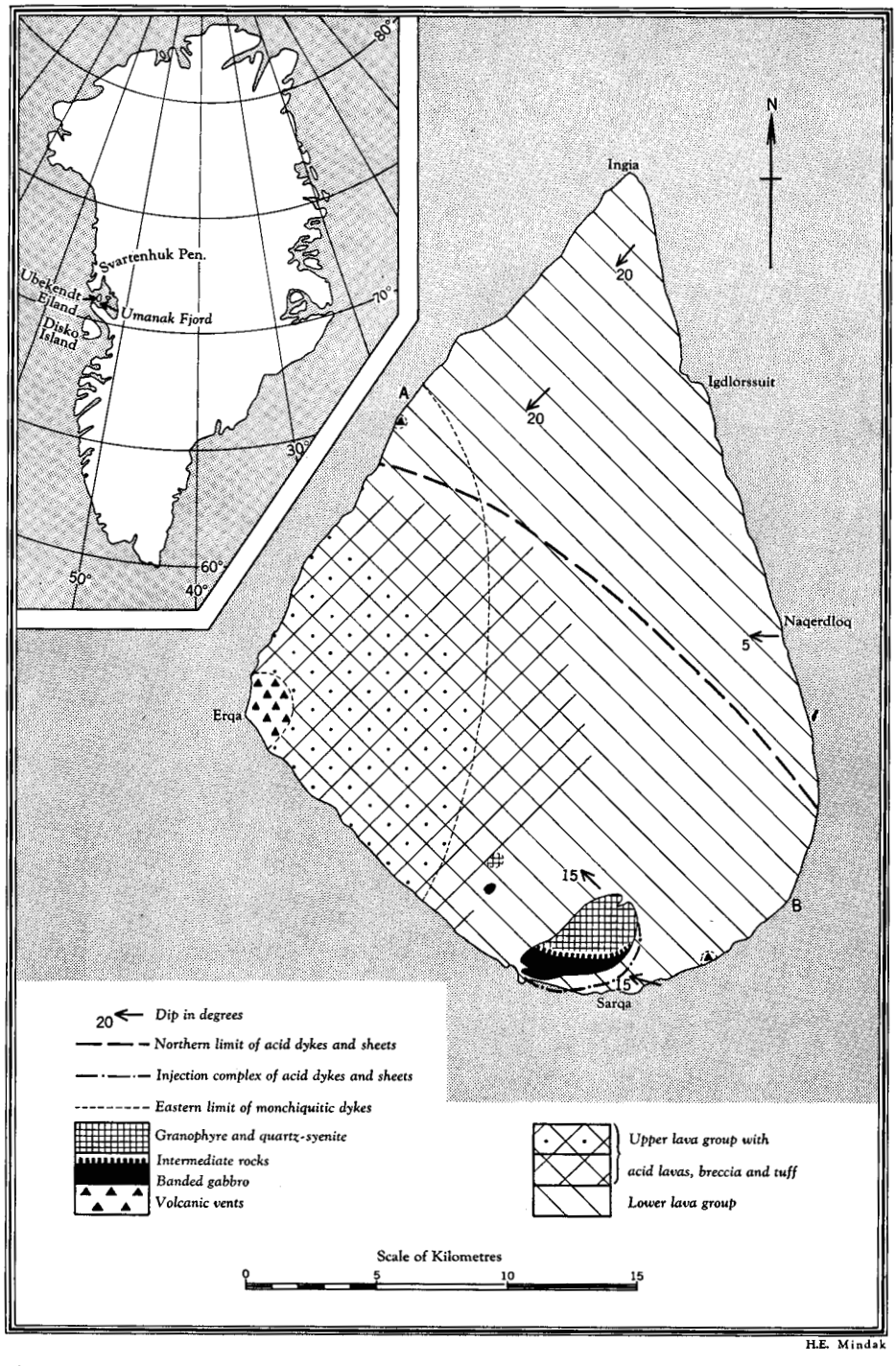

Fig. 1. Geological sketchmap of Ubekendt Ejland, West Greenland (location shown on inset). A. B — southern limit on northwest and east coast respectively of picritic intrusions. Occurrence of pyroclastic rocks in the upper group of lavas is indicated by dots.

GEOLOGICAL RESULTS OF FOUR EXPEDITIONS TO UBEKENDT EJLAND, WEST GREENLAND

Harald I. Drever*

Introduction

THE rocks in many arctic localities are particularly well exposed, and the evidence they provide of the principles of their derivation is correspondingly well displayed. Ubekendt Ejland, in the Umanak Fjord region of West Greenland (Fig. 1), is one such locality. The geology of this island is so rich in variety and so fundamentally significant that it can be predicted, without exaggeration, that it will become a classic geological locality. The principal purpose of this paper is to help to substantiate this view by recording the main geological discoveries of four expeditions (1938, 1939, 1950, and 1957) and to demonstrate in a broad conspectus how these discoveries have disclosed some lines of petrological enquiry that not only have proved to be rewarding (in terms of published and partly completed research) but also seem likely to be very fruitful in the future.

A preliminary outline of the geology of this island has already been published (Drever and Game, 1948) and it is one of the objects of the present paper to amplify and amend this earlier work. Abundance of magnesia and forsteritic olivine (Game, 1942) in the lower group of lavas, and in many of the minor intrusions that cut them, was regarded as the problem most likely to justify detailed investigation (Drever, 1956). Petrographical information obtained during this work has led to the examination (or re-examination) of many olivine-rich rocks in the Hebridean area of Scotland and in others parts of the world (Drever and Johnston, 1957, 1958, 1959). It can now be recorded that almost the maximum possible information has been assembled about the natural occurrence and variations in olivine-rich minor intrusions from the two areas — Ubekendt Ejland and the Scottish Hebrides — where they attain their most varied and prolific development. The research so far has disclosed a number of anomalies in these rocks that are not explicable in terms of the classical theory (Bowen, 1928) of crystal accumulation (cf. Drever, 1952). One of the anomalies is the fact that many of these rocks are abnormally rich in lime.

But it is not only in the development of magnesia- and lime-rich intrusions and lavas that Ubekendt Ejland is of special importance geologically. Nowhere else in the whole volcanic province, stretching from Disko

* Senior Lecturer, University of St. Andrews, St. Andrews, Scotland.

Island in the south to the Svartenhuk Peninsula in the north, is there a central intrusive complex as in the south of Ubekendt Ejland, or a suite of dykes, lavas, and pyroclastic rocks, such as those on its west coast. It is quite possible that the results of a detailed investigation of both these areas may rival in importance what has already been contributed by the rocks in the east and north.

A brief report of the 1950 expedition was published in *Arctic* (Vol. 3, No. 3) as Northern News, but no account of the writer's work on Ubekendt Ejland in 1957 has yet been published. This was mainly a detailed investigation of the eastern cliffs from a base camp on the outskirts of the village of Igdlorssuit, from which several Greenlanders were recruited. For transport an outboard-powered dingy was used. This expedition received generous financial support from the Carnegie Trust for the Universities of Scotland. It also owes much to the help of Danish residents in Greenland and the kayakers of Igdlorssuit (Drever, 1958).

Geological structure and the lava succession

The key to the structure of Ubekendt Ejland is a flat median valley bordered by mountains to the north and south (Fig. 6). It can be readily discerned on air photographs in the Danish Geodetic Institute that this median valley has been to a large extent structurally determined. It is a flat syncline with a western pitch that is responsible for the occurrence toward the west of the uppermost rocks in the succession. The lowermost rocks are at Ingia, the most northerly point.

Apart from some slumping near the coastal cliffs, which has changed the inclination of the lavas particularly in the area immediately south of Igdlorssuit, no evidence has been observed of any major faulting or block displacements. Regional dips are commonly between 15 and 20 degrees but in some places are appreciably steeper. The total thickness of the lower group of lavas can be estimated, on a simple trigonometrical basis, along a line normal to the strike from Ingia to a point on the coast northeast of Erqa. This thickness amounts to at least 5 kilometres. The characteristic lavas of the group are olivine-rich, picritic types, which are developed on a vastly greater scale than anywhere else in the world, with the possible exception of the unknown Hawaiian succession below sea-level. If to the lower group on Ubekendt Ejland the upper is added, the thickness of the visible volcanic pile is one of the greatest ever recorded and yet neither the base nor the top of the succession is exposed. Noe-Nygaard (1942) has estimated that the total thickness of the lava pile in Svartenhuk Peninsula, to the north of Ubekendt Ejland, is 10 kilometres. The extent to which picritic flows are there represented is unknown.

The lavas of the lower group represent flood eruptions from fissures now occupied by picritic dykes. Four such dykes that pass upward into flows have been observed. The lavas and pyroclastic rocks of the upper group represent the products of later central eruptions from a volcano at

Erqa. A large remnant of the neck of this volcano can now be examined for a distance of more than 3 kilometres in the high coastal cliffs at that point.

Lavas and pyroclastic rocks

In addition to their richness in olivine the lavas of the lower group are characterized by a spectacular development of vesticular banding (Fig. 4). It must be emphasized that the zeolitic component of the vesicles constitutes a very considerable part of the bulk aggregate. A typical vesicular band has been chemically analyzed. The most significant figures of percentages by weight are: SiO_2 40.99, Al_2O_3 14.63, CaO 13.86, Na_2O 2.06, H_2O+ 7.18. If such a magma were to crystallize under relatively high hydrostatic pressure, calcic plagioclase would be precipitated in place of lime zeolites. This line of enquiry will be pursued in the light of the experimental evaluation of the hydrothermal stability relations of the plagioclases and zeolites (Goldsmith and Ehlers, 1952; Fyfe, Turner, and Verhoogen, 1958, pp. 167-8; Koizumi and Roy, 1958). In some places along the magnificent cliff section the dark-green picritic rock is represented only by lenses round which sweep the highly vesicular banded facies. At other places individual flows, up to 25 metres thick and exhibiting very little vesiculation, are separated from flows above and below by a reddish, ropy slag or thin layers of tuff, but some sections of highly vesicular flows over 100 metres thick have no such evidence of any pause in lava eruption, and an enormous volume of lava must have been erupted in this part of the Umanak Fjord area in a relatively short space of time. The thick pile of vesicular picritic lavas in the northern part of Ubekendt Ejland may thus represent the tangible remains of an event unique in the history of volcanic activity during geological time.

The upper lava group, which is characterized by much greater diversity, includes olivine-free basalt, monchiquite, trachybasalt, and trachyte. Rhyolite (and pitchstone) is common toward the top of the succession in frequent association with acid pyroclastic rocks. Nepheline-basalt has been found near the acid neck at Erqa.

Minor intrusions

Approximately fifty minor intrusions of picritic type cut the lavas on the cliffs and precipitous mountain slopes of the east and northwest coasts (A to B, Fig. 1). Their occurrence is confined to the lower group of lavas but their distribution is a regional one that bears no relation to the major intrusive centre in the south. The majority of these minor intrusions are vertical or steeply inclined dykes, the remainder being inclined sheets and sills, but the inclination is often variable and the same intrusion may in one place form a vertical dyke and in another an inclined sheet or even a sill.

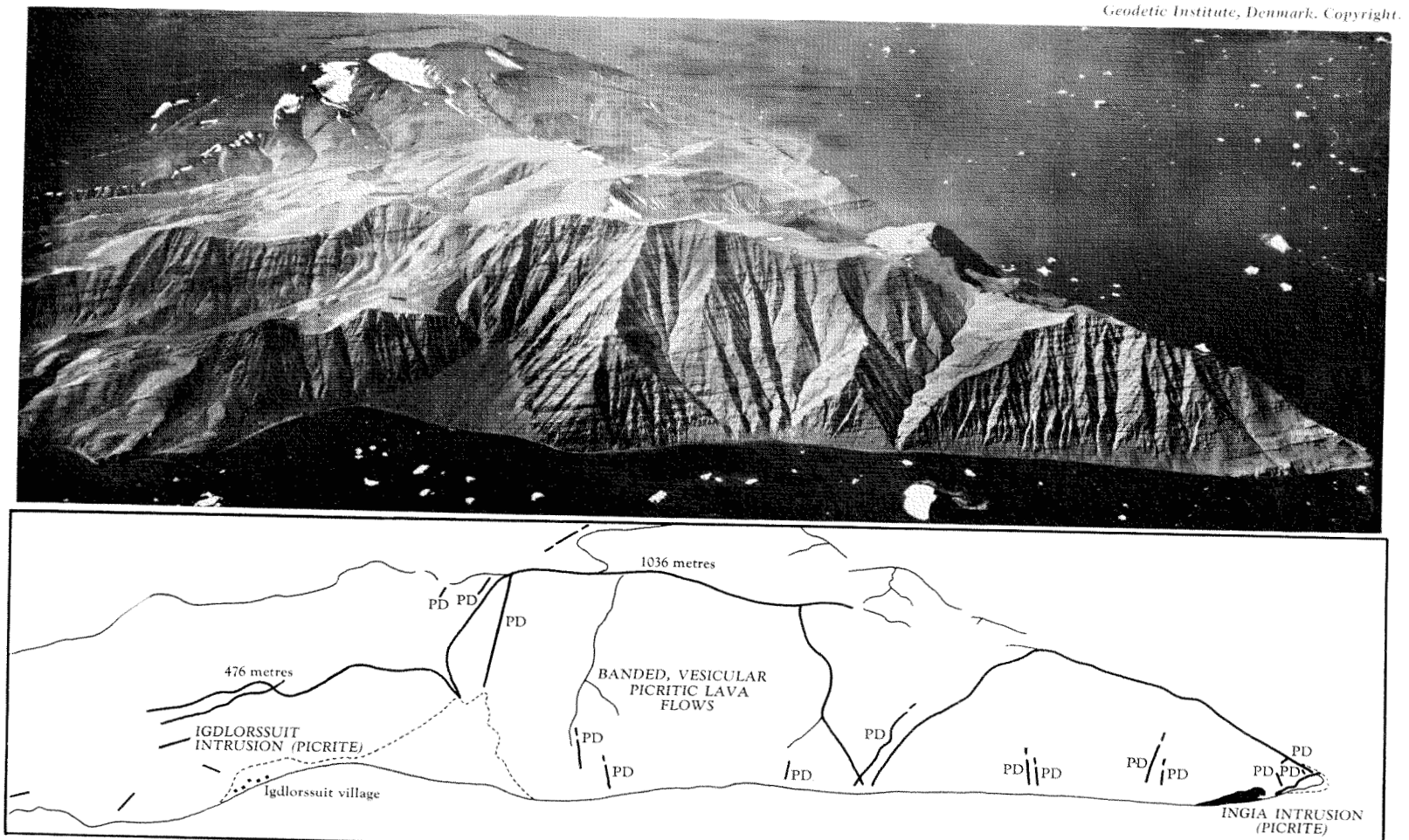

Fig. 2. Air photograph (reproduced by kind permission of the Director, Geodetic Institute, Copenhagen) of the northern part of Ubekendt Ejland taken from the east. Key sketch below shows the location of the picritic intrusions (PD — picritic dykes). The banded vesicular, picritic lavas, which are dipping southwest, are also cut by many other minor intrusions.

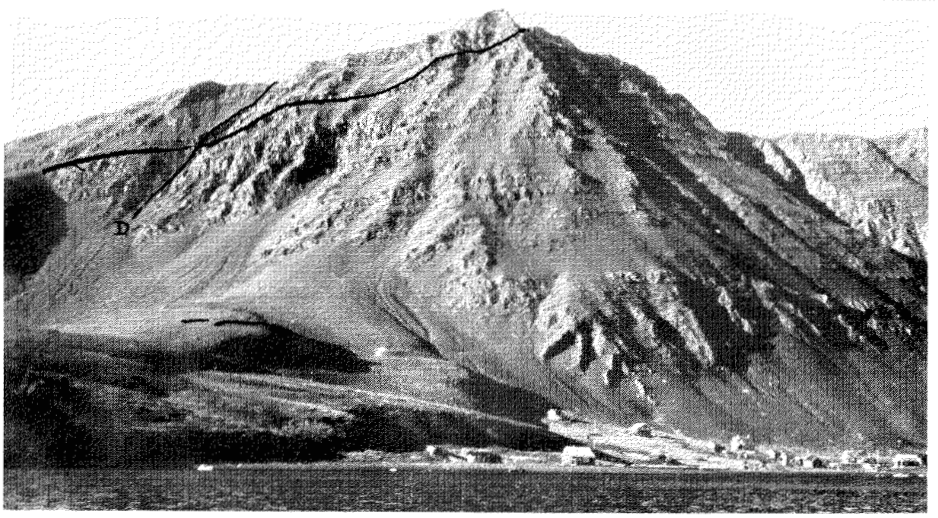

Fig. 3. The northern part of the Igdlorssuit Intrusion (shown in black) crossing the peak above the village. Coastal slumping has brought down sections of this intrusion to a point near the village. It is cut by a later basaltic dyke (D).

Irregularity in trend and in width tends to be characteristic of such intrusions. North of Naqerdloq they are beautifully fresh rocks, but farther south they become progressively less fresh, apparently owing to the proximity of the southern complex. All these intrusions are so perfectly exposed that a complete series of specimens can be collected from one quickly cooled, fine-grained margin to the other. No finer array of intrusions of this type has been recorded elsewhere, not even in their classical area of development in the Cuillins of Skye. In addition to variations across such intrusions, lateral variations for distances up to 2 kilometres can be examined in some sheets and vertical variations up to a height of 1 kilometre in several dykes. It should be mentioned, however, that in most dykes the examination of vertical variation over heights of more than 30 metres can only be achieved if the investigator is safeguarded by a fixed rope.

Fortunately, the two finest of these picritic intrusions are also the most easily accessible. They have now been designated the "Igdlorssuit Intrusion" (Figs. 2 and 3) and the "Ingia Intrusion" (Fig. 2), the former corresponding with and including an extension of what were previously referred to as Sheet 2 and Sheet 3; and the latter to Sheet 4 and Dyke 3 (Drever, 1956.) The Igdlorssuit Intrusion is now believed, on the basis of a very detailed field examination in 1957, to be a single, irregular intrusion twice repeated just above the village by slump faulting parallel to the coast that has brought it down from near the top of the mountain peak above. In favourable early morning light this olive-green intrusion can be discerned crossing the eastern face of the mountain. Igdlorssuit is thus not

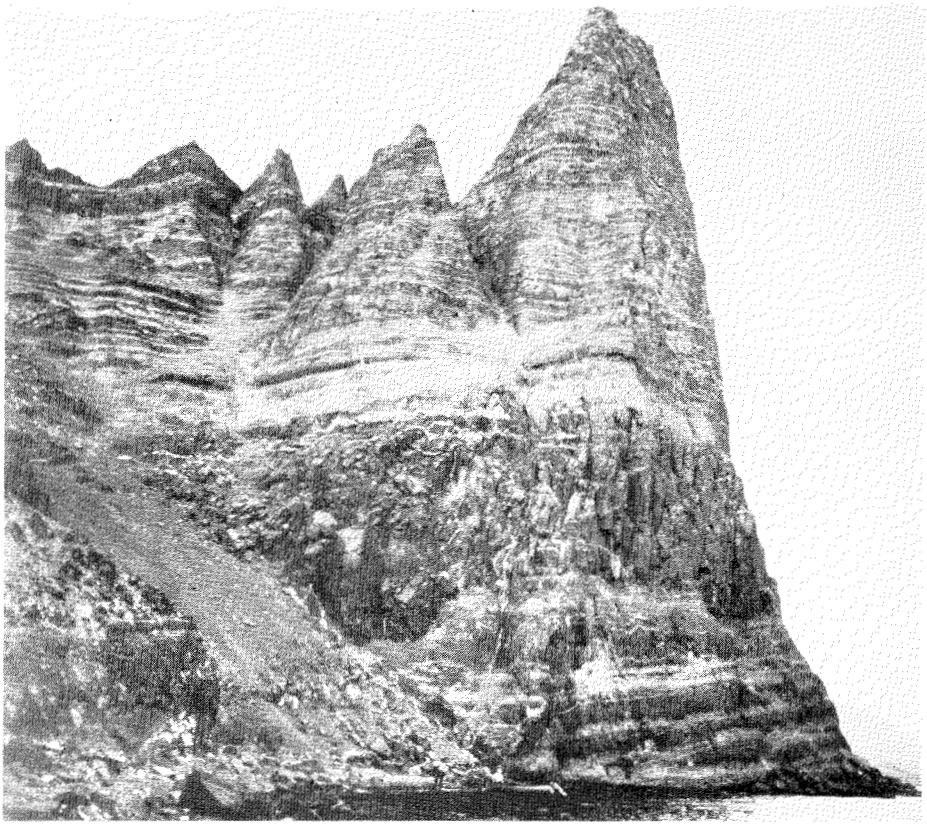

Fig. 4. Prominent peak (150 metres) on coastal cliffs 6 kilometres south of Igdlorssuit. The upper two-thirds of this cliff section are characterized by banded, vesicular, picritic flows in which zeolites are a major constituent. The lower third is characterized by more massive picritic flows in which zeolites are a relatively minor constituent. Dingy (with outboard motor) and two Greenlanders at the foot of the cliff show scale.

only one of the most picturesquely situated villages in Greenland but also a site of much geological distinction. From the crumbling, coarse-grained centre of this intrusion small but clear gem-olivines (peridots) are collected by the villagers. This gravel is about 90 per cent pure, fresh olivine. The Ingia Intrusion is the largest of its kind on the island and is banded near the top (Fig. 5). Specimens of the quickly cooled upper margin were collected in 1957 and the change in crystallization of the olivine and plagioclase from this margin to the centre has been traced in a complete series of specimens.

An important but not yet fully understood characteristic of the margins of most of these intrusions is that the olivines are thinly tabular and skeletal (Drever and Johnston, 1957) and the quickly cooled selvages are picritic, not basaltic. Only toward the centres of the thickest intrusions, including

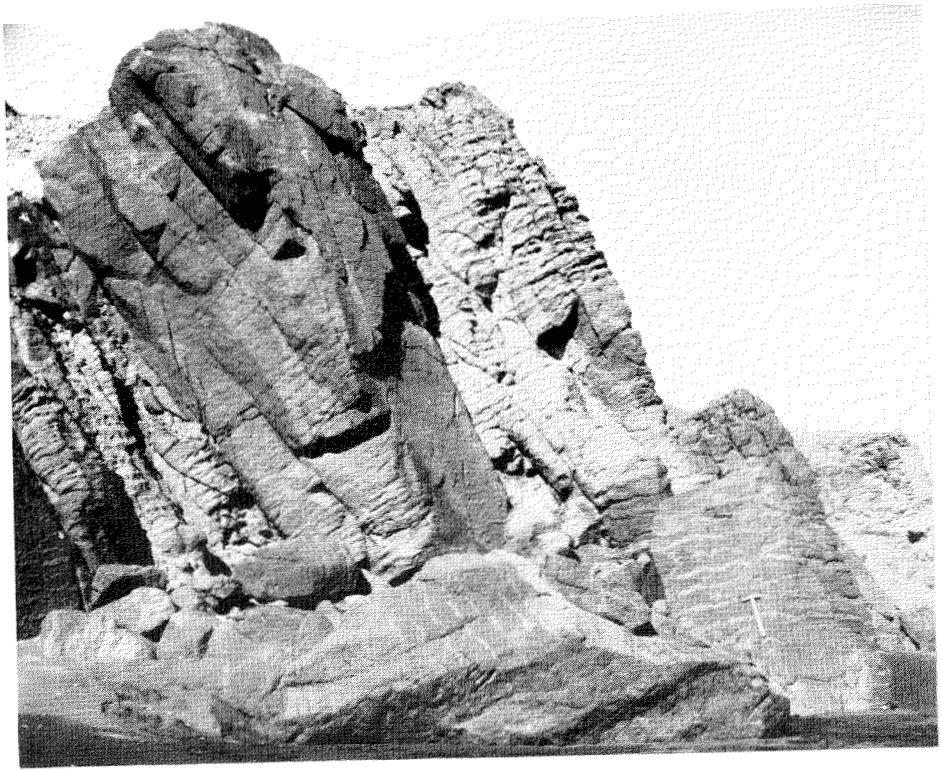

Fig. 5. Northern exposure of the Ingia Intrusion showing banding near the upper margin, which is within 10 centimetres of the top of the cliff. The bands increase in thickness downward in this picritic intrusion, which at this point is a sill.

the Ingia Intrusion, do the plagioclase feldspars develop as large crystals poikilitically enclosing equant olivines.

The mountains and coastal cliffs in the northern part of the island are intruded by a later group of at least one hundred dykes, and a few inclined sheets of basalt, calcic basalt, or dolerite, tending to be relatively constant in thickness and direction. Individual intrusions vary from about 10 centimetres to 10 metres in thickness. One of the thickest is the prominent sheet that traverses the cliffs north of Igdlorssuit continuously for a distance of 2 kilometres at a height of between 1,500 and 2,000 metres (Fig. 2). This sheet also contains at its margin olivines that are elongated and tabular. Its most characteristic feature, which it shares with many of the basaltic types, is the occurrence of phenocrysts or glomeroporphyritic groups of calcic plagioclase. Two thick members of this group of intrusions are dolerite dykes with zoned, ophitic olivines. Fine-grained, olivine-free basaltic dykes cut not only the lower but also the upper group of lavas.

Acid dykes and sheets, frequently irregular and branching, have been intruded over a wide area around the southern complex and the Erqa volcanic neck (Fig. 1). Many show evidence of explosive brecciation. Their

most intensive development, on coastal cliffs in the south (Fig. 6), is more appropriately described with the southern complex, of which they form an integral part. Here also are composite dykes and sheets with both basic and acid facies. In the same wide area of generally acid dykes some of intermediate composition also occur.

The latest minor intrusions are vertical or steeply inclined dykes that represent a return to ultrabasic material that can best be defined by the term monchiquitic. In their freshness they resemble the early picritic intrusions but differ in the fact that their predominant mineral is not olivine but subhedral augite. Xenocrysts of augite, olivine, or biotite, are common and xenoliths of feldspathic gneiss occur sometimes. Plagioclase is invariably a minor constituent and nepheline-bearing types are rare.

These monchiquitic dykes are developed in very large numbers in well-exposed cliff sections northeast and southeast of Erqa and can be investigated in almost as great detail as the picritic intrusions. They represent a manifestation of igneous activity that is quite clearly related to the centralized eruption of the rocks of the upper lava group, but they cut through all members of this group and also the acid rock that occupies the Erqa vent. It is possible that they correspond to a final phase of eruption in the form of volcanoes of puy type. Only one vent with pyroclastic material of monchiquitic affinity has so far been observed, and much work has yet to be done before the waning stages of volcanic activity on Ubekendt Ejland can be described and interpreted. Monchiquitic rocks have not been recorded anywhere else in the area of Tertiary volcanic activity stretching eastward to East Greenland, Iceland, the Faeroes, Scotland, and northern Ireland.

The southern complex

The cliffs on the south coast (Fig. 6), which here rise to heights of between 300 and 500 metres, constitute natural sections of lavas so injected by felsite and sheets of fayalite-porphyry that in some places there is more injected material than lava. These sheets may vary in direction and width but the majority are inclined toward the northwest at angles of 15 to 20 degrees. This injection zone is only a relatively narrow screen that intervenes, except at one place, between the gabbro of a major intrusive complex and the actual coast.

Particular attention has been paid to the numerous observable contacts between the acid and basic members of composite sheets. There is exceptionally clear and unambiguous evidence of an almost simultaneous emplacement of both components. At some of these contacts fayalite, iron-rich pyroxene and other minerals have been precipitated as a result of reactions. In the first account of the geology of this area (Drever and Game, 1948) it was recorded that the major intrusive mass was essentially sheet-like in form. But re-examination in 1950 proved that this was illusory. It was emplaced vertically, in spite of the fact that the inclination of the banding, layering, and lamination in the gabbro (Fig. 7) is about the same in amount

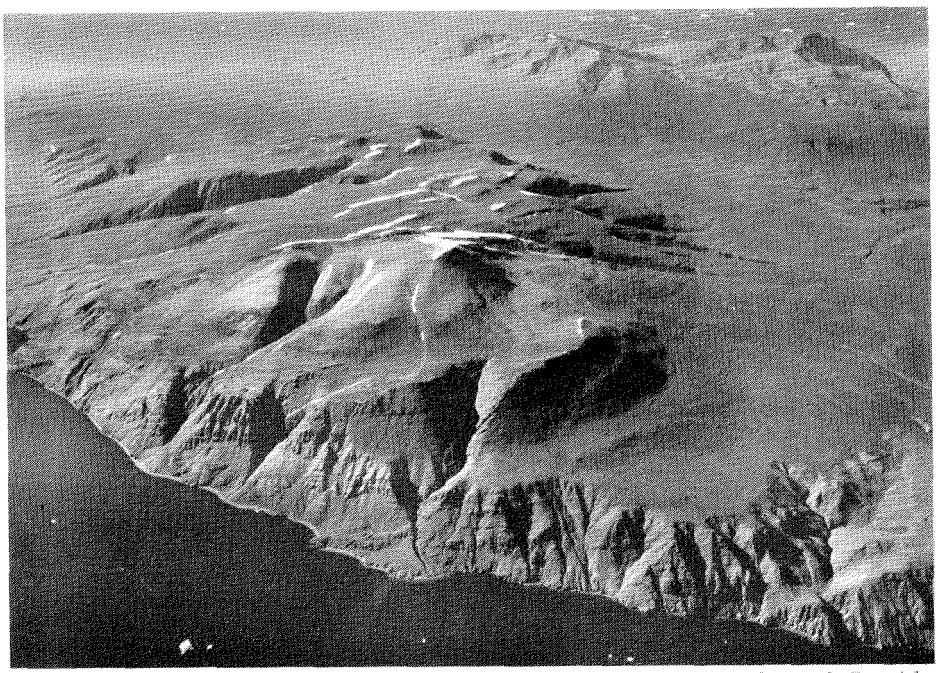

Fig. 6. Air photograph (reproduced by kind permission of the Director, Geodetic Institute, Copenhagen) of the southern end of Ubekendt Ejland. Light-coloured granophyre of the major intrusion forms the highest ground. The lavas have a westerly and north-westerly inclination and are profusely injected with sheets of fayalite-porphyry and felsite.

and direction as the dip of the lavas and in spite of the sheet-like appearance of the highest and acid part of the intrusive mass. In gullies that transect the cliffs the gabbro can be followed upward and observed to intrude the lavas as irregular tongues. The gabbro is not intruded by the acid sheets, and junctions between them are not clear cut (as between gabbro and lava); transitional rock always occurs. It can be inferred from this that the gabbro was emplaced after the injected acid material but before it had congealed. This view is supported by the fact that in some of the composite sheets and dykes a basic facies is demonstrably later than the acid. In other cases the relations between these two facies suggest simultaneous intrusion and two composite intrusions cut the gabbro. Large rafts of highly metamorphosed lava or, more rarely, of composite sheets may be entirely surrounded by gabbro. Compared with the gabbros in the upper part of the well-known Skaergaard Intrusion in East Greenland (Wager and Deer, 1938) this gabbro is less rich in iron and commonly contains some mica and amphibole.

Above the gabbro is a variety of intermediate rocks containing andesine, quartz, pyroxene, fayalite, hornblende, and biotite, in varying proportions. Above this zone, which does not appear to be more than about 20

metres thick, there is granophyre (and quartz-syenite) to the top of the highest point on the island, 1,141 metres. This acid material is a little less than 400 metres in vertical section. The increase in dip of the lavas immediately to the north of the granophyre must be due partly to inflation when the acid magma was emplaced. The upper part of the intrusive granophyre is in fact the dome-shaped top of a deep-seated mass that has comparatively recently been uncovered by erosion. It is conceivable that very few if any Tertiary plutonic rocks were exposed prior to the period of maximum glaciation in West Greenland.

Current and future research

The research on the picritic rocks of the northern part of the island is now well advanced. Comparative research on similar rocks in the Hebridean area of Scotland has been published or is nearing completion. An experimental approach to the problem of their origin is being undertaken by P. J. Wyllie*. Further detailed factual information on variations in the picritic intrusions was obtained on Ubekendt Ejland in 1957, including their relationship with the picritic lavas. More examples of these lavas are being sectioned, including a representative series from one thick flow, and some are being analysed chemically. This chemical work is financially supported by the Royal Society of London. Twenty chemical analyses (including trace elements) of rocks from the southern complex have been made and over 400 thin sections examined. Preparation of this work for publication has been planned systematically with priority for that on picritic rocks. Several lavas and dykes from the upper group on the west coast have also been chemically analysed and much of the preliminary microscopic work has been completed.

In the investigation of this island, with so much of significance to geology, it would be rash to forecast any finality. There are enough problems for at least four doctorate theses. Future field work should concentrate mainly on the areas away from the coasts, which are largely unexplored, while there is hardly any limit to what can still be achieved on the southern coastal cliffs, where it can truly be said that the tougher the climb the more rewarding will be the discoveries.

Conclusions

On Ubekendt Ejland four British arctic expeditions have discovered some fundamental evidence, exceptionally well exposed, in the following major petrological fields of investigation.

Magmas more magnesian or more calcic than basalt or both.

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* Assistant Professor, Dept. of Mineral Industries, Div. of Earth Sciences, Penn. State University.

Fig. 7. Layered and laminated gabbro of the southern complex exposed in a gully through the cliffs on the south coast of Ubekendt Ejland. A Greenlander is standing in the gully.

Petrogenetic analogy of the massive development of calcic zeolites (in banded lavas) and the anorthositic facies in basic plutons.

Co-existence of acid and basic magmas, their contact phenomena and the products of their interaction.

There are also some other promising lines of enquiry, such as the evolution of the eruptive sequence as a whole.

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