The Tertiary geology of Hold with Hope, northern East Greenland

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The Hold with Hope peninsula, between 73° 25′N and 74° 05′N, is one of the major outcrop areas of Tertiary volcanic rocks in the East Greenland coastal area from 70°–76°N. The peninsula measures approximately 75 km (N–S) by 45 km (E–W) and rises to 1509 m in the ice-covered Spaths Plateau. The area is more or less bisected by the major eastward-draining valley of Tobias Dal (fig. 32).

The authors spent sixty days in the area from late June to late August, 1976, mapping on the 1:250000 scale. The aims were to establish (a) the lava stratigraphy, (b) the historical evolution of the Tertiary volcanic rocks, (c) to extend the reconnaissance mapping of the Lauge Koch expeditions (Koch & Haller, 1971) and (d) to sample as widely as possible the Tertiary rock formations. In addition, a brief reconnaissance was made to Wollaston Forland (74° 20′N).

Previous work

The salient features of earlier investigations are reviewed by Noe-Nygaard (1976). The fact that Hold with Hope consists mainly of Tertiary lavas overlying Mesozoic and late Palaeozoic sediments was established by Vischer and Maync working under the direction of Koch (1950) and incorporated in published geological maps (Koch & Haller, 1971). Acid intrusive rocks together with altered lavas have long been known from Kap Broer Ruys where it has been suggested that there may be a Tertiary plutonic centre (Noe-Nygaard, 1976) and breccias and Tertiary sediments were known from the area north and north-east of Myggebugten.

Geological summary

Permian and Triassic sediments cropping out in the northern part of Hold with Hope are overlain by coarse pebbly grit and conglomerates in the Stensios Plateau area. The latter were designated lower Cretaceous (Koch & Haller, 1971, Plate 10). Elsewhere, further south a series of black shales, siltstones and finely-laminated sandstones crops out beneath the lavas. This was also identified as lower Cretaceous (Koch & Haller, 1971).

Between these relatively fine-grained sediments and the volcanic rocks of Hold with Hope there occur local developments of coarse quartzitic conglomerate up to 3 m thick. This is inferred to be of late Cretaceous or lower Tertiary age, and to signify a major rejuvenation of the contemporary land surface prior to the onset of volcanism. A similar conglomerate underlies the Tertiary lavas in south-east Wollaston Forland.

Volcanism commenced with an explosive phase during which a substantial sequence of poorly bedded ashes accumulated. While exposures are sparse, these have their maximum development in the vicinity of Spaths Plateau and appear to be absent south of Tobias Dal and in the Home Forland area (fig. 32).

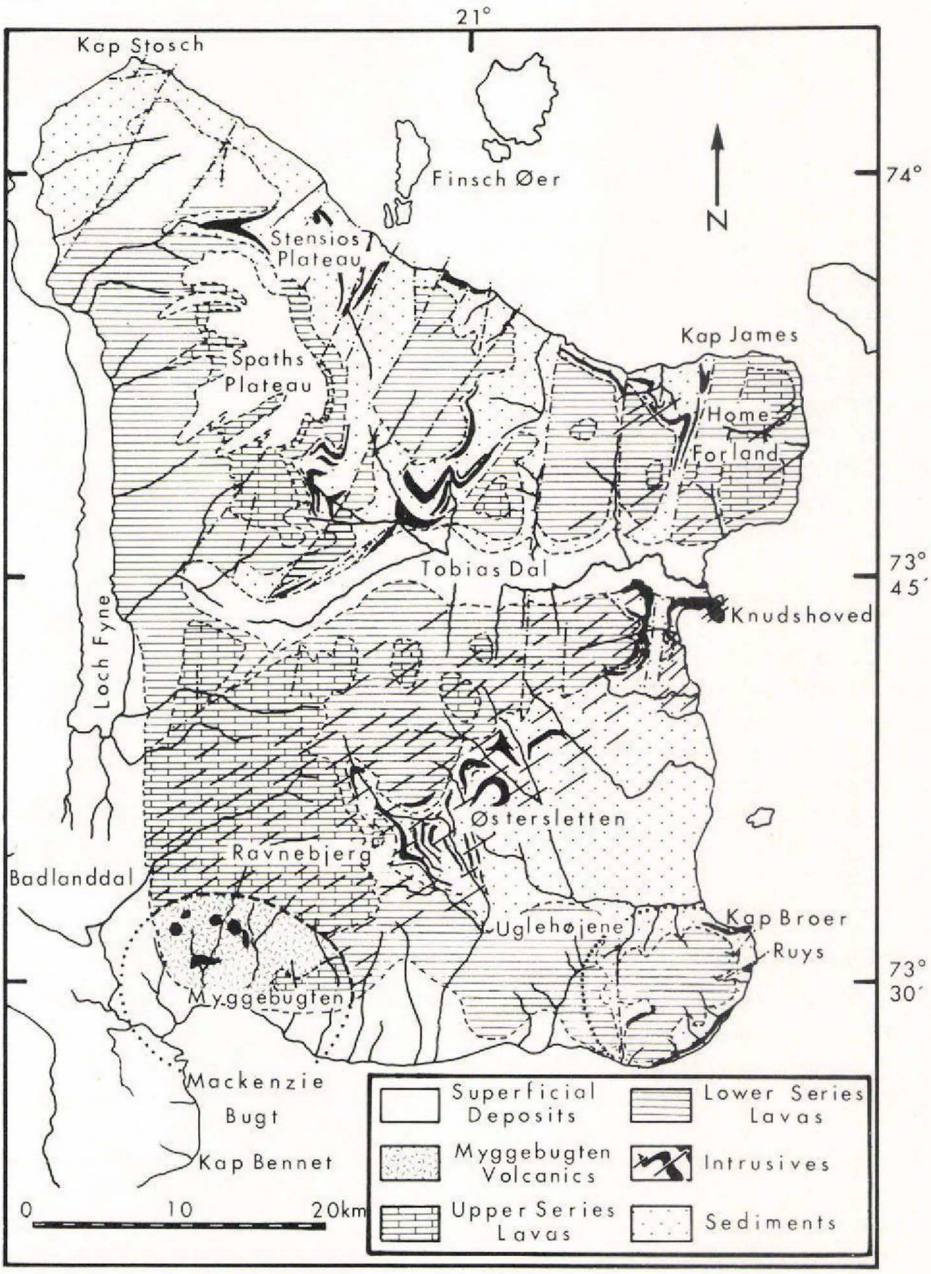

Fig. 32. Geological sketch map of Hold with Hope, northern East Greenland. Dotted line around the Kap Broer Ruys area indicates outer limits of metamorphic aureole.

After the ash phase, basic lavas accumulated over a wide area, building up a lava plateau at least 600 m thick. The lava sequence is of very wide extent and was spilled sub-aerially across a landscape of low relief, resting on a variety of older rocks ranging from lower Triassic through lower Cretaceous to the Cretaceous/Tertiary (?) conglomerates and ash horizons. Thin coal partings associated with shaly ashes immediately below the lower lavas at one locality suggest a low-lying vegetated landscape.

The plateau lavas are divisible into two series: the lower series consists of aphyric to sparsely feldsparphyric basalts showing a monotonous uniformity. This series, which includes those described by Noe-Nygaard & Pedersen (1974) from Kap Stosch, is inferred to be wholly tholeiitic. The upper series, following conformably and possibly gradationally after the lower, involves a more diverse sequence of lavas, many of which are notably porphyritic.

Lower series

The lower series is between 400–450 m thick across Hold with Hope. While individual flows range up to 40 m thick, average thickness is approximately 9 m. Individual lavas may be of wide lateral extent and show considerable continuity of outcrop in prominent escarpments. Columnar jointing is well developed in some of the thicker flows. While original flow surfaces are rarely – if ever – preserved, the undeformed and approximately spherical form of amygdales suggests that these lavas were predominantly of pahoehoe type. Scoriaceous autoliths, derived from near-surface facies of the lava flows, are commonly present.

Brick-red oxidised tops to individual flows first appear in the topmost 50 m of the lower series, and may reflect relatively long time intervals between successive flows during which weathering took place. With the exception of one thin horizon south-east of Kap Stosch containing hyaloclastites and lava pillows, the evidence suggests that the lavas were erupted sub-aerially over a landscape of low relief.

Lavas with characteristics identical to those of the Hold with Hope lower series appear, from our brief reconnaissance, to predominate in the Wollaston Forland lava plateaux; and they probably compose the lavas of Jackson Ø (Tyrrell, 1932).

Three small tuff/agglomerate pipes were recorded on Hold with Hope which could relate to activity in lower basalt times, or in the case of two, to the early period of ash deposition.

Upper series

This series is seen only in relatively small outliers except in the region south of Tobias Dal and extending south to Ravnebjerg where it covers an area of about 250 km² (fig. 32). Although the higher lavas have been lost by erosion, a sequence of up to 200 m remains. The base of the series is poorly defined but was taken to be at the level at which clinopyroxene and/or olivine phenocrysts first make an appearance.

The more mafic lavas, which form the majority of flows, especially towards the south, range from oceanite-type picrites to ankaramites in which both olivine and deep green clinopyroxene phenocrysts occur in profusion. Feldsparphyric flows, with or without accompanying ferromagnesian phenocrysts, are also notable components of the upper series, as are slightly porphyritic to aphyric lavas with marked fissility parallel to the flow surfaces.

The field characteristics of the latter strongly suggest mugearitic compositions. Some flows, including both oceanitic and mugearitic (?) types, contain sparse gabbroic and peridotitic inclusions.

The average flow thicknesses are close to 4 m and the lateral continuity of lower series lavas is generally lacking. Columnar jointing tends to be poorly developed except in some of the thicker (up to 15 m) mugearite flows. Flows are sometimes separated by scoriaceous agglomeratic layers up to 1 m thick; frequently, deep weathering has destroyed flow surface features and left bright red oxidised tops. Rounded undeformed amygdales and occasional well-preserved pahoehoe-toe features suggest that the upper series also consists predominantly of pahoehoe-type lavas. Pipe amygdales are occasionally present in flow bases.

Upper series lavas do not appear to have been preserved north of Spaths Plateau. During the reconnaissance to Wollaston Forland, the three topmost flows on the highest mountain, Saddlebjerg (1143 m), were found to be of porphyritic trachybasaltic type and to contrast with the uniform lower series basalts which appear to compose the remainder of the local lava plateaux. Apart from their analogous position in the stratigraphic sequence there is however, no obvious reason to correlate these three flows with the upper series lavas of Hold with Hope.

Zeolites are developed within the lavas over and around a broad (30–40 km) domical region centred on Tobias Dal which is characterised by occurrence of chalcedony, quartz and calcite in amygdales and veins.

Dolerite sills

The sedimentary series beneath the lavas, particularly the Cretaceous, was intruded by a multiplicity of dolerite sills. These also cut the ashes and basal flows of the lower series basalts. The sills are predominantly of relatively homogenous dolerite with slightly feldsparphyric chilled marginal facies. However, north of Tobias Dal composite sills occur, with doleritic and picritic facies and occasionally felsic segregates. The larger sills range up to 50 m thick and are conspicuous landscape features, particularly along the north-east coast of the peninsula. Columnar jointing is well developed in the sill complex. The sills frequently display sharply transgressive relationships to their surroundings and some steep-sided dyke-like bodies may represent feeder channels. Lithologically the sill complex can not readily be correlated with either series of plateau lavas and it is tentatively concluded that the bulk of the sills are younger that the preserved plateau lavas.

Dyke swarms

Subsequent to the eruption of the plateau lavas and emplacement of the sill complex, a major dyke swarm was injected along a broad (*c.* 25 km) zone extending NE–SW across central Hold with Hope from Home Forland to Badlanddal (fig. 32). The swarm attains its maximum intensity across a 10 km band transecting the Ravnebjerg area. The majority of the dykes are aphyric or slightly feldsparphyric basalts although a few oceanite dykes have the same general trend. The swarm remains sufficiently dense across the high ridges (i.e. over 800 m) of Ravnebjerg for it to be reasonable to assume that they themselves acted as feeder

channels for a still higher succession of plateau lavas of which, in Hold with Hope, nothing remains.

Outside the main dyke swarm, dykes are rare and have variable trends except in the vicinity of Myggebugten where localised dense swarms are also encountered (see below).

The Kap Broer Ruys district

In this area acid sheets intrude the lavas and underlying sediments, and post-date the sills. Their age relationships with the NE–SW dykes is undetermined. The acid intrusives are recognisable over a region some 15 km across, from thin felsite sheets in the lower series basalts of Uglehøjene to more substantial bodies of porphyritic felsite or granophyre in the mountains west of Kap Broer Ruys. The latter include what is probably the partially unroofed top of a stock intruding Mesozoic and Tertiary sediments and lavas which have been substantially metamorphosed. Evidence of alteration occurs over a subcircular area some 12 km in diameter (fig. 32) in which lower series lavas are chloritised and sediments highly indurated. In the central part of this zone, in an area *c.* 5 km in diameter, the lavas have been metamorphosed to such an extent that almost all indications of the normal lava stratification (and 'trap topography') are obliterated and the smooth-outlined mountains are mantled by frost-shattered altered basalt debris. In this central area epidote occurs within the basalts and both basalts and hornfelsed shales (porcellanites) have experienced sulphide mineralisation, with introduction of iron sulphides.

The Myggebugt area

In the extreme south-west of Hold with Hope, north and north-east of the abandoned Myggebugt radio station, deep melt-water channels are incised into the land surface sloping south from Ravnebjerg, exposing a structurally complex and petrographically diverse assemblage of volcanic rocks. This area represents the shallowly eroded site of a substantial central volcano and we shall refer to this as the Myggebugt Central Complex. Only the north-east sector is preserved; the remainder is inferred to be obscured beneath the drift of Badlanddal and the waters of Mackenzie Bugt (fig. 32). To the south-west the Kap Bennet hills appear (from inspection by binoculars and of aerial photographs) to be composed of lavas (possibly of upper series type – Noe-Nygaard, 1976) cut by dykes and are inferred to lie beyond the boundary of the complex.

The complex involves the following components:

(a) *Ankaramitic basalt lavas;* these appear identical to those of the upper series of Ravnebjerg except that they are altered (chloritised and, less generally, epidotised) and may show much steeper dips (up to 40°) than lavas outside the complex.

(b) *Aphyric to slightly feldsparphyric basalt lavas;* these differ from the lower series lavas in being characteristically scoriaceous and with deformed, stretched vesicles suggestive of aa-type flows. Average flow thickness is difficult to determine but they appear to be generally thin (< 5 m). Furthermore, they appear to lie stratigraphically above the ankaramites. We suggest that these lavas comprise a series younger than the upper series, that they are locally derived and that they are probably preserved through down-faulting within a caldera. They are here termed the non-porphyritic central series. Near Mackenzie Bugt

these lavas are hornfelsed with development of epidote and sulphide: further inland they have been pervasively altered and degraded to incoherent chlorite-clay assemblages.

(c) *Pyroclastic deposits;* the gorge sections reveal an abundance of green chloritic tuffs and agglomerates. For the most part these are unbedded and composed of assorted angular blocks of basaltic and doleritic rocks, generally of recognisable local origin. Occasionally however, acid rocks appear and some tuffs are composed of pumiceous rhyolitic fragments. While the majority of outcrops may be part of tuff-pipe or agglomerate neck infillings, some show bedding and are probably part of tuff cones. One rhyolitic tuff, with indications of eutaxitic structure may be a welded ash flow.

(d) *Sediments;* in a gorge about 5 km north-east of the abandoned radio station, bedded conglomerates occur and are believed to be intercalcated with non-porphyritic central series lavas and pyroclastic deposits. The conglomerates, of which some 10 m is exposed, consist of rounded fragments of non-porphyritic basalt and also contain, at certain horizons, abundant branches and trunks of silicified wood (Orvin, 1931; Hoeg, 1931). At another locality a few metres thickness of black shales and sand are exposed. These sediments are inferred to be lacustrine deposits accumulated within an ephemeral calderalake whose flanks were, during periods of volcanic quiessence, thickly forested.

(e) *Minor intrusives;* the rocks listed under (a)–(d) above are intruded by a profusion of hypabyssal sheets and plugs. While the majority of these are of basaltic composition, a minority involve intermediate to acid rock-types. The main NE–SW dyke swarm is for the most part truncated and obliterated by the central complex; thus the main NE–SW fissuring pre-dated the complex, although a few NE–SW dykes are found to intrude the non-porphyritic central series basalts. Around the northern borders of the complex a locally dense swarm of NW–SE trending dykes was observed, cutting the majority of NE–SW dykes. A dyke swarm trending roughly N–S has also been noted from the central area of the complex.

Large numbers of doleritic sheets also occur around the northern and eastern sectors of the complex. Orientations are variable and several generations are involved; these sheets are believed to be parts of cone-sheet swarms within the complex.

At least two dolerite units occur which, from their jointing patterns, are thought to be parts of thick sub-horizontal sheets. Whether these were intrusive or thick ponded crater- (or caldera) lava-lake units was not ascertainable. One is composed of fresh unaltered oceanitic picrite and must be one of the youngest units of the complex. Thus it would appear that strongly olivine-phyric basalt eruption was not confined to the period of upper series lava emission. Other basic masses probably represent infilled, sub-cylindrical necks. Of these, two may be described as gabbroic and form intrusions 1–2 km across.

Crushing and small-scale faulting are common in the central complex. Some fracture zones show minor mineralisation with the development of calcite, quartz and (rarely) fluorite.

We conclude that the Myggebugt Central Complex represents a long-lived central volcano within which the lower series basalts and sub-lava sediments were down-faulted to below the present erosional level. Activity was intermittently explosive. While acid magmas were involved, magmatism was predominantly basaltic. While the relative ages of the Myggebugt

Central Complex and the Kap Broer Ruys acid intrusives are unknown they could, on available evidence, represent more or less contemporaneous activity at centres some 30 km apart; both are evidently late, major events in the Tertiary igneous history of Hold with Hope.

Magnetic observations

Using a portable 'flux-gate' magnetometer, the lower series basalt lavas and the lower part of the upper series lavas were found to be reversely magnetised. However, the upper part of the upper series lavas, the sill complex and the regional dyke swarm appear to show uniformly normal polarity. This observation corroborates the conclusion drawn earlier, that the sill complex post-dates at least the lower part of the upper series lavas. Of the very few readings obtained in the Myggebugt Central Complex, reversed readings suggest that a second polarity change may have taken place before volcanism terminated in the Hold with Hope area.

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