DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2002/39

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Contribution to the SNF 2002 project "Neogene uplift, erosion and redeposition in West Greenland"

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Abstract

Palaeogene basalts overlie Cretaceous–Paleocene sediments throughout the Nuussuaq Basin, 69°–72°N, central West Greenland. While the sediments are cut off to the east by a major fault system, the Cretaceous Boundary Fault System (CBFS), the basalts extend east and north-east of this fault system where they lie directly on Precambrian basement. The sub-basalt surface in the basement area shows considerable relief. This relief is at two scales: a relief with a range in altitude up to 600 m and a wave length of the order of 10–15 km, and a relief with an altitude difference of almost 2000 m and a wave length of the order of 300 km. The 10–15 km wave length relief is particularly conspicuous in the northern part of the area (72°10′–72°40′N). The *c.* 300 km wave length relief constitutes a very broad arch or half-dome, rising from sea level in the north-west to *c.* 400 m at the border of the Inland Ice at 72°45′N, and to over 1900 m at 71°40′N. Between this and the inner part of Nuussuaq peninsula (*c.* 70°30′N) there are no outcrops of basalt east of the CBFS, even on summits over 2100 m high. Where basalts reappear on the north-east side of Nuussuaq, the sub-basalt surface lies between 1400 and 1600 m a.s.l., with a local palaeo-ridge rising to over 1900 m. The southernmost outcrop of basalt east of the CBFS lies in south-east Nuussuaq; here the sub-basalt surface has descended to *c.* 1100 m a.s.l. A weak west-wards post-basalt tilt can be demonstrated in inner Svartenhuk Halvø and an even weaker northwards tilt in the mountains east of Ukkusissat Fjord, so it is likely that at least part of the uplift of the *c.* 300 km wavelength arch is due to post-basalt doming. To what extent the feature already existed as a topographic high prior to basalt extrusion is not known.

Introduction

Before one begins to speculate on the cause(s) of Neogene uplift in West Greenland (Chalmers 2000), one must first do all one can to quantify the uplift and to date the phase(s) during which it took place.

In order to quantify the uplift, one must identify marker horizons or surfaces that have been uplifted and also know where these lay relative to sea level prior to the start of uplift. The altitude of marker horizons in shallow water marine sediments provides some of the best information about the amount of net uplift in uplifted areas and also a maximum age of the uplift (assuming the sediments contain age-diagnostic fossils). Other, quite different, indicators of the amount and maximum age of uplift are erosion surfaces, assuming that these are plains that were at or near the base level of erosion at the time of formation and that they can be dated in some way.

Onshore West Greenland the only pre-Quaternary marine sediments are those occurring in the Cretaceous–Paleocene Nuussuaq Basin (69°–72°N); these are bounded to the east and north-east by a major fault system referred to as the Cretaceous Boundary Fault System (CBFS; Chalmers *et al.* 1999), so marine sediments are not available as indicators of uplift in the hinterland of the basin. However, the middle–upper Paleocene basalts that overlie the Cretaceous–Paleocene sediments over most of the Nuussuaq Basin extend across the CBFS and lie directly on the Precambrian basement north-east and east of the fault system. Thus the subsurface of the basalts in this hinterland area constitutes an erosion surface of known age, the form and altitude of which might provide some information on the uplift history of the region.

The contact between Paleocene lavas and the underlying basement has been observed over much of the hinterland of the Nuussuaq Basin, mainly through binoculars, and its position recorded on aerial photographs. Since this boundary is usually distinct on aerial photographs, both on oblique and on vertical photographs, its position can also be plotted in areas where there are no field observations. When it comes to drawing a map of the boundary, the situation is less satisfactory, because the existing topographic maps in the areas north of 72°N and east of 54°W are of very poor quality, and the published geological maps cannot be used to prepare a contour map of the sub-basalt land surface. The altitudes of this surface shown in the sketch map Plate 1 give only an *approximate indication* of the true altitudes.

Summary of observations on the sub-basalt surface in the basement area east and north-east of the Cretaceous Boundary Fault System (CBFS)

Outcrops of basalt overlying Precambrian basement occur between Upernavik Isfjord in the north and Rink Isbræ in the south, and again in the inner part of Nuussuaq peninsula (Fig. 1; Plate 1).

In the northern area, between Upernavik Isfjord and the inner part of Ukkusissat Fjord, the sub-basalt surface lies at altitudes between sea level and *c*. 800 m a.s.l., lowest on the shores of Qeqertaq and Innerit where it descends south-westwards below sea level (Fig. 2a). In this area the surface shows conspicuous relief, up to at least 600 m; the 'wave length' of the relief is of the order of 10–15 km (Figs 2b, 3a and 3b). Passing south-eastwards the general altitude of the surface rises, reaching a maximum of about 1950 m between Umiammakku Isbræ and Rink Isbræ (see Plate 1). There is also a rise in the level of this surface passing from the outcrops flanking the innermost part of Inngia Isbræ, where it is *c*. 1200 m a.s.l., to the high ground between the front of this glacier and Umiammakku Isbræ to the south where the surface is up to 1800 m a.s.l. On the peninsula south of Kangilleq, where the highest peak in the entire region occurs (2280 m a.s.l.), no basalt has been observed, nor is there any basalt on the highest peaks on Upernivik Ø or on the peninsula to the east, which are 2115 m and 2150 m a.s.l. respectively. Passing southwards, basalt overlying basement east of the CBFS does not occur again until the inner part of Nuussuaq peninsula (see below). Interestingly enough, the relief of the sub-basalt surface seems to be more subdued where the surface rises over 1000 m a.s.l. Exceptions occur, however. In inner Svartenhuk Halvø, immediately south-west of the intersection of 72°N and 54°W, a >1650 m a.s.l. peak or ridge of basement rises over 500 m above the surrounding, gently undulating sub-basalt surface (Larsen & Grocott 1992). Another example occurs at the outer end of the peninsula between Ukkusissat Fjord and Inngia Fjord, where there is an isolated outcrop of basalt just over 1000 m a.s.l., while *c*. 10 km to the north-east the sub-basalt surface is over 1400 m a.s.l.

Basalt overlying Precambrian basement reappears to the south in the inner part of Nuussuaq, south and south-west of Uummannaq (Fig. 1). East of the Kuuk fault the sub-basalt surface is between 1400 and 1600 m a.s.l. In spite of this 200 m variation in altitude, the relief of the surface here is not as pronounced as in the area between Laksefjorden and inner Ukkusissat Fjord. However, between the Ikorfat and Kuuk segments of the CBFS the sub-basalt surface rises 700 above the surroundings in a NW–SE-trending ridge which reaches a maximum height of over 1900 m a.s.l. (Pedersen *et al*. 1996, fig. 6). The only remaining outcrop of basalt east of the CBFS on Nuussuaq is on a 1266 m high peak north of Saqqaq; here the sub-basalt surface is only about 1100 m a.s.l.

Questions and speculations concerning the sub-basalt surface east and north-east of the CBFS

The first question that arises concerning the sub-basalt surface is its altitude above sea level prior to uplift. Unfortunately nothing concrete can be said about this. Since the surface is obviously not a peneplain, its position relative to the base level of erosion at the time just before basalt extrusion is not known. Locally in the mountains flanking Ukkusissat Fjord and around the inner end of this fjord there are hyaloclastite breccias both at the base of the basalts and as horizons within the subaerial flows; these breccias show northward-dipping mega-cross-bedding, indicating northward flow of the lavas into water bodies (Henderson & Pulvertaft 1987, plate 3; Larsen 1981). If the bodies of water were lakes and not embayments of the sea, which is most likely (Larsen & Pulvertaft 2000), the occurrence of hyaloclastite breccias tells us nothing about the original altitude of these rocks and the surface which underlies them.

The next question concerns the regional arch or half-dome in the sub-basalt surface, a feature discussed by Larsen (1981). This feature has a wave length of the order of 300 km with an apex over 2280 m a.s.l. situated somewhere between Kangilleq and Appat. Superimposed on this feature is the shorter wave length relief which seems to be more marked in the northern, lower part of the arch than in the highest parts. This short wave length relief is obviously a pre-basalt feature, but the regional arch could be either a pre-basalt feature or the result of regional, post-basalt crustal warping, or a combination of these. Note that very few faults have been observed in the basement area east of the Nuussuaq Basin (Henderson & Pulvertaft 1987), so post-basalt block faulting is not the main cause of variations in the altitude of the sub-basalt surface.

On Svartenhuk Halvø, north-east of the CBFS, there is evidence of post-basalt tilting of the basement area. Here the boundary between the two main formations in the lavas, the Vaigat Formation (lower) and Svartenhuk Formation, dips west at an average of 2.3°, which is approximately the same as the general dip of the sub-basalt surface in this area (Larsen & Pulvertaft 2000, fig. 8, reproduced here as Fig. 4). However, if the contact between the Vaigat and Svartenhuk Formations is extrapolated eastwards to the east side of Ukkusissat Fjord at this dip, it would reach a level of more than 2000 m a.s.l. on the peninsula between outer Ukkusissat Fjord and Inngia Fjord, in which case the exposed lavas here would belong to the Vaigat Formation. However, lavas of the Svartenhuk Formation overstep the Vaigat Formation at *c.* 72°N in north-eastern Svartenhuk Halvø where they lie directly on basement (Larsen & Grocott 1992), and the outcrops in the high area east of Ukkusissat Fjord also belong to the Svartenhuk Formation. Furthermore the sub-basalt surface here is at ‘only’ *c.* 1450 m a.s.l., so it seems that the westerly component of tilting and also the slope of the sub-basalt surface has levelled off from an average of 2.3° in inner Svartenhuk Halvø to less than 1° in the outer part of Ukkusissat Fjord.

The behaviour of a hyaloclastite breccia horizon within subaerial basalts east of Ukkusissat Fjord suggests a northward component of syn-volcanic tilting. Mega-cross bedding in this horizon dips northwards, and over a distance of about 18 km the thickness of the horizon increases from zero in the south to about 100 m in the north. This suggests that the lake into which the basalts flowed deepened to the north, and that the lake floor dipped north at *c.* 0.3°. As far as could be ascertained in the field, the upper surface of the breccia horizon also dips north at a similar angle, indicating a later component of tilt.

From the scant evidence just presented, it is concluded that the sub-basalt surface between Ukkusissat Fjord and the outer coast was subjected to post-basalt tilt with a westerly component of dip between less that 1° and 3° and an even lower northerly component. Given that this degree of post-basalt tilting in the basement area can be demonstrated, the entire N–S arching of the sub-basalt surface *could* be tectonic, and not a palaeotopographic feature of Late Cretaceous/early Paleocene age. However, even if it is tectonic, it could be related to the Eocene tectonics that also gave rise to the complex structures in the basin area in Svartenhuk Halvø described by Larsen & Pulvertaft (2000), and not to Neogene uplift. Whatever the truth, it should be noted that in the south-west corner of Upernivik Ø, west of the apex of the arch, there are tidal-estuarine and coastal plain sediments of Late Albian–Early Cenomanian age that are down-faulted relative to the basement but occur up to 800 m a.s.l. (Midtgaard 1996). The uplift of these sediments need not, however, have occurred in the Neogene. To the west, subaerial lavas form almost all Ubekendt Ejland, dipping approximately westwards under the sea. No Cretaceous or Paleocene sediments are exposed on Ubekendt Ejland, nor, apart from a single outcrop, are there any occurrences above sea level of the thick hyaloclastite breccias that underlie the subaerial basalts everywhere else in the Nuussuaq Basin. Thus the net displacement of Ubekendt Ejland relative to sea level since the middle Paleocene has been subsidence, presumably along one or more major faults concealed in the sound between Ubekendt Ejland and Upernivik Ø.

Returning to the basement area east of the CBFS, *if* the regional arch in the sub-basalt surface is the result of uplift during the Neogene, does this require renewed movement on the CBFS? This question cannot be answered fully. Post-basalt displacement on this fault system can be demonstrated on Svartenhuk Halvø and could possibly have taken place in southern Nuussuaq, but it is not known if any of this movement took place during the Neogene, and in any case the displacements on the CBFS in these areas indicate subsidence of the basement hinterland relative to the basin area and tell us nothing about possible late uplift of the apex of the arch along the fault system.

On Svartenhuk Halvø, where the evidence of post-basalt activity on the CBFS is clear, the post-Paleocene uplift of the basin area relative to the basement to the north-east can be read from Fig. 4, which is reproduced from Larsen & Pulvertaft (2000, fig. 8, p. 22). On Nuussuaq, north and north-west of Saqqaq, basalts of the Nordfjord Member occur in the top few tens of metres of the 1266 m peak east of the CBFS but at 1520–1580 m a.s.l. on Giesecke Monument 25 km to the north-west, west of the CBFS (Pedersen & Larsen 1987). This indicates either a post-basalt uplift of the *basin* area on the CBFS, as on Svartenhuk Halvø, or a 0.66° regional post-basalt tilt to the south-east that affected both sides of the fault system. The latter is the most likely, as in north-east Disko on the opposite side of Vaigat, the Niaqussat Member marker horizon in the basalts dips evenly at 0.66° to the south-east, creating a drop in level of 750 m over a distance of 65 km without the intervention of any faults (Larsen & Pedersen 1992, fig. 5, reproduced here as Fig. 5). (The Niaqussat Member immediately overlies the Nordfjord Member.) There is no evidence of post-basalt displacement on the Kuuk segment of the CBFS (this fault segment is a hinge fault associated with the NNE-dipping Qaarsut ramp – see Chalmers *et al.* (1999)), while post-basalt displacement on the Ikorfat branch of the CBFS is a downthrow to the south-west (Chalmers *et al.* 1999). As already mentioned, there must also have been post-basalt fault movements in the sound between Ubekendt Ejland and Upernivik Ø where the Nuussuaq Basin borders the apex of the arch, but these can have been subsidence of Ubekendt Ejland rather than uplift of the arch, and so provide no evidence one way or the other about possible post-basalt uplift of the arch – it could have been there beforehand.

Finally, some remarks concerning the short wave length relief seen in the sub-basalt surface, especially in the northern part of the area. It is obvious from what has been described and illustrated in the foregoing that the early Paleocene landscape was immature. For a landscape to be immature, there must have been an immediately preceding uplift. In the case in question this means that there must have been uplift in the Late Cretaceous–earliest Paleocene. This is in perfect accordance with the development of the Nuussuaq Basin where Dam & Sønderholm (1994, 1998) and Dam *et al.* (1998, 2000) have demonstrated a series of phases of uplift and channel incision and infill that took place between middle Campanian and middle Paleocene time.

Final comments

Post-Maastrichtian uplift of the basement has taken place east of the Ikorfat branch of the CBFS, as demonstrated by the occurrence of diagnostic ammonites 900 m a.s.l. on the north side of Nuussuaq, just east of this fault (Birkelund 1956). Within the Nuussuaq Basin, the occurrence on Nuussuaq of dinoflagellates of Danian age up to 800 m a.s.l. (Nøhr-Hansen *et al.* in press) proves that the basin has undergone a post-Paleocene uplift of at least this amount; if the overlying hyaloclastite breccias were entirely erupted into a marine rather than lacustrine environment, the net uplift of the basin could be 400 m more. The question is whether the hinterland of the basin has undergone more, less, or the same uplift as the basin. The sub-basalt surface in the hinterland is a feature which might throw light on this issue, and must also be taken into consideration in any comprehensive study of landscapes through time in central West Greenland. At present, however, the relative contributions of pre-basalt relief and later uplift of the surface are not known, and no evidence concerning the age of hinterland uplift is available. A detailed photo-geological study would certainly provide a better picture of the sub-basalt surface, and might also reveal a pattern of very low-angle dips in the basalts consistent with a tectonic origin of the *c.* 300 km wavelength arch described in the foregoing sections.

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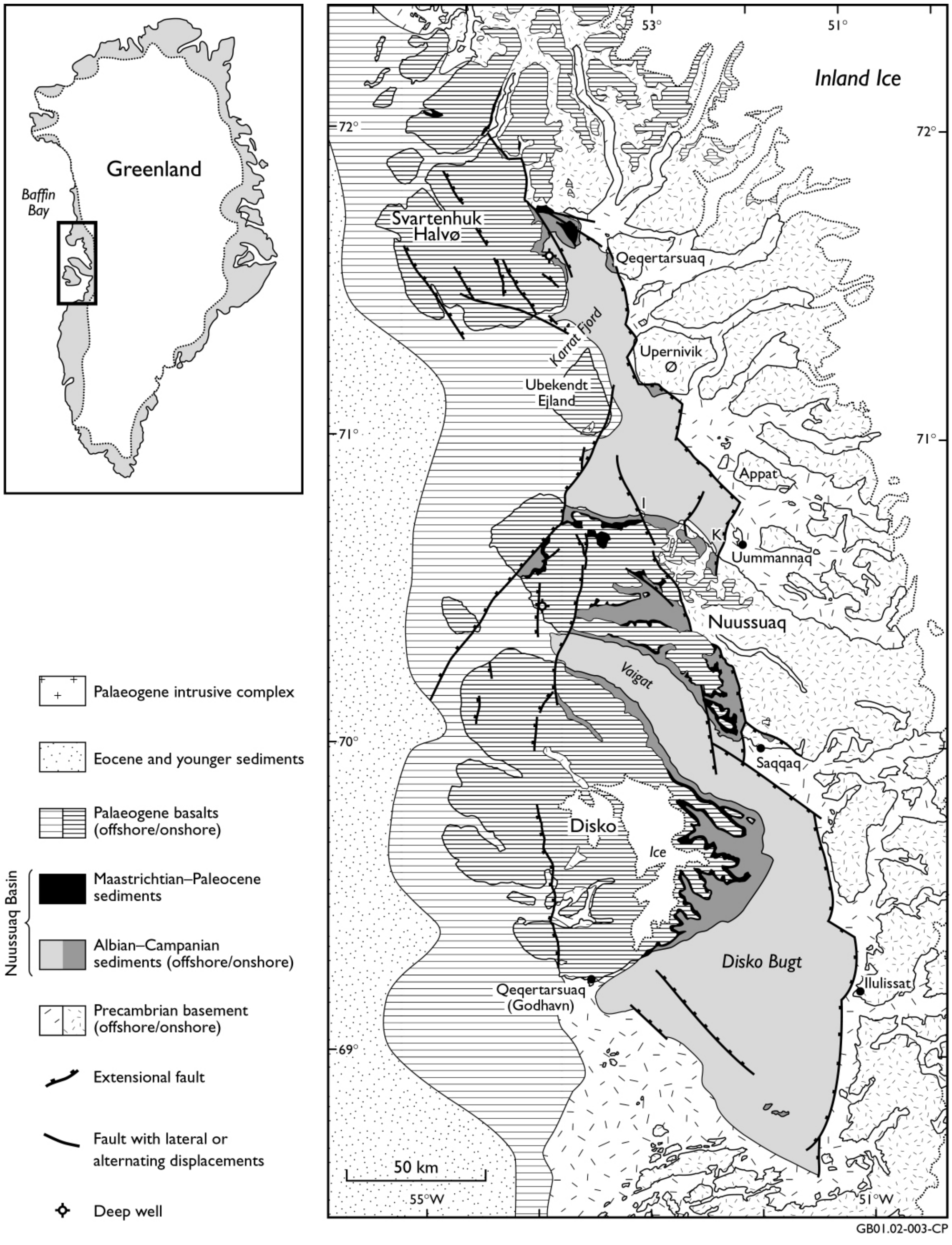


Fig. 1. Simplified map of the Nuussuaq Basin. I: Ikorfat; K: Kuuk.

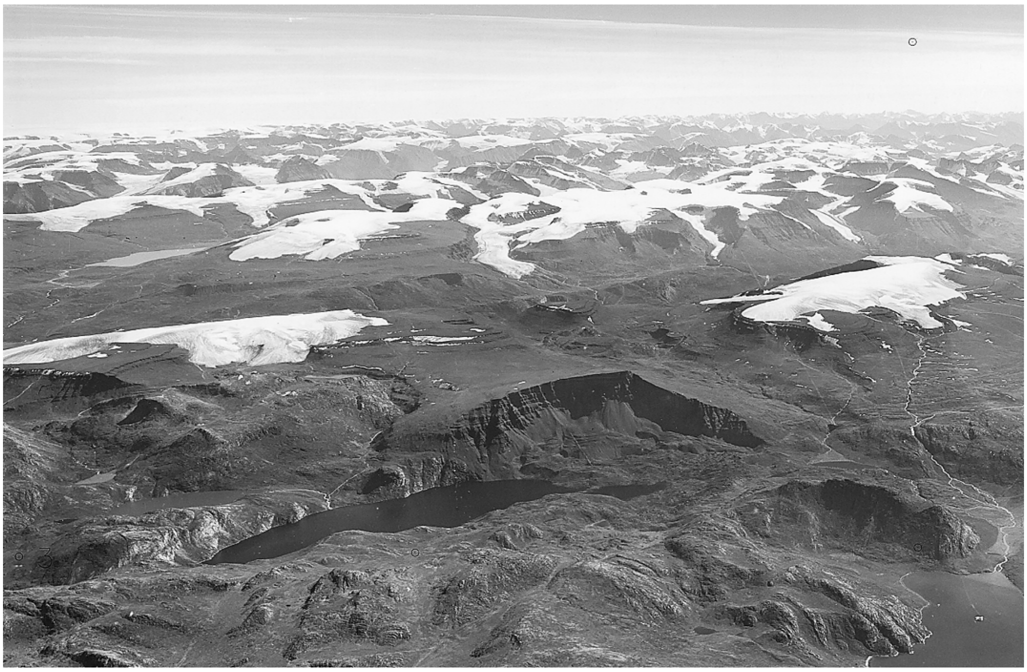


Fig. 2. **a**: View north-west across Sullua to Qeqertaq, showing the contact between basement and Paleocene basalts. The height of the cliffs of basalt on the left is about 600 m a.s.l. Detail from KMS oblique aerial photo 530C N, 5899.

b: View south-eastwards over the inner part of Innerit peninsula. The surface of the lake in the foreground is 190 m a.s.l., while the basement hill between this and the small ice cap above and to the left is *c.* 900 m a.s.l. The relief on the sub-basalt surface is about 500 m. Detail from KMS oblique aerial photo 530D S, 3369.

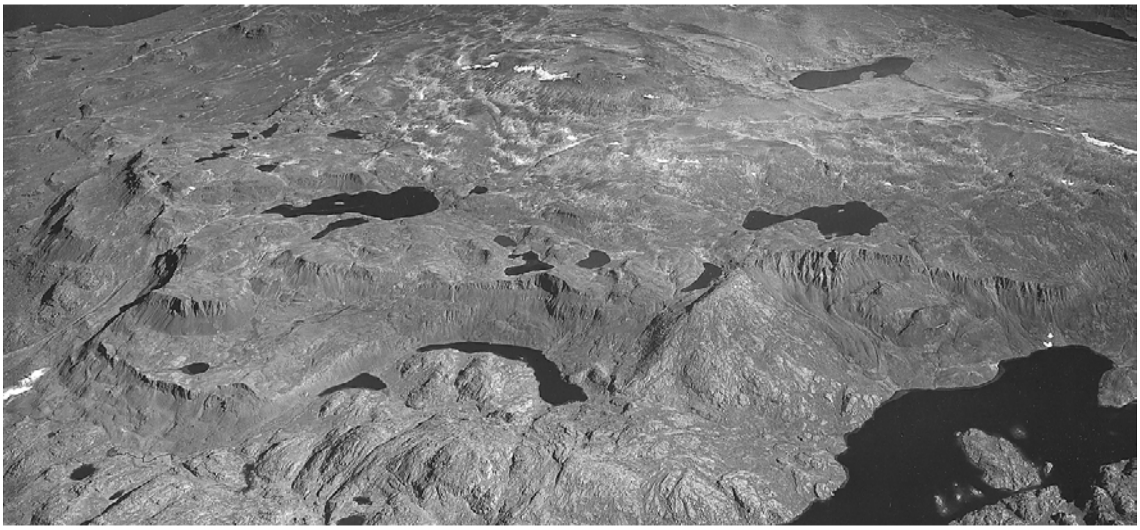


Fig. 3. **a**: View south-east across some of the country about 15 km north-west of the inner end of Ukkusissat Fjord. Note the hill in the sub-basalt surface rising to the left from the lake in the lower right. The height of this hill above the lake level is about 300 m. Detail of KMS oblique aerial photo 530C S, 9263.

b: The same country as shown in **a**, seen from farther away. The notes were made on 5th July 1967 from a peak south of Laksefjorden. The inner part of Ukkusissat Fjord is seen in the background, right of centre. NF: Nukavsak Formation; g: granite; β: basalt. Detail of KMS oblique aerial photo 530D S, 3379.

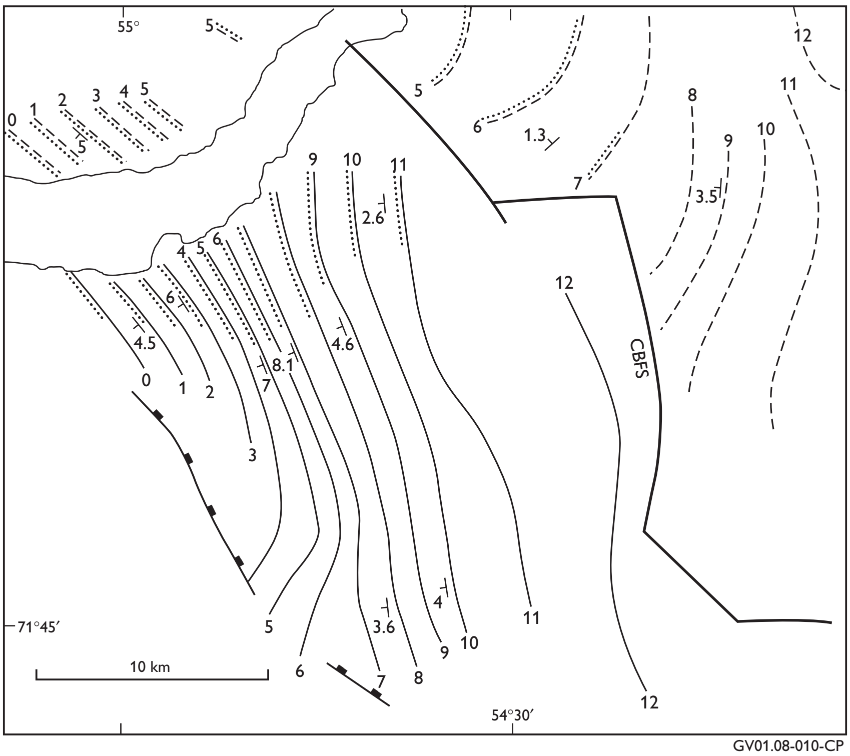


Fig. 4. Structural contour map of the base of the Svartenhuk Formation in the northern part of Svartenhuk Halvø. Contour interval 100 m. Dots along contours indicate where the Svartenhuk Formation overlies intrabasaltic non-marine sediments. CBFS: Cretaceous Boundary Fault System. From Larsen & Pulvertaft (2000, fig. 8).

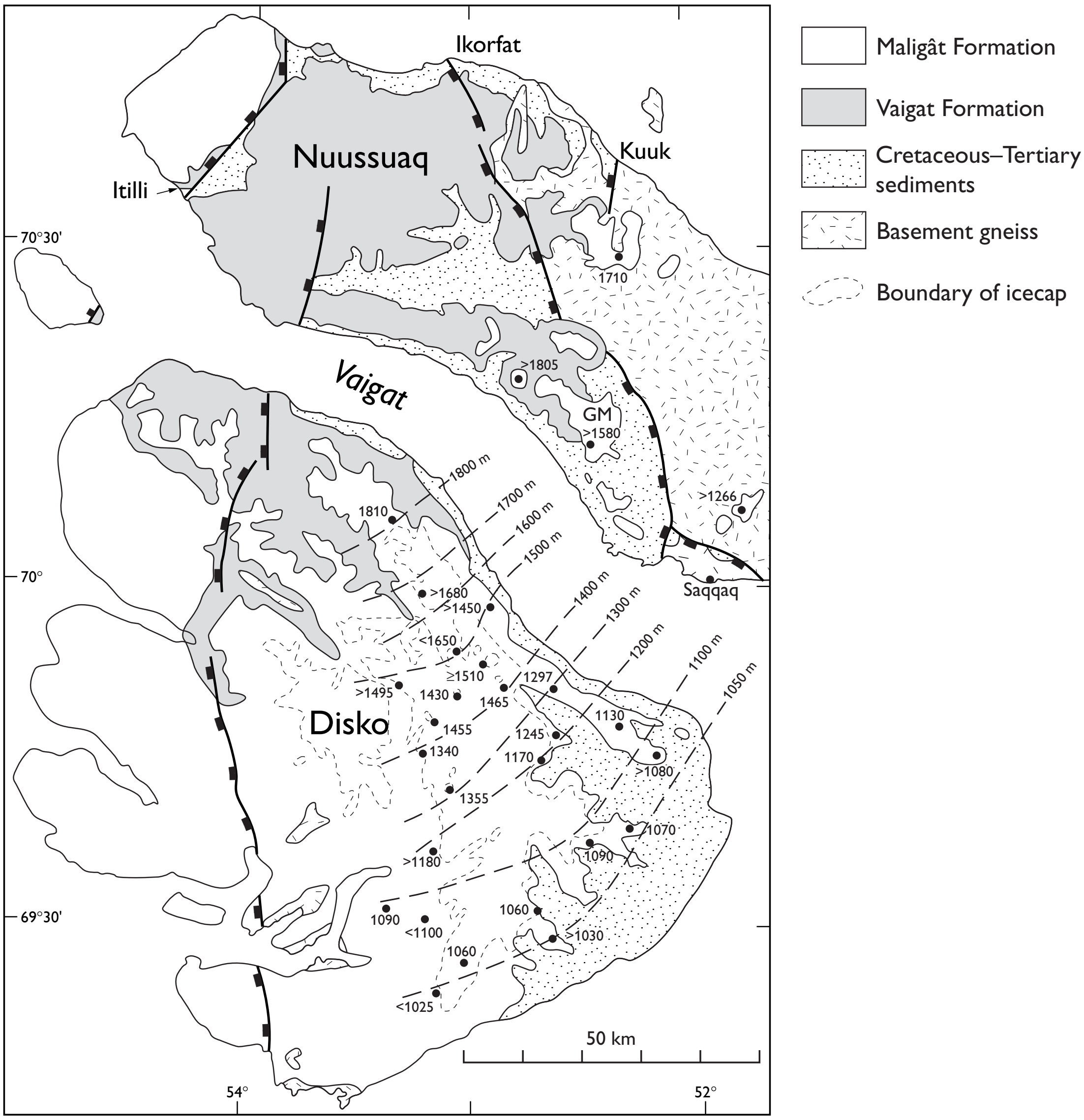
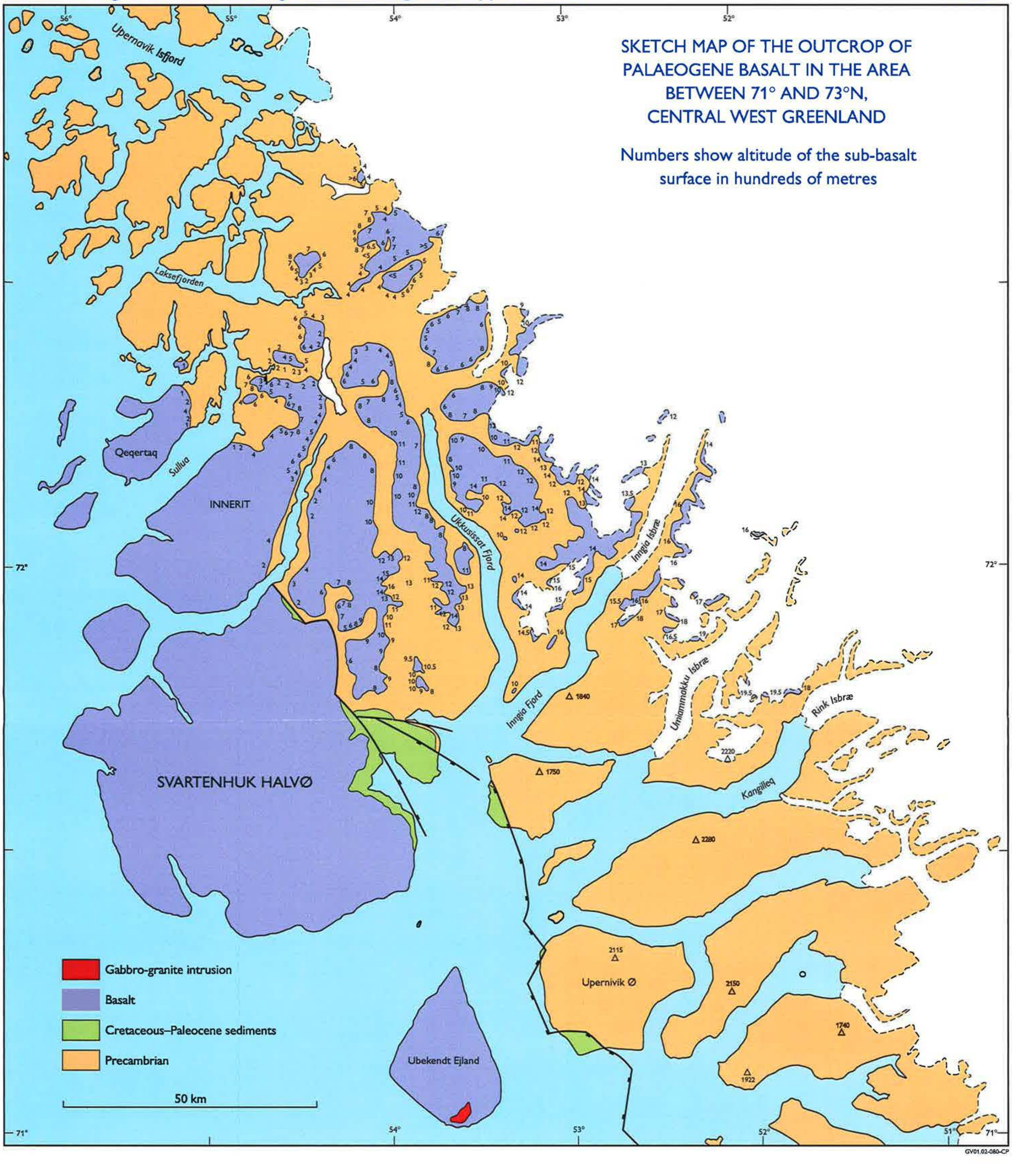


Fig. 5. Contours for the base of the Niaqussat Member/top of the Nordfjord Member in north-east Disko. GM: Giesecke Monument. Slightly modified from Larsen & Pedersen (1992, fig. 5).


SKETCH MAP OF THE OUTCROP OF
PALAEOGENE BASALT IN THE AREA
BETWEEN 71° AND 73°N,
CENTRAL WEST GREENLAND
Numbers show altitude of the sub-basalt surface in hundreds of metres
Upernavik Isfjord
Laksefjorden
Qeqertaq
Sullua
INNERIT
Ukkusissat Fjord
Inngia Isbræ
Inngia Fjord
Umiammakku Isbræ
Rink Isbræ
Kangilleq
SVARTENHUK HALVØ
Upernavik Ø
Ubekendt Ejland
Gabbro-granite intrusion
Basalt
Cretaceous–Paleocene sediments
Precambrian
50 km
GV01.02-080-CP