Recumbent Folding and Flat-Lying Structure in the Precambrian of Northern West Greenland

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Recumbent folding and flat-lying structure in the Precambrian of northern West Greenland

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[Plate 8]

The Precambrian of West Greenland north of 69° 30′ is part of a lower Proterozoic orogenic complex characterized by low dips and the lack of any clear regional trend. Well-preserved metasedimentary cover rocks occur within this complex. The gneisses of the complex are regarded as belonging to a reactivated basement.

In one area, the Umanak–Rinks Isbrae area, a structural contour map has been prepared for a marker level near the base of the metasedimentary cover. This map shows a relatively simple pattern of domes; little or no crustal shortening has taken place since the deposition of the cover sediments. However, the structure of the gneiss below is characterized by isoclinal recumbent folds.

There are metabasite bodies in the gneiss. These were emplaced into rocks that were already migmatitic gneiss at the time of basite intrusion. The metabasites were affected by the recumbent folding, so the recumbent folds must have attained their present form at a relatively late stage in the structural development of the gneiss. The recumbent folds and flat-lying structure in the gneiss are interpreted as being due at least partly to lateral adjustments in the gneiss infrastructure during the metamorphism and doming of the younger metasedimentary suprastructure. Crustal shortening has not played an important part in the structural development.

Introduction

In Precambrian metamorphic terrains it has frequently been noted that there are extensive areas in which the schistosity and banding of the rocks is flat-lying or gently dipping. Explanations of this feature have not always been forthcoming; the notion of load metamorphism, which was at one time popular, has long since been discarded (Read 1949, p. 189), but there is no generally accepted new explanation. In northern West Greenland, however, where the exposure is outstanding and the relief considerable (up to 2200 m), it appears that the general low dip of the gneisses is the consequence of the development of highly adpressed isoclinal recumbent folds which in turn are thought to be due at least partly to lateral adjustments of the gneissic basement during the metamorphism and doming of a younger supracrustal cover, in an area where there has been little or no crustal shortening.

Greenland, the world's largest island, is a major Precambrian shield area flanked to the north and northeast by Palaeozoic fold belts. The Precambrian shield area consists of an Archaean craton in south-central Greenland bordered to the north and south by lower Proterozoic orogenic complexes. In previous reviews of the Precambrian of Greenland (e.g. Pulvertaft 1968) the whole of the Precambrian of west Greenland north of the Archaean craton was said to belong to a single lower Proterozoic complex – the Nagssugtoqidian complex. However, during the compilation of the 1:500000 sheet Søndre Strømfjord–Nûgssuaq (Geological Survey of Greenland 1971) it became clear that there is a marked difference in structural style between the Nagssugtoqidian south of Jakobshavn and the Precambrian terrain north of Jakobshavn. The southern area is characterized on a regional scale by a fairly regular ENE trend and steep dips, while north of Jakobshavn, at least as far north as Melville Bay, there is no obvious regional strike, dips are generally low, and the most obvious structures are domes (Escher & Burri 1967; Henderson & Pulvertaft 1967; Escher & Pulvertaft 1968). On account of this structural contrast the Precambrian north of Jakobshavn is no longer included in the Nagssugtoqidian, but is referred to by the Geological Survey of Greenland as the Rinkian complex.

The most instructive and best known part of the Rinkian complex is the type area centred on Rinks Isbrae and extending from 70° 30′ to 72° 30′ N. A general account of the geology has been presented by Henderson & Pulvertaft (1967), and 1:100000 coloured maps of the area have been published by the Geological Survey of Greenland (sheets 71 V2 syd, 71 V2 nord and 72 V2 syd). It is with this area, hereafter referred to as the Umanak–Rinks Isbrae area, that the present account is primarily concerned.

STRATIGRAPHY

The Precambrian rocks of the Umanak–Rinks Isbrae area of northern West Greenland have been divided into two main units – the Umanak gneiss and the Karrat group.

The *Umanak gneiss* is the lower group and is most widespread in the southern part of the area (figure 1). The predominant rock type is grey biotite gneiss or hornblende–biotite gneiss of tonalitic to granodioritic composition. The rock varies from well banded to weakly banded, and in places it is nebulitic or homogeneous. Frequently the gneiss is migmatitic, the leucosome usually occurring in the form of concordant lit-par-lit layers (stromatic structure). Concordant and discordant pegmatites are also present.

Fortunately, grey gneiss is not the only rock in the Umanak gneiss unit. Among other rocks there are three major horizons which have been given the status of formation.

The lowest of these formations is the Nunataq Formation. This is 600 m thick in its maximum development, and consists of almost equal proportions of semipelitic schist, amphibolite and hornblende schist. Along one flank of its outcrop the formation shows a narrow zone in which a variety of rocks are interlayered – siliceous to semipelitic schists, quartzite, marble and calc-silicate, amphibolite, cordierite–anthophyllite rock, and graphitic schist.

Higher up in the gneiss there occurs a major marble formation – the Marmorilik Formation. Dolomitic marble, often tremolitic, dominates the formation, but at both the upper and lower borders fine-grained granular semipelite, calc-silicate, graphite schist, graphitic psammite, and quartzite intervene between the marble and the gneiss, and horizons of similar rocks occur within the formation. Current bedding has been found in quartzite at the base of the formation.

The marble formation has been subjected to a great deal of internal folding and tectonic thickening and thinning, so that its original thickness is hard to estimate. In the type section, where no internal folding could be detected, a minimum thickness of 1300 m was measured. Whatever its original thickness, the Marmorilik Formation as seen today represents a formidable volume of marble. According to the regional interpretation of the area, the marble lies in reworked Archaean basement; if this view is correct, it is one of the largest Archaean marbles known.

The third formation, the Sermikavsak Formation, is a conspicuous, 50 to 100 m thick, banded amphibolite horizon in which there is a little carbonate and biotite schist.

In addition to the horizons designated formations, there are thin horizons of banded amphibolite, biotite–garnet (–sillimanite) paragneiss or schist, and hornblende augen gneiss. Most of these are found in the gneiss stratigraphically below the Marmorilik Formation. The banded amphibolite horizons are by far the commonest. Besides amphibolite, in which garnet, diopside and biotite are often to be found, these horizons contain fine-grained more feldspathic rocks, layers of biotite–garnet (–sillimanite) schist and quartzose or graphitic rock with iron sulphide, and lenses of ultrabasic rock. It is largely the presence of the banded amphibolite horizons that allows the recognition of the isoclinal recumbent folds in the gneiss.

Of less immediate value to structural analysis, but of immense chronological interest, are the occurrences of anorthosite and gabbro-anorthosite in the Umanak gneiss. These occurrences have not yet been fully mapped out, but it is clear that their form is not regular. In the area of their maximum development the anorthositic rocks occur in zones more than 650 m wide, but elsewhere they are reduced to thin layers or merely a row of lenses in the gneiss. Everywhere, even in the broadest zones, the anorthositic rocks have been broken up into lenses which are oriented in the regional strike (figure 7, plate 8). The structure within the lenses, as expressed by hornblende and biotite schlieren, is however oblique to the general trend.

In all these features, and also in the composition of their plagioclase (*ca.* An_{70}), the anorthositic rocks of the Umanak area are very similar to the migmatized gabbro-anorthosite (without chromite) seen in many parts of the Archaean craton in Greenland, for example in the inner part of Ameralik and Godthåbsfiord (Windley 1969, p. 908). Anorthositic layers in gneiss are becoming an identity card for the Archaean, and their presence in the Umanak gneiss confirms the interpretation that this gneiss is reworked Archaean basement.

As to the ultimate origin of the gneiss itself, little can be said. One major sheet of hornblende–biotite augen granodiorite is slightly discordant to the horizons in the gneiss and is interpreted as an intrusive sheet. There are also a few thick layers of very homogeneous biotite gneiss which are regarded as having been intrusive granites. The origin of the remainder of the gneiss is obscure.

The *Karrat group* is a group of well-preserved metasediments overlying the Umanak gneiss. It is divided into two formations – the Qeqertarssuaq Formation and the Nukavsak Formation. The Qeqertarssuaq Formation is of variable thickness, reaching a maximum of 3000 m in the country west of Rinks Isbrae. Away from this area it thins rapidly and is only a few tens of metres thick in some places. Lateral and vertical variations in lithology characterize the formation. Where the formation is thickest it consists largely of rather pure quartzite. This wedges out in, and interdigitates with, garnet–staurolite (–sillimanite) schist. In addition, the formation contains amphibolite and calcareous hornblende schist, and occasional thin marbles and ultrabasic lenses. The highest rock in the formation, immediately underlying the Nukavsak Formation, is a hornblende schist or amphibolite horizon which extends throughout the entire area and is found even in places where the remainder of the formation is reduced to a few metres thickness. This facilitates the recognition of the base of the Nukavsak Formation, even at great distances.

The Nukavsak Formation is at least 5000 m thick and is remarkably uniform, showing no facies variation over 9000 km² of almost uninterrupted outcrop. The formation is a metamorphosed flysch sequence or greywacke suite, consisting of thinly interbanded fine-grained semipelite (sometimes showing grading) and pelitic schist. Minor amounts of calc-silicate form lenses in the semipelite layers. Rare horizons of rusty-weathering graphite–pyrrhotite schist provide the only departure from the general monotony of the formation.

Relations between the Umanak gneiss and the Karrat group

The banding at the base of the Karrat group is nearly always concordant with the banding in the Umanak gneiss directly below. There is generally a transition between the Karrat group and the gneiss, but the transition zone is often no more than a few tens of metres wide. The grade of metamorphism in the Karrat group increases approaching the gneiss. Most of the Nukavsak Formation is in upper greenschist facies, but towards the bottom of the formation garnet and sillimanite appear, especially where the Qeqertarssuaq Formation is thin. The schists of the Qeqertarssuaq Formation commonly carry garnet, staurolite, and also sillimanite. Kyanite has been found, and there is also a single occurrence of cordierite in the formation. Most of this formation is thus in amphibolite facies. Sometimes there are phyllonitic rocks at the boundary between the gneiss and the metasediments of the Karrat group, and this boundary is clearly a zone of movement. Where strong movements have taken place along this boundary, the zone of amphibolite facies metamorphism in the Karrat group is narrow. Along the lower flank of the Kigarsima nappe, which has carried gneiss and a thin mantle of Karrat group metasediments over right-way-up Karrat group (see later), the metamorphic gradient is inverted. Thus there is a clear spatial relationship between increasing metamorphism in the Karrat group and the proximity of the Umanak gneiss.

In spite of the transitional features summarized in the foregoing, the Umanak gneiss is regarded as the reactivated basement upon which the Karrat group was deposited. It is perhaps best to admit that this view is based on a certain bias, but the bias is one which anyone seeing the striking contrast between the Umanak gneiss and the metasediments of the Karrat group is likely to have. When, as is the case in the northern part of the area, the transformation of the lower part of the Qeqertarssuaq Formation into gneiss has taken place, it can be *seen* to have done so. The resulting granular siliceous gneiss with metasedimentary relics is quite unlike the Umanak gneiss.

Further evidence for the view stated above is the presence of anorthositic layers in the gneiss, and the distribution of metabasite bodies. The latter are metamorphosed intrusive bodies which are quite common in the Umanak gneiss but extremely rare in the Karrat group. This can mean either that most of the metabasite bodies are earlier than the Karrat group, and the host gneiss therefore earlier still, or that the crystalline gneiss fractured and admitted magma more readily than the sedimentary cover, i.e. that the physical contrast between what is now gneiss and metasediment was established before the intrusion of the metabasite bodies and hence before the folding and metamorphism that has affected these bodies. In either case the implication is that the Umanak gneiss existed before the deposition of the Karrat group.

Structure

Structures involving the Karrat group

The basis for the structural understanding of the Umanak–Rinks Isbrae area is the structural contour map of the base of the Nukavsak Formation (Henderson 1969). This map reveals a rather simple pattern of domes (figure 1), and shows that the area has not been subjected to any significant crustal shortening since the deposition of this formation. Two of the domes are slightly overturned on one side, but the others are rather gentle structures. Around the steeper domes the cover rocks in the rim synclines become tightly pinched as they are traced downwards.

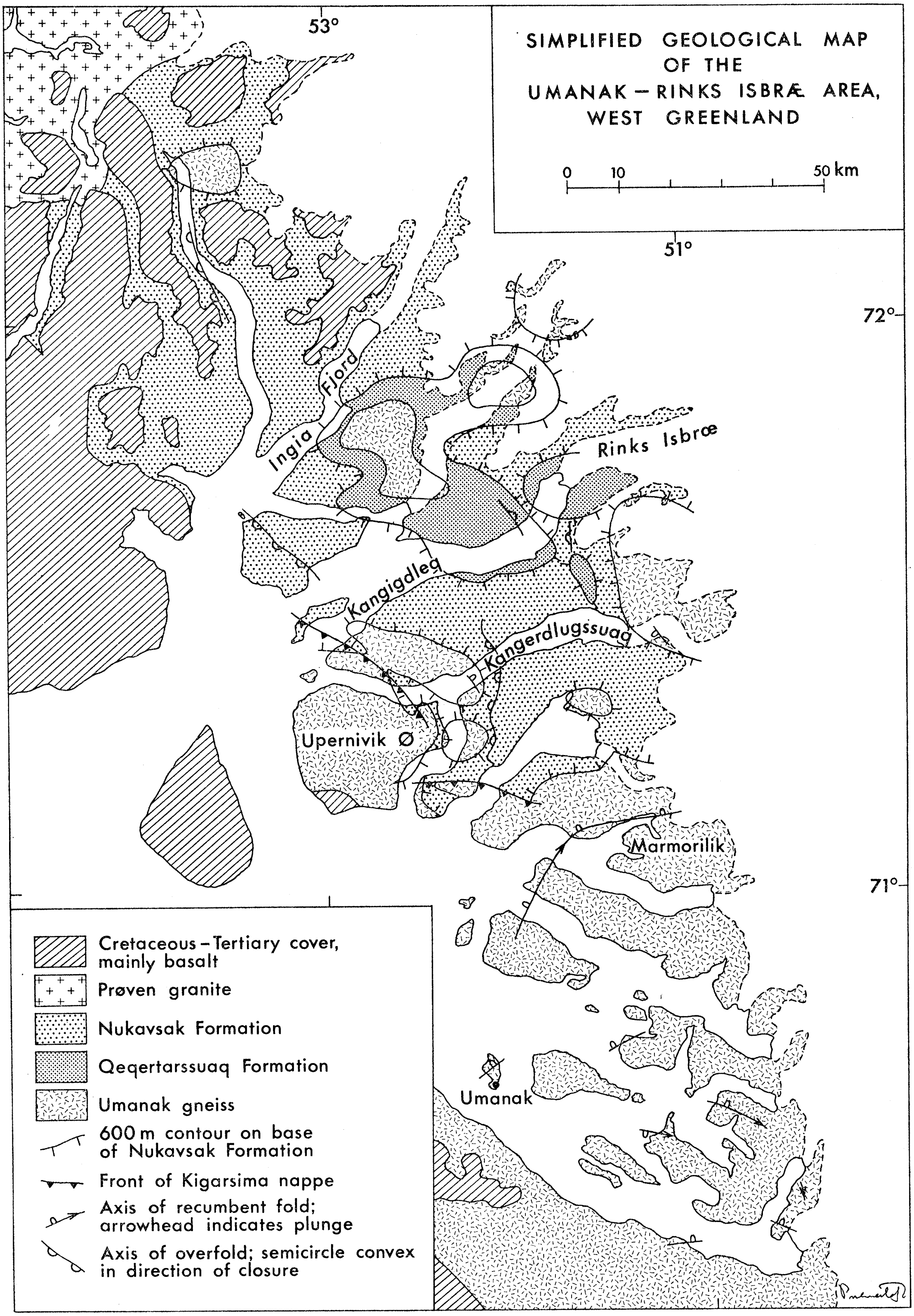


Figure 1. Simplified map of the Umanak–Rinks Isbrae area, showing the distribution of the main rock units and structures. To eliminate the complexities resulting from the interplay of alpine relief and low dips, the map shows the distribution of rock units as defined by the 600 m structural contour.

In contrast to the simple structure shown by the base of the Nukavsak Formation, the structures within the formation are complex. Folding within the formation began with the development of tight angular zig-zag folds of moderate size, and proceeded with the generation of great overturned folds which refolded the zig-zag folds. These overfolds occur entirely within the Nukavsak Formation and never involve the Umanak gneiss or the Qeqertarssuaq Formation.

The folds in the Nukavsak Formation are thought to be gravity-induced structures which slid off the slopes created by the rising domes. The axial directions and vergence of the overfolds are consistent with this suggestion.

As for the cause of the doming, Henderson (1969) has convincingly argued that the domes represent the buoyant upwellings of reactivated gneiss basement into the metasedimentary cover. The relative density of the gneiss is about 2.66 and that of the Nukavsak Formation about 2.77 (Henderson 1969, p. 138); due to a steeper thermal gradient at the time of metamorphism and deformation, the difference between these relative densities is likely to have been greater when doming took place. Ramberg (1967) has shown how a lighter layer underlying a heavier is unstable and will rise buoyantly in domes; Ramberg's centrifuge experiments provide a satisfactory explanation of the doming in the Umanak–Rinks Isbrae area, and can also explain the concordance between cover and basement (Ramberg 1967, p. 119).

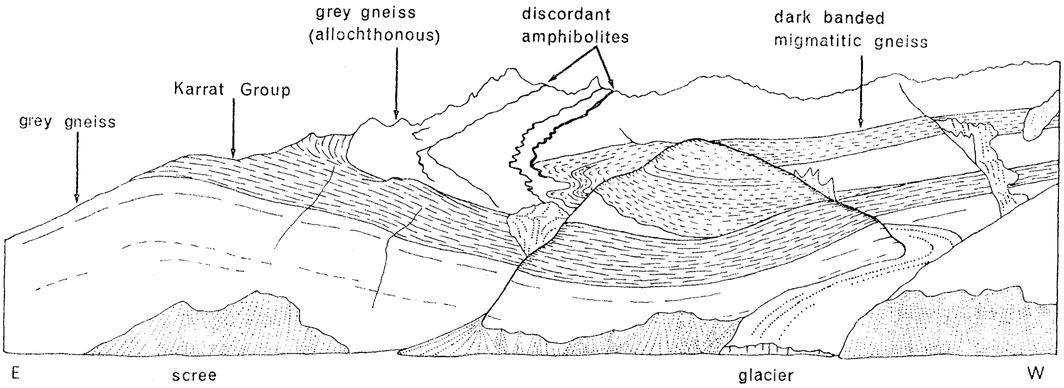


Figure 2. Sketch of the Kigarsima nappe as seen on the north side of Upernivik Ø. The summit of the ridge is 1692 m high.

The Qeqertarssuaq Formation behaved in an ambiguous manner during the doming. If a structural contour map were prepared for the base of the Qeqertarssuaq Formation (this has not been done because the gneiss-Qeqertarssuaq Formation boundary cannot be positioned sufficiently accurately in inaccessible areas) the southern part of the great dome between Kangigdleq and Ingia fiord would not be brought out. However, it is here that the Qeqertarssuaq Formation is thickest, and that quartzite dominates the formation. That the Qeqertarssuaq Formation where it is mainly quartzite (relative density 2.65 to 2.74) should be part of the buoyant mass is consistent with Ramberg's model. Furthermore, in the same area the minor folds in the Qeqertarssuaq Formation have a style which is far closer to that of folds in the gneiss than to the shapes of folds in the Nukavsak Formation, and a major overfold is seen in the Qeqertarssuaq Formation which is not reflected in the structural contours of the base of the overlying Nukavsak Formation.

Structurally, therefore, the Qeqertarssuaq Formation during deformation had more in common with the gneiss than with the Nukavsak Formation. Where the Qeqertarssuaq Formation is thin, its presence need not be taken into the account when describing the structural pattern.

After the development of domes and gravity-induced overfolds was complete, a large nappe structure, the Kigarsima nappe, carried gneiss and a mantle of Karrat Group rocks from the southwest into the area of domes (figure 2). The root of the nappe is not exposed; the structure is pivoted in the southeast but in the northwest it has moved at least 20 km to the northeast. The nappe appears to have had a momentum of its own, for where the nose of the nappe meets one of the large overfolds in the Nukavsak Formation, the latter has been deformed and buckled in a chaotic manner suggesting intrusion rather than refolding by the later nappe. Thus the nappe is most likely another expression of gravity tectonics, and not an indication of tangential stress. It is a late structure, and is not connected to the recumbent folding with which this paper is primarily concerned.

Structures within the Umanak gneiss

Superficially the structure in the Umanak gneiss appears to be simple and rather flat-lying, and to conform to the pattern of domes described in the foregoing. On closer inspection it can be seen that there are several isoclinal recumbent folds in the gneiss (figures 5 and 6, plate 8). These are particularly striking in the southern part of the area, where one recumbent fold has an overlap of about 60 km.

The disharmony between the structure within the Umanak gneiss and the simple domal pattern expressed by the base of the Nukavsak Formation was once taken as evidence that the gneiss must be older than the Karrat group (Henderson & Pulvertaft 1967), since it was regarded as unlikely that such striking recumbent folding could have taken place in the gneiss after the deposition of the Karrat group. This argument is no longer pressed, because it is now thought that the recumbent folds in the Umanak gneiss attained their present form at a relatively late stage in the structural development of the area, possibly during the generation of the domes. Evidence for this revised interpretation has been provided by the behaviour of metabasite intrusions in the gneiss.

Metabasite bodies and their structural relations

Metabasite bodies are to be found throughout the Umanak gneiss, though only locally are they abundant. The bodies form pods and blocks and also rather continuous sheets, which vary in thickness from less than a metre to more than 50 m. The original form and attitude of the bodies is not known. There is more than one generation of metabasite, but the majority of the bodies were emplaced before the last main phase of deformation in the area, and their present form can tell us much about the later deformation of the gneiss. A few sheets show field relations and textures suggestive of syn- to late-kinematic emplacement (Watterson 1968).

Many of the metabasite bodies appear at first sight to be concordant to the structure in the gneiss. However, closer inspection reveals that the margins of these bodies cross-cut migmatitic structures and banding in the gneiss at a narrow angle. Fine-grained chilled margins are occasionally recognizable. It is quite clear that the metabasite bodies were emplaced into rocks that were already migmatitic gneiss at the time of basite intrusion.

The metabasites vary from basic to ultrabasic in composition. The basic bodies are amphibolite. The larger pods and blocks are composed of plagioclase, hornblende, pyroxene (as relics), garnet, and sometimes biotite and opaque accessories. The margins are often foliated. Thinner basic bodies show equilibrium textures, and are composed of hornblende, plagioclase, and a little biotite.

The ultrabasic bodies are best described as bronzite picrites, and carry the following minerals in varying proportions: orthopyroxene, olivine, clinopyroxene, plagioclase, biotite. They resemble some of the pre-Nagssugtoqidian dykes described from the Fiskefjord area in the Archaean craton by Berthelsen & Bridgwater (1960, pp. 25–35). In spite of having field relations similar to the big amphibolite bodies and of being cut by pegmatites, the picrite bodies show remarkably little evidence of regional metamorphism. The plagioclase is sometimes densely clouded, and there is an irregular, patchy development of fine-grained pale amphibole in some slices, but otherwise primary minerals and textures are well preserved. The margins are fine-grained, although the actual contacts with gneiss are often blurred in a 10 to 15 cm wide transition zone.

In describing the structural relations it is best to consider the continuous sheets and disrupted bodies separately.

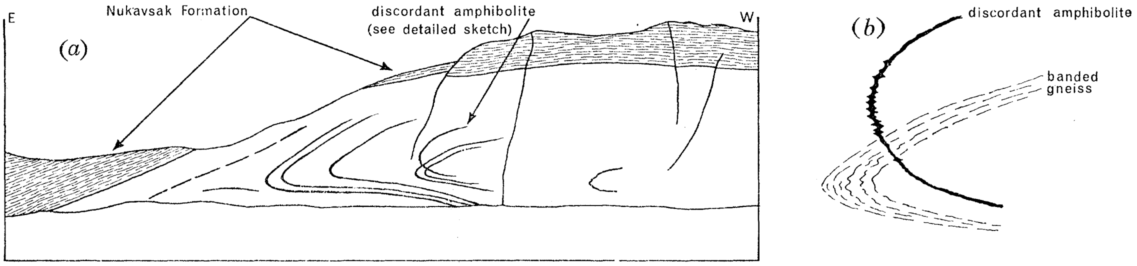


FIGURE 3 (*a*). Sketch of a cliff on the south side of Kangerdlugssuaq fiord, showing a recumbent fold and folded discordant amphibolite in the Umanak gneiss. The cliff is up to 1650 m high. (*b*) Detail of the same cliff, showing the folded amphibolite sheet in relation to the fold shown by the banding in the gneiss.

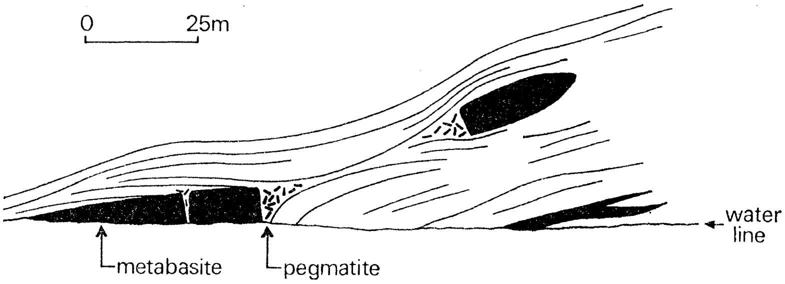


FIGURE 4. Sketch of a disrupted metabasite (picrite) body in the Umanak gneiss.

(i) *Continuous sheets.* Continuous sheets of amphibolite are seen in the gneiss in the cores of domes in the Karrat group. One example is shown in figure 3. The gneiss underlying the Karrat group here shows a distinct recumbent fold which is not reflected by the base of the Karrat group. The amphibolite sheet is affected by the *same* recumbent fold, although the axial surface of the amphibolite fold is displaced relative to the axial surface of the fold expressed by banding in the gneiss. On the flanks of the fold there is scarcely any visible discordance between the amphibolite and the gneiss banding. The situation is thus exactly what is to be expected when discordant planes are folded together (Ramsay 1967, pp. 499 and 508). The precise mechanism of folding need not be discussed here; it is the timing that is of interest. The discordant amphibolite is younger than the formation and migmatization of the gneiss, and the generation of the recumbent fold must therefore be younger still.

There are other examples of recumbent closures expressed by discordant amphibolites in the gneiss below the Karrat group. In every case the recumbent folding must be a late event which took place after the formation of the gneiss basement and the intrusion of the basite sheet, nevertheless the Karrat group is not involved in the folding. The case of the folded discordant amphibolites in the core of the Kigarsima nappe (figure 2) is not relevant, since this is a late nappe involving both gneiss and Karrat group rocks.

(ii) *Discontinuous blocks and lenses*. Isolated blocks of metabasite are to be seen mainly in the southern part of the area. As already mentioned, these are discordant to the structure in the gneiss, although the angle of discordance is often very low.

The blocks are in many cases quite obviously the disrupted portions of once more continuous sheets (figure 4). The rectangular shapes of the blocks as seen in many cliff sections are clearly not primary intrusion forms (figure 8, plate 8). Fine-grained margins are found on the long sides of the rectangles but not at the blunt ends.

Structurally the important feature of these metabasite bodies is the degree of separation of the blocks that is often seen. The block seen in figure 8 (plate 8) is hundreds of metres from the nearest similar block. This is boudinage in an extreme form, and implies a very considerable extension of the host gneiss since the intrusion of the original dykes or sheets of basite. Such a degree of extension is consistent with the isoclinal recumbent style of folding in the area, which suggests that the recumbent folds attained their present form after the intrusion of the basite bodies.

It should be noted that the banded amphibolite horizons show far less disruption than the metabasites. This is perhaps attributable to a greater amount of biotite in the banded amphibolite, and to the presence of schist bands in the horizons. On the other hand, it is possible that primary structural features such as jointing have also influenced the later behaviour of the basic rocks.

Concluding discussion

From the foregoing descriptions it can be inferred that the development of isoclinal recumbent folds and consequently of the flat-lying structure in the Umanak gneiss took place relatively late in the history of the area, and was separated from the initial formation and migmatization of the gneiss by a period of intrusion of basic–ultrabasic sheets or dykes.

It is thought that the development of the recumbent folds took place during the doming and metamorphism of the Karrat group. If the rare discordant amphibolite sheets in the Qeqertarssuaq Formation are correlatives of the folded discordant amphibolites in the gneiss, the recumbent folding of the latter must have taken place after the deposition of supracrustal formations and hence presumably during the doming. If the correlation of these basic sheets is unacceptable, there is still reason to believe that the recumbent folds were developed, or at least attained their present form, during the deformation of the Karrat group, if only because the alternative is less plausible. If the recumbent folding was entirely earlier than the deposition of the Karrat group, the metabasite bodies would have been affected not only by this phase of deformation but also by the deformation and metamorphism that affected the overlying Karrat group, and the state of preservation of minerals and textures seen in some of the metabasites would be even more remarkable than it is if only one phase of deformation affected the bodies.

It should be added that there is every reason to believe that a cover of Karrat group once extended over the southern part of the Umanak area where recumbent folds and flat-lying structure are most striking. There is not the slightest suggestion anywhere in the present exposure of the Nukavsak Formation that one is approaching the margin of a sedimentary basin, so the formation must have extended far outside its present limits.

The striking disharmony between more or less contemporaneous structures in the reactivated basement and in the metasedimentary cover is very much in accordance with the 'Stockwerk' concept of Wegmann (1935*a*). The reactivated basement is the infrastructure, the Nukavsak Formation is the suprastructure, and the Qeqertarssuaq Formation takes up an intermediate position, though not quite in the sense of Wegmann. The situation is very like that which Wegmann himself described in the east Greenland Caledonides (Wegmann 1935*b*, plate III), where recumbent folds are seen in the reactivated basement below a less folded metasedimentary cover.

It remains to explain how the recumbent folds in the Umanak gneiss formed when the structure expressed by the base of the overlying Nukavsak Formation is a relatively simple pattern of domes. Two possibilities exist: (1) modification of earlier folds by stretching and flattening connected with the rise of the domes; (2) flow folding. The two processes could of course have acted together, flow contributing to the modification of the earlier structures. The two possibilities are now considered in turn.

The Umanak gneiss is reworked Archaean basement, thus it is certain to have had a complex structure before the onset of lower Proterozoic orogenic activity. The present structures in the gneiss must therefore owe their present form partly to an earlier structural pattern in the area. Given a structural pattern such as that in the Frederikshåb area in the Greenland Archaean (see, for example, Andrews 1968), the stretching and flattening required to produce the structural pattern in the Umanak gneiss would not be very great, and certainly not greater than what is shown by the metabasite bodies to have taken place.

Most of the folds in the Umanak gneiss have the character of flow folds as described by Wynne-Edwards (1963, 1964). Lateral flow in the source layer is a corollary of gravitative dome development, so that it is not unreasonable to suggest that flow is the main cause of the recumbent folds in the Umanak gneiss. However, the available observations on late recumbent closures in the cores of the domes show that these face away from the centres of the domes. This is the opposite to what is seen, for example, in salt domes, where material flows in towards the centre of the dome, and folds likewise face inwards.

Returning to the first possiblity, the proposed extension and flattening of pre-existing structures requires stretching in the outer part of the dome. This is again not in accordance with salt dome behaviour, where it is the cover, and not the salt, that is stretched. Perhaps the active source layer in the Umanak domes is below the level of the late recumbent structures. Alternatively, the structural pattern could conceivably be the result of a single, incomplete, cycle of convective overturn in the infrastructure (cf. Talbot 1971).

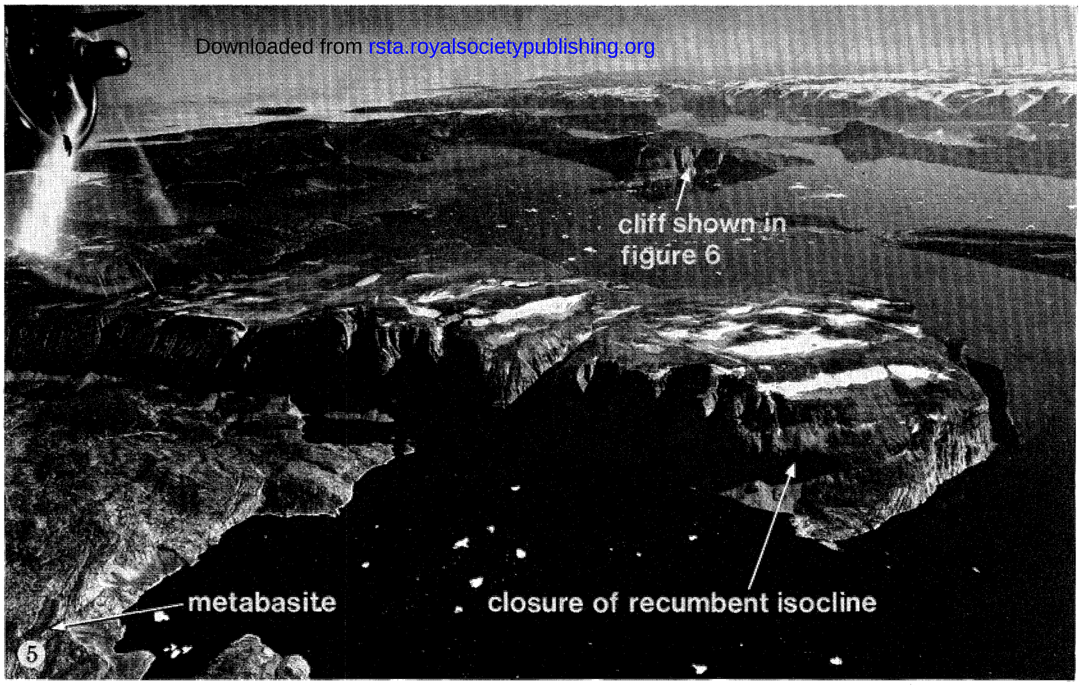
DESCRIPTION OF PLATE 8

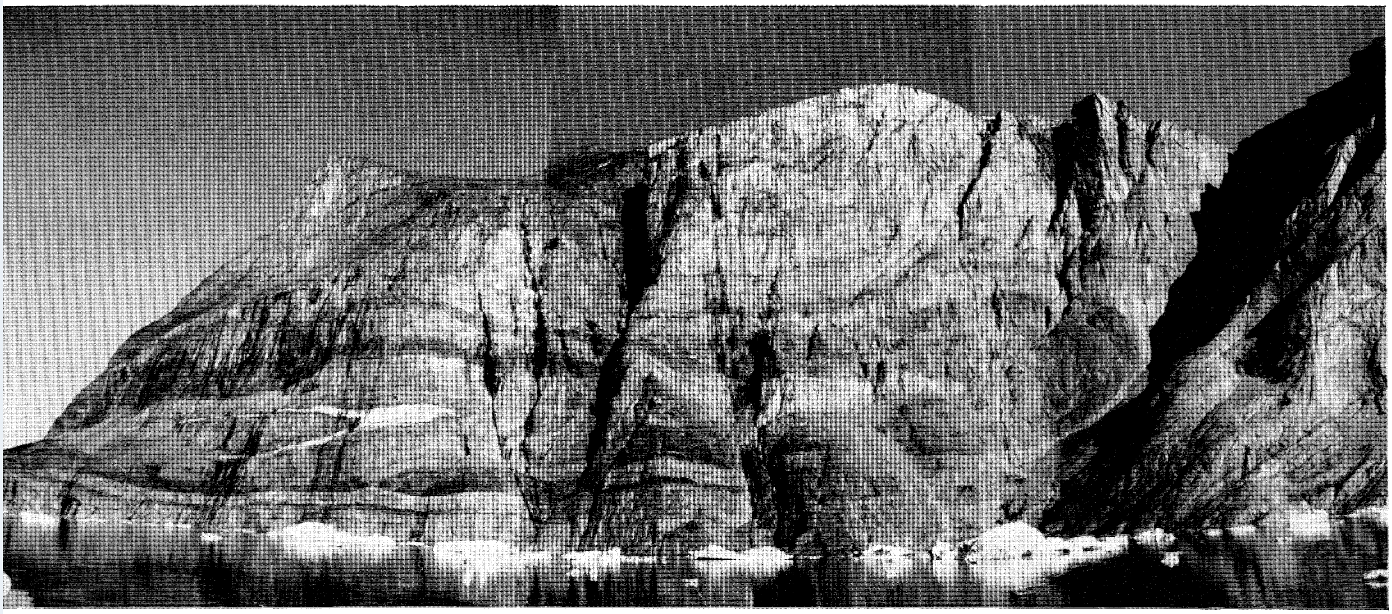
FIGURE 5. Oblique aerial photograph of the southeastern part of the Umanak area. Note the general low dip, and the very tight isoclinal recumbent fold in the lower part of the cliff in the foreground. The cliff is about 950 m high. The core of the recumbent isocline is banded amphibolite which closes at the right-hand side of the cliff. Photograph reproduced by permission (A. 373/72) of the Geodetic Institute, Copenhagen.

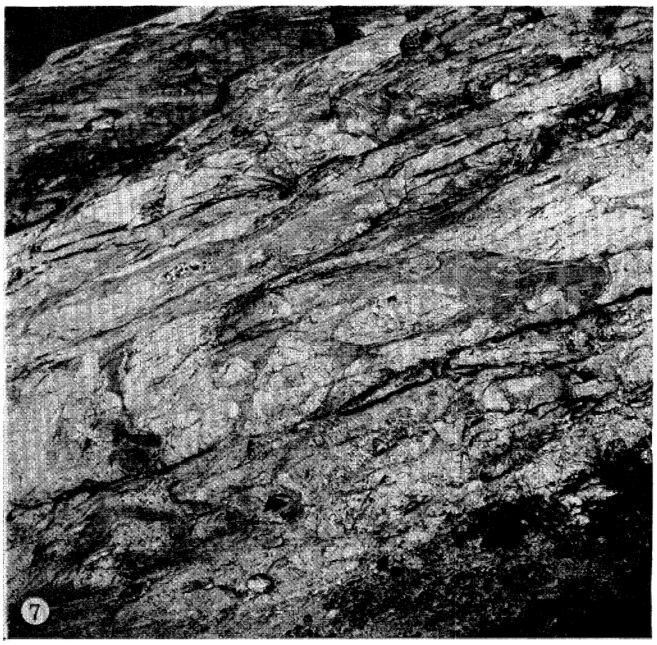
FIGURE 6. Recumbent fold in the Umanak gneiss. The main dark band is banded amphibolite with rusty layers; the white band is a marble horizon but not necessarily a correlative of the Marmorilik Formation. Height of cliff 860 m.

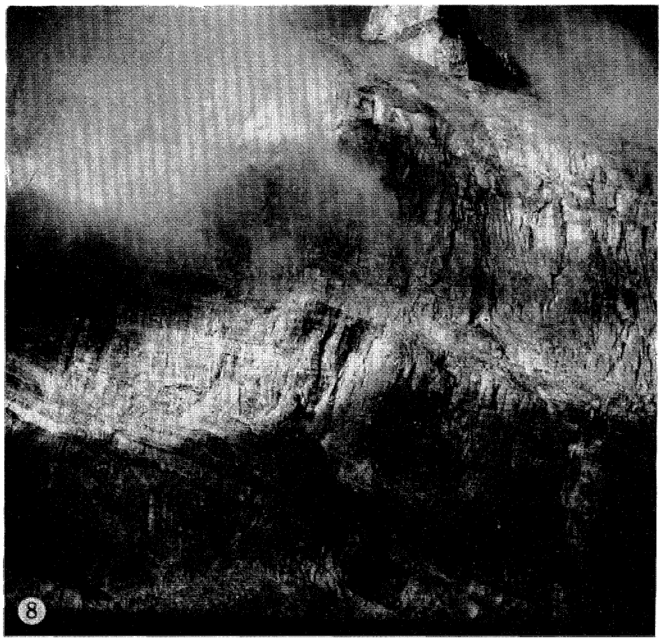
FIGURE 7. Typical outcrop of gabbro-anorthosite in the Umanak gneiss. Note the broken-up lenticular nature of the gabbro-anorthosite.

FIGURE 8. Block of metabasite in gneiss (near sea level). The dark horizon above is banded amphibolite in the closure of an isoclinal recumbent fold.









FIGURES 5 TO 8. For legend see facing page.

(Facing p. 544)

At this point the discussion is best closed, because more field work, and not more speculation, is what is now required.

The writer is grateful to the Director of the Geological Survey of Greenland for permission to publish this paper. The field work in the northern part of the Umanak–Rinks Isbrae area was carried out jointly with G. Henderson, whose painstaking preparation of the structural contour map provided the basis for our understanding of the structure of the area.

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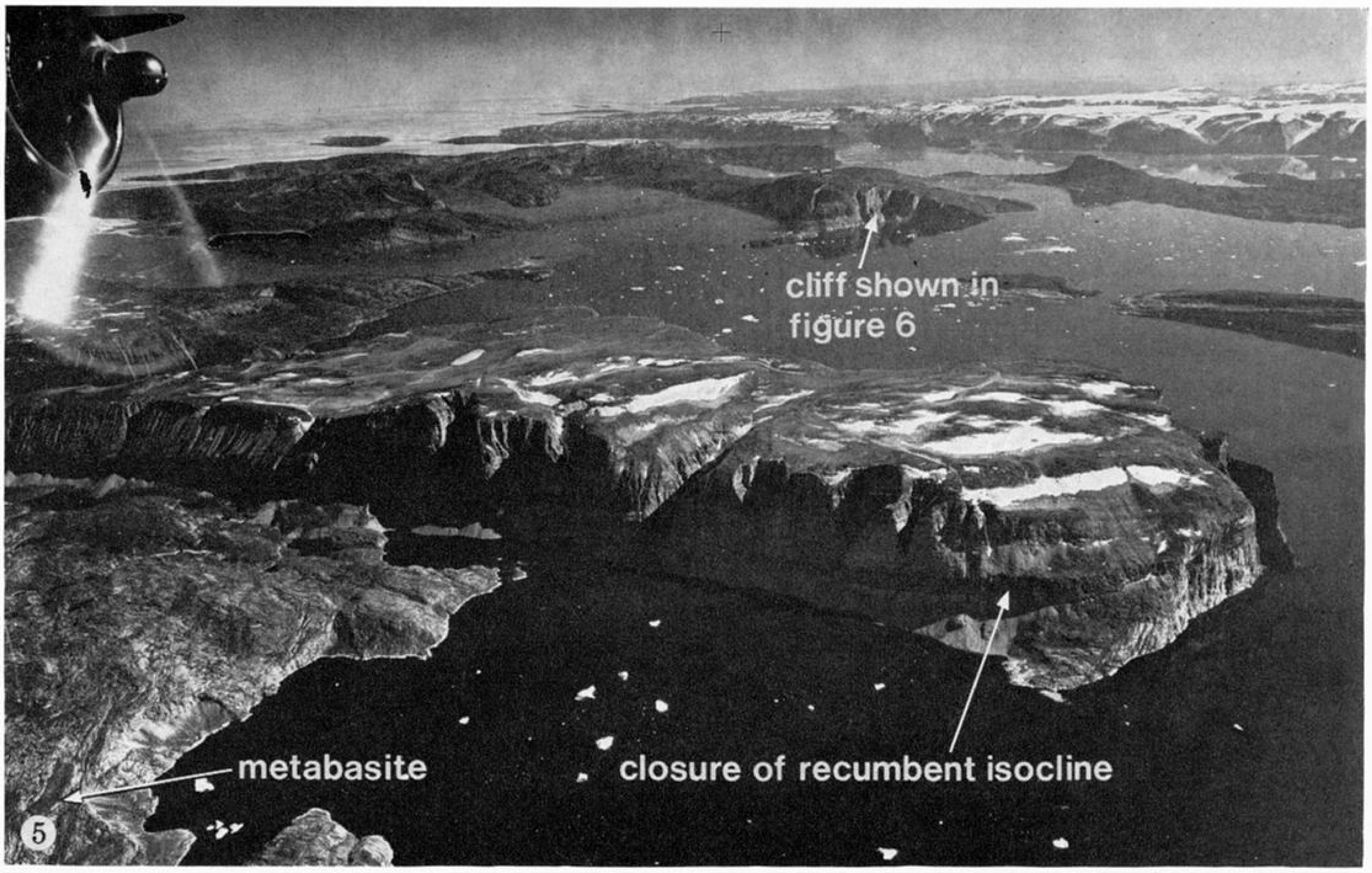

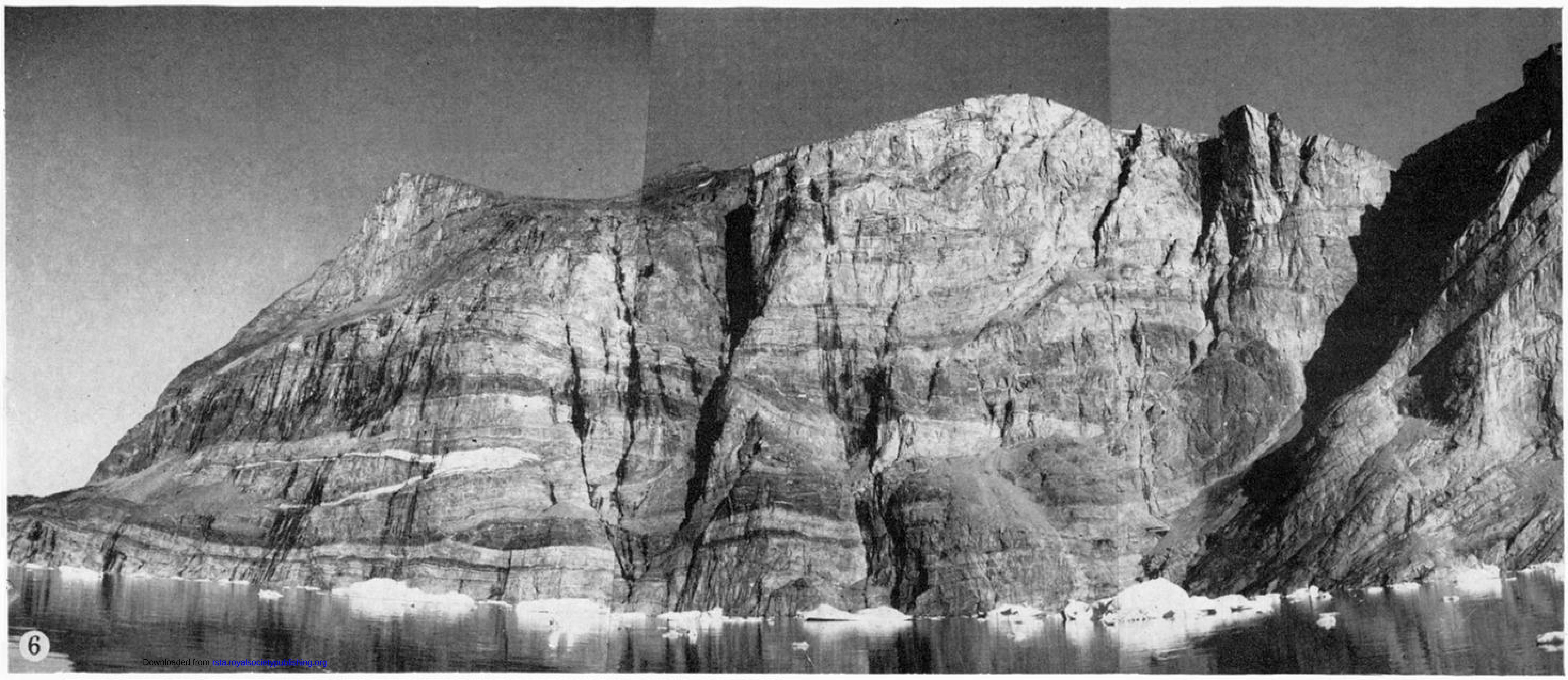

FIGURES 5 TO 8. For legend see facing page.