Rinkian mobile belt of West Greenland

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Fig. 100. In the foreground mountains on the south side of the fjord Kangerdlugssuaq showing dark metamorphosed flysch overlying light grey gneisses in a large dome structure. Alfred Wegeners Halvø is visible in the middle distance. Route 526 B no. 5954. Copyright Geodetic Institute.

Introduction

In previous reviews of the Precambrian of Greenland the whole of the Precambrian of West Greenland north of the Archaean block was said to belong to a single Lower Proterozoic complex – the Nagssugtoqidian complex. However, during recent compilation of 1:500 000 maps it became clear that there is a marked difference in structural style between the Nagssugtoqidian south of Jakobshavn and the Precambrian terrain to the north. The southern region is characterised over wide areas by a fairly regular ENE trend and steep dips, while north of Jakobshavn, at least as far north as Melville Bugt, there is no obvious regional strike, dips are generally low, and the most obvious structures are large domes. On account of this structural contrast the Precambrian north of Jakobshavn is no longer included in the Nagssugtoqidian, but is referred to as the Rinkian mobile belt. The boundary between the Nagssugtoqidian and the Rinkian mobile belts coincides with an important sinistral transcurrent fault zone at Pâkitsoq, directly north of Jakobshavn (fig. 101).

The Rinkian mobile belt can be conveniently divided into the following three areas:

(1) The Atâ Sund area in the south, dominated by a very large gneiss dome surrounded by a rim syncline of metasedimentary and metavolcanic rocks.
(2) The central Umanak – Rinks Isbræ area, characterised structurally by gneiss domes and recumbent folds, and notable for the most extensive outcrops of metasediments in the Precambrian of West Greenland.
(3) The Upernavik – Kraulshavn area in the north, characterised by granulite facies rocks and the oc-

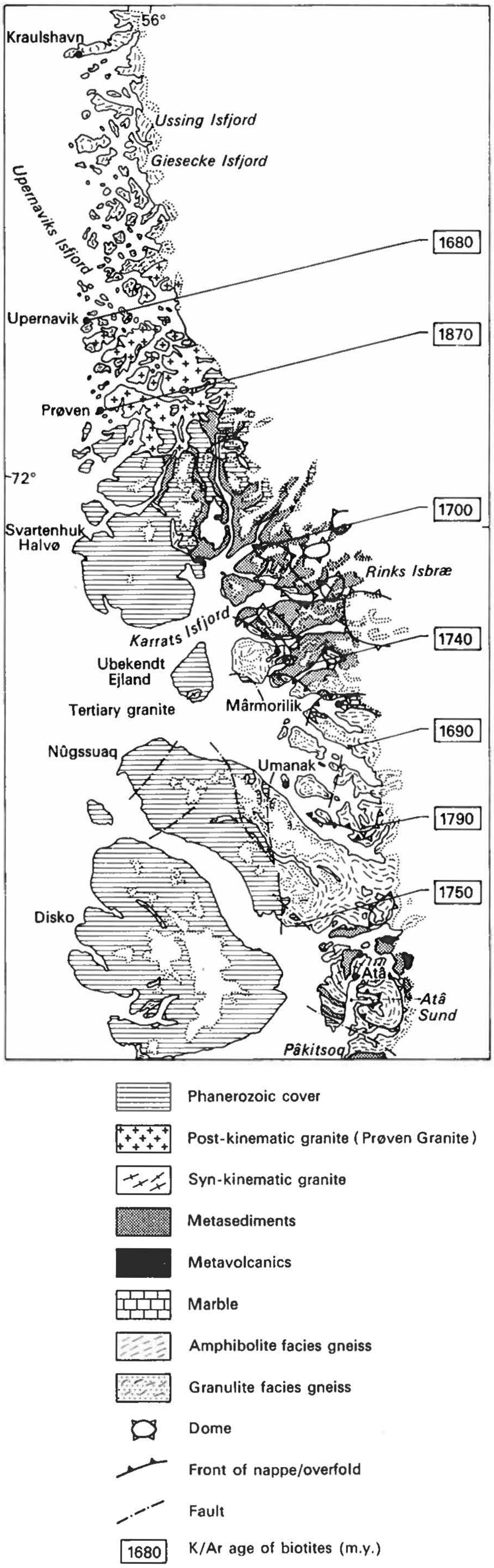


Fig. 101. Geological sketch map of the Rinkian mobile belt in West Greenland.

currence of a large intrusive granite–charnockite body.

Throughout the three areas the planar structures show relatively low dips, and the plunge of fold axes and linear structures is likewise low.

Seven K-Ar age determinations have been carried out on biotites from both gneisses and metasediments in the Rinkian mobile belt; these all gave ages in the range 1870–1680 m.y. (Larsen & Møller, 1968; Bridgwater, 1971) (fig. 101).

The Atâ Sund area

The Atâ Sund area is only known from reconnaissance work, and its stratigraphy and structural history are still tentative (Escher & Burri, 1967).

Stratigraphy

The Precambrian rocks in the Atâ Sund area can be divided into three main units: (1) the gneiss basement, which includes the paragneisses found within it; (2) a younger group of metasedimentary and metavolcanic rocks which overlies the gneiss basement; (3) a huge granite sheet developed along the contact between the younger supracrustals and the basement rocks (fig. 102).

The gneiss basement

The dominant rock type in this basement is a light grey granodioritic gneiss composed mainly of quartz, oligoclase and biotite. Granitic veins, consisting essentially of microcline and quartz, are widespread in this gneiss. Amphibolite bands and lenses are common, particularly in the southern part of the Atâ Sund area. On Arveprinsens Ejland the basement contains thick units of light reddish grey siliceous gneiss composed mainly of quartz, garnet, plagioclase and biotite; both graphite and sillimanite occur locally in minor amounts, so these gneiss units may be of metasedimentary origin.

In the northern part of the Atâ Sund area, in southern Nûgssuaq, augen gneisses are common. These often show strong cataclastic textures, suggesting that they originated by shearing of porphyritic granites. Migmatitic gneisses occur mainly in the border zone between the granite sheet and the basement.

The metasedimentary and metavolcanic rocks

Supracrustal rocks form a curved synclinal belt that extends from the northern part of Arveprinsens Ejland towards the east where it disappears under the Inland Ice (fig. 102). The contact between supracrustals and gneisses is in most places obscured by the big granite sheet. In the limited area near the Inland Ice where this granite is not present, the banding and foliation in the gneisses are everywhere concordant with the stratification of the supracrustals. Any angular discordance that may have been present has been obliterated by a strong Rinkian deformation that affected both the gneisses and the supracrustal rocks. There is however metamorphic and structural evidence that strongly suggests that the gneisses represent a basement to the supracrustal sequence and were already in a strongly deformed and metamorphosed condition at the time of deposition of the cover rocks.

The relatively low degree of deformation and metamorphism over much of the supracrustal belt has made it possible to map out two formations of supracrustal rocks: a lower formation comprising essentially quartzite and mica schists, and an upper formation consisting mainly of metavolcanic rocks and semipelitic schists.

Quartzites (including orthoquartzites) form the lower part of the lower formation, except in those areas where their place is taken by quartz-biotite schists. Thick sill-like bodies of amphibolite are common in the quartzites. The quartzites are overlain in most places by dark graphitic phyllites in which there are thin marble horizons, and garnet-staurolite schists. There are often appreciable amounts of hematite in the phyllites, and on Anap nunâ hematite accompanied by magnetite forms layers several metres in thickness. Ripple marks are common in the phyllites. The phyllites are succeeded in many places by carbonate-bearing quartzites; these are often brecciated and contain thin conglomerate horizons. At the top of the lower formation there is almost everywhere a thick sequence of chlorite-sericite schists.

The upper formation consists essentially of semipelitic schists interlayered with thick horizons of basic to intermediate metavolcanic rocks. The semipelitic schists are banded rocks, thin layers of quartz-muscovite-biotite schist alternating with thicker beds in which quartz and plagioclase predominate. Graded bedding and current bedding are locally well preserved in the quartz-plagioclase-rich rocks. Calc-silicate lenses, composed largely of quartz, actinolite, plagioclase and carbonate, are found in the semipelitic schists throughout the formation. The metavolcanic rocks are found for the most part in the lower part of the formation. They are generally highly altered rocks, occurring today as hornblende-chlorite-muscovite schists; locally, however, primary volcanic features can be recognised, in particular structures of the kind associated with lapilli tuffs.

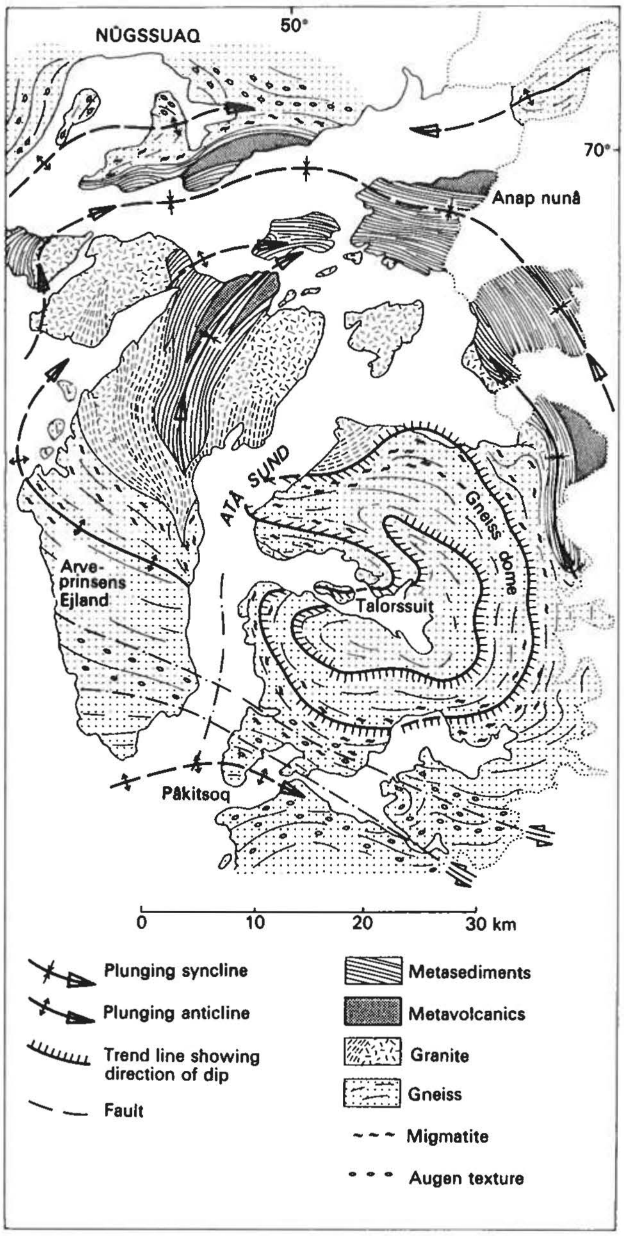


Fig. 102. Simplified geological map of the Atâ Sund area.

The granite sheet

The granite in the Atâ Sund area forms a huge sheet between the gneiss basement and the overlying supracrustal series. Its thickness exceeds 2000 m in the northern part of the body. The composition varies from granodioritic or tonalitic at the borders to granitic in the central part. The contact between granite and gneiss is always gradual, the banded and

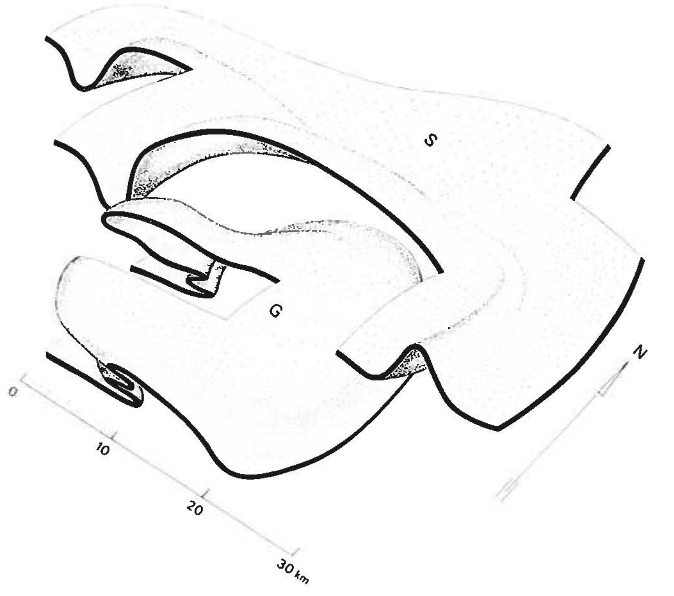


Fig. 103. Stereogram showing a hypothetical reconstruction of the Talorssuit gneiss dome (G) and the rim syncline of supracustral rocks (S).

veined gneiss changing gradually, often over several kilometres, into a foliated granite in which the strike and dip of the foliation is parallel to that in the neighbouring rocks. These observations suggest that the granite originated at least partly by modification and homogenisation of the adjacent gneisses. Where the granite borders on basic rocks in the supracrustal belt, the contact is a zone of agmatite. The central part of the granite sheet is generally very homogeneous and lacks foliation.

Structure

A large dome structure, the Talorssuit dome, occupies the central part of the Atâ Sund area (figs 102, 103). This is formed of basement gneisses and has a diameter of approximately 25 km. The western flank of the dome is strongly overturned towards the west, with the result that a nappe-like structure is developed that has an overlap of as much as 12 km. In the central part of the dome the gneiss is relatively homogeneous while in the outer part there is extensive migmatite. There is evidence that shows that the basement gneisses were deformed and metamorphosed several times prior to the updoming; at least three older phases of deformation can be recognised.

In the northern part of the Atâ Sund area, supracrustal rocks form a wide syncline which curves round the northern part of the Talorssuit gneiss dome (figs 102, 103). This 'rim syncline' is in fact built up of two synclines whose axial trends vary locally in direction. On Arveprinsens Ejland the two synclines diverge and are separated by a distinct anticline. In contrast to the basement gneisses, the supracrustal rocks show no evidence of having been strongly deformed before the formation of the dome and accompanying rim syncline. This supports the suggestion that the supracrustal rocks were deposited on an already strongly deformed and metamorphosed gneiss basement.

The large size and rather flat shape of the Talorssuit dome make it difficult to believe that it was formed by the interference of two or more phases of folds. It is considered more likely that diapiric movements played an important part in the formation of the dome structure, possibly initiated or at least assisted by the slightly lower density of the gneisses relative to the supracrustal rocks.

At Påkitsoq, in the southern part of the Atâ Sund area, a wide transcurrent shear zone cuts the south-western part of the Talorssuit dome. This shear zone, which is oriented WNW–ESE, is a zone of sinistral displacement and it marks the boundary between the Rinkian mobile belt and the Nagssugtoqidian belt to the south. Within the shear zone there are mylonite zones that can reach several hundred metres in width. The mylonites are completely recrystallised and form compact rocks which in many places are cemented and veined by quartzofeldspathic material. Thus the shear zone is probably a late-plutonic structure seen in relation to the processes which led to the up-doming and concomitant development of the rim syncline.

Metamorphism

The main constituents of the gneisses are plagioclase, quartz and biotite; hornblende is present everywhere in at least minor amounts, and is locally concentrated in mafic bands. This indicates that the gneisses recrystallised under amphibolite facies conditions. This must also have been the case in the lower part of the supracrustal succession, where staurolite, garnet and sillimanite are common. Higher in the supracrustal sequence the widespread occurrence of chlorite, muscovite and epidote, and the lack of any relics of high grade minerals, show that conditions of metamorphism never exceeded those of greenschist facies. Textural and other evidence suggests that the main metamorphism in the gneisses and lower supracrustals outlasted the last main phase of folding and doming, recrystallisation in the rocks being in the main post-kinematic.

Zones of retrograde metamorphism, in which epidote and chlorite are abundant, are found in several places. The retrograde metamorphism is always associated with the development of brittle-shear zones and mylonites. Epidote and chlorite occurring in shear fractures within the wide shear zone separating the Nagssugtoqidian and Rinkian mobile belts are thought to have developed during late movements or phases of rejuvenation of this old transcurrent shear zone.

The Umanak – Rinks Isbræ area

The Umanak – Rinks Isbræ area is the best known part of the Rinkian mobile belt (Henderson & Pulvertaft, 1967; Pulvertaft, 1973). It extends from 70°30′ to 72°30′ N and is characterised by rugged, alpine terrain (fig. 100).

Stratigraphy

The Precambrian rocks of the Umanak – Rinks Isbræ area can be divided into two main units – a lower basement dominated by gneiss (Umanak gneiss), and an overlying succession of well preserved supracrustal rocks (the Karrat Group). The reasons for regarding the lower unit as a reactivated basement to the cover rocks of the Karrat Group will be given in a later section.

The basement (Umanak gneiss)

The basement is exposed throughout the southern and south-western parts of the area, and in the cores of domes to the east and north (fig. 104). The predominant rock is grey biotite gneiss or biotite-hornblende gneiss of tonalitic to granodioritic composition. Frequently the gneiss is migmatitic, the leucosome usually occurring in the form of concordant lit-par-lit layers. Concordant and discordant pegmatites are also present. In the area south of Mârmorilik there is an extensive slightly discordant body of homogeneous biotite-hornblende granodiorite of generally coarse grain size, with prominent feldspar megacrysts. Foliation is lacking over much of this body, but is developed in narrow zones along the contacts, and to the south, where the body becomes thinner and assumes the character of an augen gneiss. South of Mârmorilik there are also considerable areas of leucocratic fine-grained granite that is younger than the coarse granodiorite.

The predominantly gneissic basement is diversified by a number of horizons of supracrustal rocks, of which three have been given the status of formation, despite uncertainty as to their relative ages.

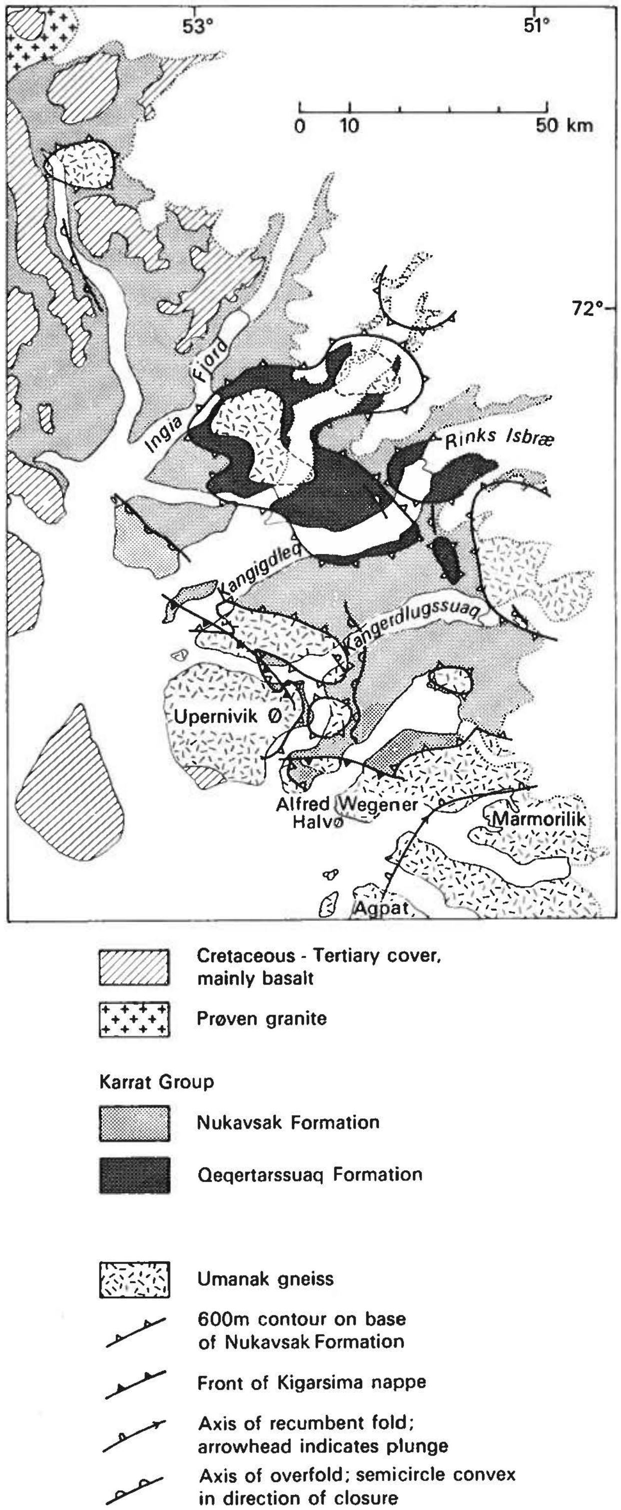


Fig. 104. Simplified geological map of the Umanak–Rinks Isbræ area, showing the distribution of the main rock units and structures.

The lowest of these formations 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.

At a higher structural level there occurs a major carbonate formation – the Marmorilik Formation – which is the most extensive and striking marker horizon in the gneiss area. Dolomitic marble, often tremolitic, and calcite marble dominate the formation (A. Garde, personal communication), but at the lower border other sediments such as fine-grained granular semipelite, calc-silicate, graphite schist, graphitic psammite, and quartzite intervene between the marble and the gneiss, and thin horizons of similar rocks occur within the formation. Current bedding has been found in the quartzite at the base of the formation. An important lead-zinc deposit, the Sorte Engel ore body (Nielsen, this volume), occurs as a concordant layer in the marbles a little over midway up the succession. The Marmorilik 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 a section near Mârmorilik where no internal folding could be detected, a minimum thickness of over 1000 m has been measured.

Structurally the highest of the three horizons within the Umanak gneiss that have been given the status of formation is a conspicuous, 50–100 m thick, banded amphibolite horizon in which there is a little carbonate and rusty-weathering biotite schist.

In addition to the horizons designated formations, there are thinner horizons of banded amphibolite, biotite-garnet (-sillimanite) paragneiss or schist, and hornblendic augen gneiss in the basement.

There are important occurrences of anorthosite and leucogabbro in the Umanak gneiss in the southern part of the Umanak – Rinks Isbræ area. 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 rows of lenses in the gneiss. Everywhere, even in the broadest zones, the anorthositic rocks have been broken up into lenses which are orientated parallel to the regional strike. The structure within the lenses, as expressed by hornblende and biotite schlieren, is however oblique to the general trend.

In all these features, as well as in the composition of their plagioclase (*c.* An_{70}), the anorthositic rocks of the Umanak – Rinks Isbræ area are very similar to the migmatised anorthosites and leucogabbros seen in many parts of the Archaean craton in Greenland (Bridgwater *et al.*, this volume).

The supracrustal cover (Karrat Group)

The thick sequence of well preserved supracrustal rocks that constitutes a cover series in the Umanak – Rinks Isbræ area is referred to as the Karrat Group. The Karrat Group is divided into two formations: the Qeqertarssuaq Formation (lower) and the Nukavsak Formation (upper).

The Qeqertarssuaq Formation is of variable thickness, reaching a maximum of 3000 m in the country west of Rinks Isbræ. 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 characterise 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. A few thin slightly discordant sheets of amphibolite occur in the quartzite in the inner part of Kangigdlek fjord. The highest member 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 Qeqertarssuaq Formation is reduced to a few metres in thickness. The contrast between the dark grey or almost black colour of this hornblende schist-amphibolite horizon and the brown tone that characterises the Nukavsak Formation enables one to map the boundary between the Qeqertarssuaq and Nukavsak Formations accurately even in areas where the outcrops are completely inaccessible.

The Nukavsak Formation is the most widespread formation in the Umanak – Rinks Isbræ area, dominating the country from Alfred Wegeners Halvø to the northern limit of the area, and giving the mountains and slopes to the fjords their sombre grey-brown colouring. The formation has been estimated to be of the order of 5000 m thick and is remarkably uniform, showing no lateral or vertical variation in facies over 9000 km² of almost uninterrupted outcrop. The sequence consists almost exclusively of alternating fine-grained semipelite and pelitic schist. Bed thicknesses vary, being generally measurable in decimetres though beds over 2 m do occur. The semipelitic layers have been seen in places to be graded, but sole structures have not been observed (such structures would be liable to have been planed off by bedding-plane movements during the extensive folding that the formation has undergone). The rocks consist essentially of quartz, plagioclase An_{25-35}, biotite, muscovite and small amounts of secondary chlorite. The semipelite shows a predominance of quartz and plagioclase, while the pelitic schist consists mainly of micas and small amounts of chlorite. The semipelitic layers are interpreted as metamorphosed immature or muddy sandstones deposited by turbidity currents, while the pelites represent shales. The formation as a whole has the character of a flysch.

A distinctive feature of the semipelitic layers is the not uncommon occurrence of pale greenish grey lenses and discontinuous layers of calc-silicate seldom exceeding 10 cm in thickness. The calc-silicate rock is fine-grained, and consists mainly of quartz, actinolite, calcic plagioclase and carbonate. The calc-silicate material is regarded as a product of diagenetic and metamorphic segregation, since calc-silicate lenses have been seen in fold closures oriented at a wide angle to the bedding but parallel to the axial surface of the folds.

The only departure from general monotony in the Nukavsak Formation is the occurrence of rare horizons of rusty-weathering graphite-pyrrhotite schist. One such horizon is prominent in Kangerdluarssuk fjord.

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.

There is a broad similarity between the stratigraphy of the Karrat Group and that of the supracrustal belt in the Atâ Sund area. The main contrast between the two successions is in the amount of metavolcanic material; amphibolite of presumed volcanic origin is only a very minor constituent of the Karrat Group.

Relations between the Umanak gneiss and the Karrat Group

No angular discordance or basal unconformity has been observed at the base of the Karrat Group. However, the preservation of an angular unconformity could hardly be expected in an area which has undergone the degree of deformation and metamorphism that has taken place in this part of the Rinkian mobile belt. The banding at the base of the Karrat Group is nearly always parallel to the banding in the Umanak gneiss directly below. There is generally a transition between the metasediments and the gneisses, but the transition zone is often no more than a few tens of metres wide. The grade of metamorphism in the Karrat Group increases from upper greenschist facies to amphibolite facies as the gneiss is approached. Sometimes there are phyllonitic rocks at the boundary between the gneiss and the metasediments, and the 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.

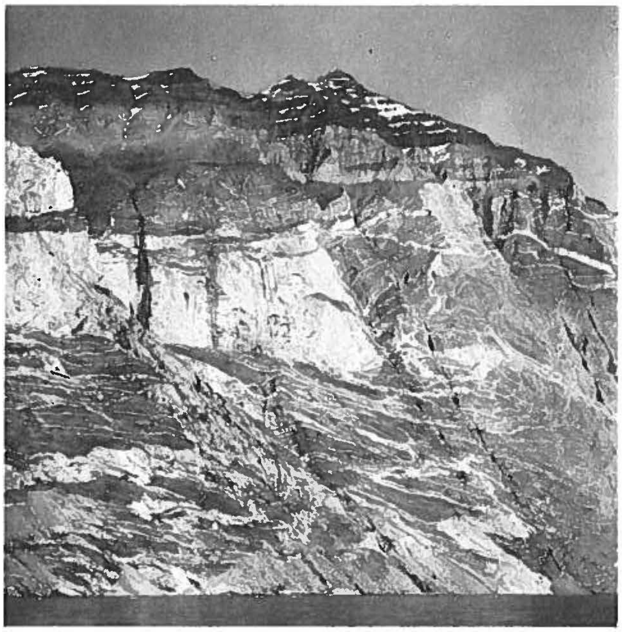


Fig. 105. Intense granite veining in the lower part of the Nukavsak Formation in the northern part of the Umanak–Rinks Isbræ area. Tertiary plateau basalt caps the mountains. Height of the cliff about 1100 m.

In spite of the transitional character of the gneiss-metasediment boundary over most of the area, evidence of extensive transformation of metasediment into gneiss is seen only in the northern part of the area, where a granular siliceous gneiss with metasedimentary relics quite unlike the normal Umanak gneiss has been developed at the expense of the quartzitic rocks at the base of the Qeqertarssuaq Formation.

In the northern part of the area, in particular around the northernmost gneiss dome, there is intense veining of the rocks of the Karrat Group and the underlying gneiss. The veins, some of which attain a considerable thickness (fig. 105), consist of pegmatite and fine-grained granite. The veining is one of the latest events in the development of the Rinkian mobile belt in this area.

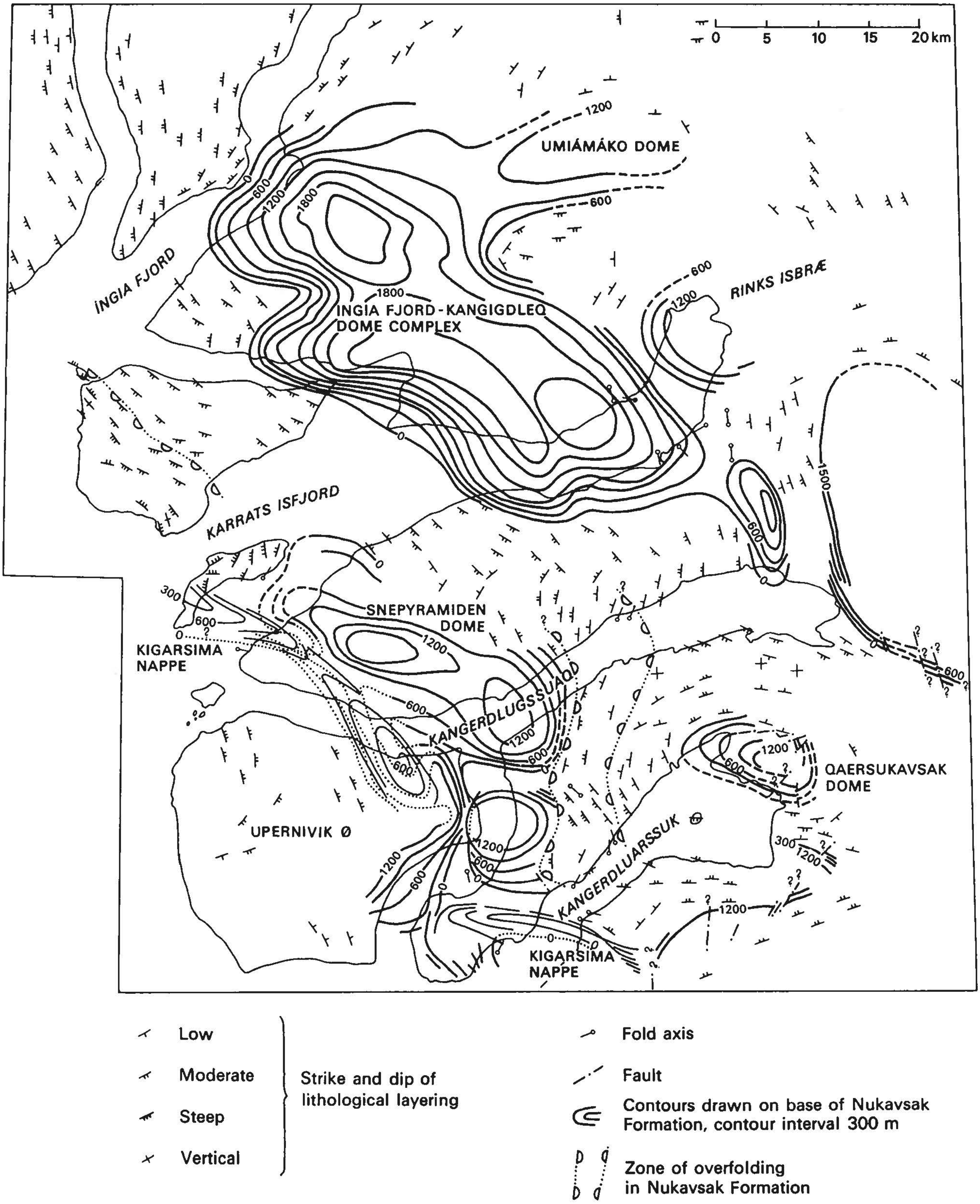


Fig. 106. Simplified structural map of the central part of the Umanak–Rinks Isbræ area, showing structural contours for the base of the Nukavsak Formation and additional structural features in the metasediments and gneisses.

Structure

Structures involving the Karrat Group

The basis for the structural understanding of the Umanak – Rinks Isbræ area is the structural contour map of the base of the Nukavsak Formation (Henderson, 1969). This map reveals a rather simple pattern of domes (fig. 106), 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.

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 buoyant upwellings of gneiss into the metasedimentary cover under plutonic conditions, and that the structures are analogous to those Ramberg (1967) produced in centrifuged models with reversed density gradient. The relative densities of the gneiss (*c.* 2.66) and Nukavsak Formation (*c.* 2.77) are consistent with this suggestion.

The Qeqertarssuaq Formation appears to have behaved as part of the buoyant mass, together with the gneiss, during the doming. This can be explained by the relative density of the quartzite of this formation which is nearer that of the gneiss than to that of the Nukavsak Formation. Where the Qeqertarssuaq Formation is thin, its presence need not be taken into account when describing the structural pattern.

After the development of the 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 south-west into the area of domes (figs 107, 108). The root of the nappe is not exposed; the structure is pivoted in the south-east but in the north-west it has moved at least 20 km to the north-east (fig. 104). 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 that the later nappe forced its way into the earlier structures. 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 either to the overfolds in the Nukavsak Formation or to the recumbent folding in the Umanak gneiss.

A biotite *lineation* is found throughout much of the Nukavsak Formation over the entire area in which it is exposed. In contrast to the wide spread of axial directions of major and minor folds, the trend of the biotite lineation is everywhere between ESE–WNW and E–W (a single exception of a SW-plunging lineation is known from the northern part of the area). The significance of this biotite lineation is not understood. Clearly it has no direct relation to any folds. It is possible that this lineation with its rather constant trend over a wide area bears a closer relation to the regional stress field and pattern of crustal movement at the time of recrystallisation than do any of the folds.

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 (fig. 109). These are particularly striking in the southern part of the Umanak – Rinks Isbræ area, where one recumbent fold, the Nunârssugssuaq nappe, has an overlap of about 30 km. This structure involves the Marmorilik Formation.

The striking contrast between the extensive recumbent folding in the Umanak gneiss and the relatively simple domal pattern expressed by the base of the Nukavsak Formation has been taken as evidence suggesting that the gneiss is older than the Karrat Group (Henderson & Pulvertaft, 1967), since it was regarded as unlikely that so much recumbent folding could have taken place in the gneiss after the deposition of the Karrat Group without the rocks of this group becoming involved in the folding. The strength of this argument depends on whether one can be sure that the recumbent isoclinal folds in the Umanak gneiss are early structures. This in turn depends on the structural evidence provided by metabasite bodies in the gneiss.

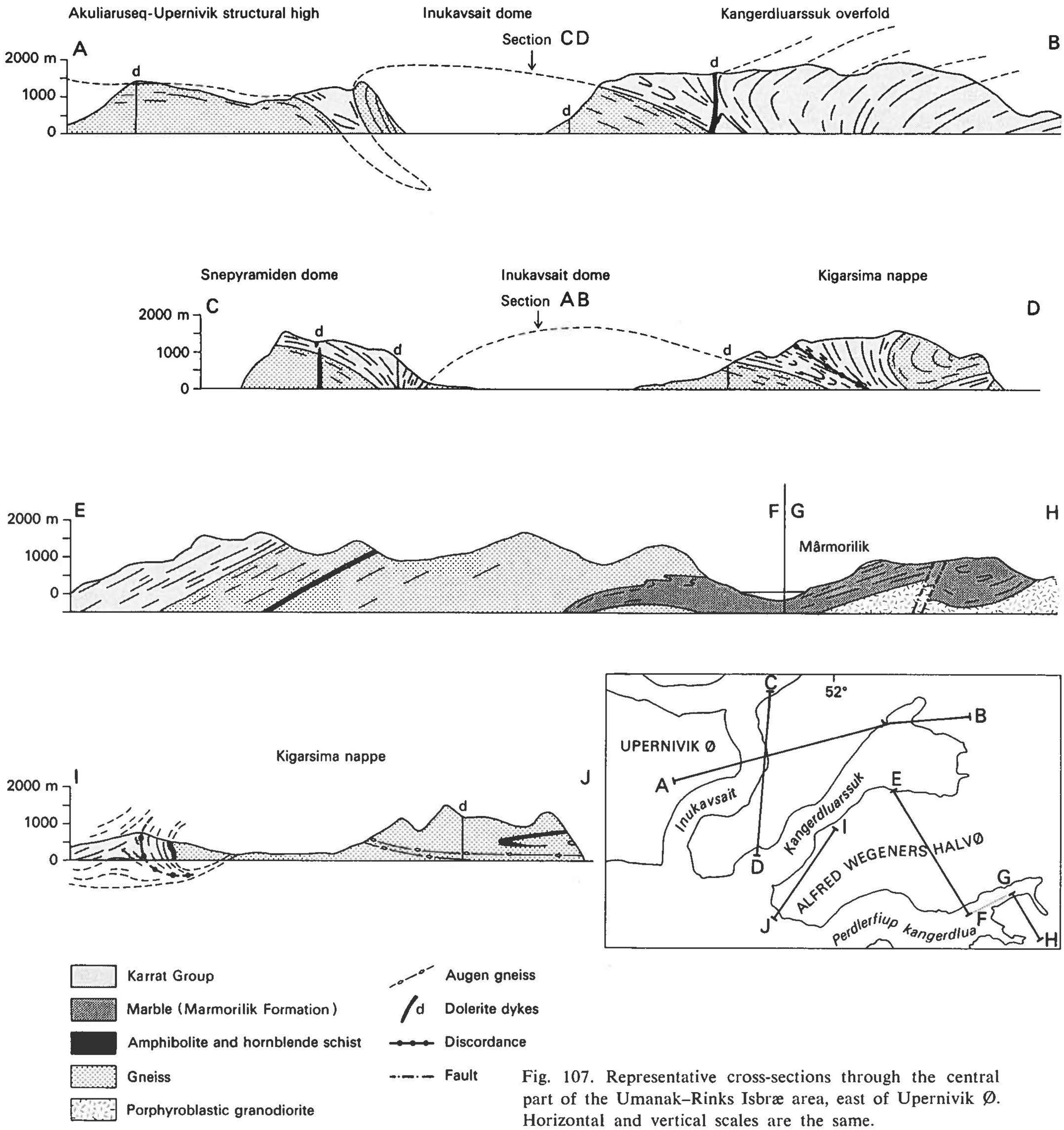


Fig. 107. Representative cross-sections through the central part of the Umanak–Rinks Isbræ area, east of Upernivik Ø. Horizontal and vertical scales are the same.

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. 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 recognisable. It is thus quite clear that the metabasite bodies were emplaced into rocks that were already migmatitic at the time of basite intrusion.

The metabasites vary from basic to ultrabasic in composition. The basic bodies are amphibolite; relic pyroxene has been observed in some of the larger bodies, while thinner bodies show equilibrium metamorphic textures and are composed of hornblende, plagioclase and a little biotite. The ultrabasic bodies are best described as bronzite picrites; 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.

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

Continuous sheets. Continuous sheets of discordant amphibolite are seen in the cores of gneiss domes in the Karrat Group. A particularly instructive example is shown in fig. 110. The gneiss here shows a distinct recumbent fold which is not reflected by the base of the overlying Karrat Group. The amphibolite sheet is however 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. Since the discordant amphibolite is younger than the formation and migmatisation of the gneiss, the generation of the recumbent fold must be still younger, whatever fold mechanism is responsible for the structure.

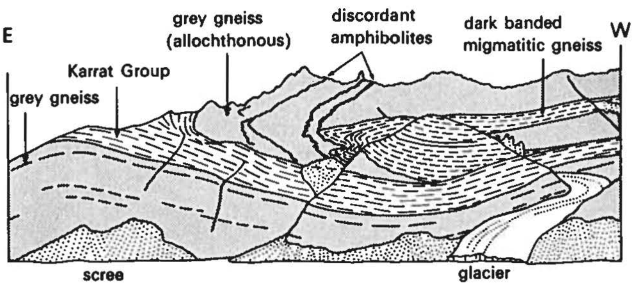
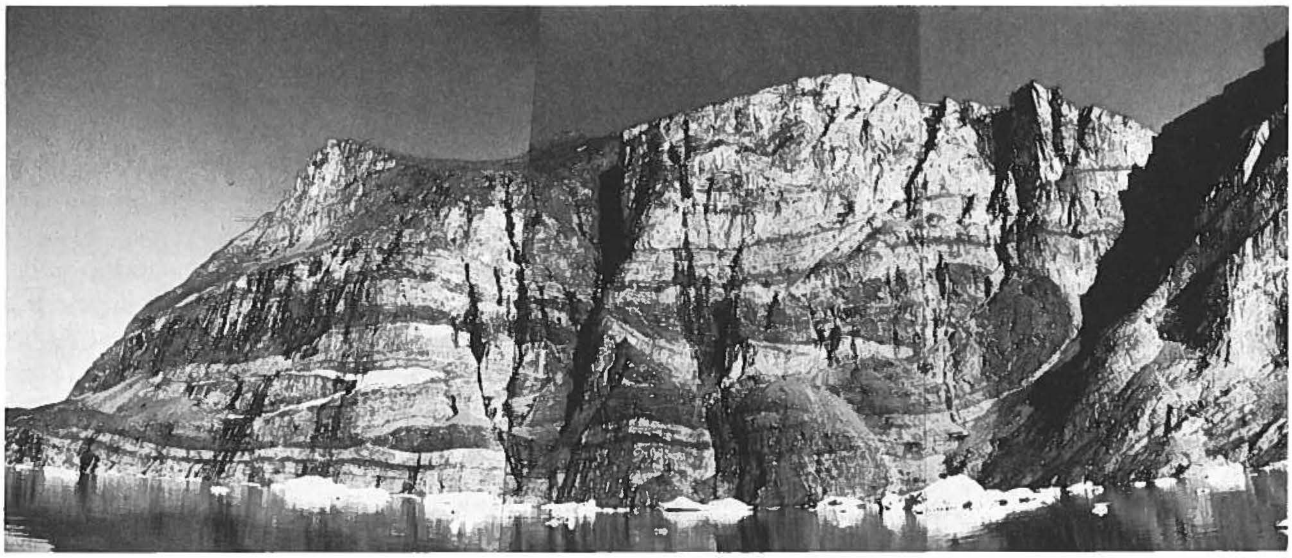


Fig. 108. Sketch of the Kigarsima nappe as seen on the north side of Upernivik Ø. The summit of the ridge is 1692 m high.

Discontinuous blocks and lenses. Isolated blocks of metabasite are seen mainly in the southern part of the Umanak – Rinks Isbræ area. The blocks are in many cases quite obviously the disrupted portions of once more continuous sheets. The rectangular shapes of blocks as seen in many cliff sections are clearly not primary intrusion forms; fine-grained margins are found on the long sides of the rectangles but not at the blunt ends. Since such blocks are now separated by distances of up to a few hundred metres, there must have been 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 this part of 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 the presence

Fig. 109. Recumbent isoclinal fold in the gneisses in the southern part of the Umanak–Rinks Isbræ area. The main dark band is amphibolite; the white band is a marble horizon. Height of cliff 860 m.



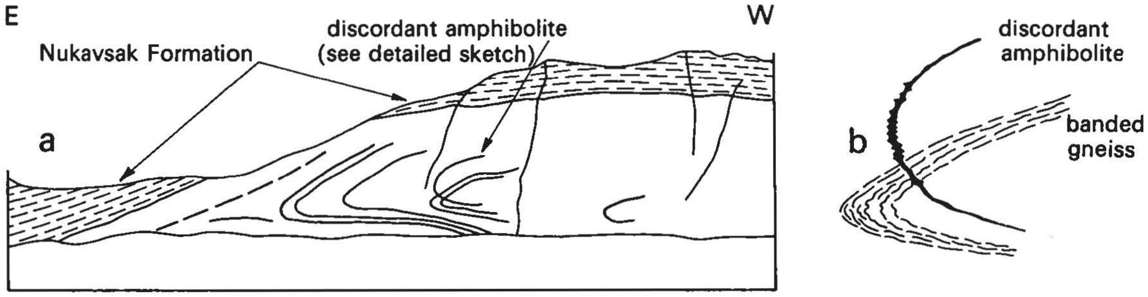


Fig. 110. *a.* Sketch of a cliff on the south side of the fjord Kangerdlugssuaq, showing a recumbent fold and folded discordant amphibolite in the Umanak gneiss. Height of cliff 1650 m. *b.* Detail of the same cliff, showing the folded amphibolite sheet in relation to the fold expressed by the banding in the gneiss.

of schist bands in these horizons. Primary structures such as jointing may also have influenced the later behaviour of the basic rocks.

From the foregoing descriptions it can be inferred that the isoclinal recumbent folds in the Umanak gneiss developed, or at least attained their present form, relatively late in the history of the area, after the intrusion of basites into already migmatitic gneiss. If the rare discordant amphibolite sheets in the Qeqertarssuaq Formation are correlatives of the folded discordant amphibolites in the gneiss, one can go further and conclude that folds such as that shown in fig. 110 were developed after the deposition of the Karrat Group, most likely during the doming. Thus structural disharmony, and the occurrence of recumbent folds in gneisses below a relatively simple dome pattern as defined by a marker horizon, do not constitute compelling evidence that the gneisses belong to an older basement.

Metamorphism

The rocks of the basement have recrystallised under amphibolite facies conditions; the quartzo-feldspathic gneisses commonly contain hornblende, and in basic horizons the following assemblages are typical: plagioclase + hornblende ± diopside; plagioclase + hornblende + biotite ± quartz. Garnet is common in mafic bands in the southern part of the area. Paragneiss and schist bands contain plentiful biotite and garnet, often accompanied by sillimanite. Calc-silicate rocks found in the outermost parts of the Marmorilik Formation invariably contain tremolite or diopside, but conditions of metamorphism in the inner part of the formation do not appear to have advanced beyond those of the greenschist facies (J. Dohlmann and A. Garde, personal communication). Cordierite-anthophyllite rocks have been found locally in two of the supracrustal horizons in the basement.

The lowest formation of the Karrat Group, the Qeqertarssuaq Formation, has also recrystallised under amphibolite facies conditions. Staurolite and garnet are characteristic components of the semi-pelitic and pelitic schists, and both these minerals may be accompanied by sillimanite. Kyanite and cordierite have been recorded in Qeqertarssuaq schists, but are rare.

The grade of metamorphism in the greater part of the Nukavsak Formation is difficult to determine on account of the lack of diagnostic features. On account of the absence of alumino-silicates in the pelitic rocks and of diopside in the calc-silicate lenses, it is thought that conditions never exceeded those of upper greenschist facies. Near the base of the formation, especially in areas where the Qeqertarssuaq Formation is thin, the rocks are much more coarsely recrystallised than in the main part of the formation; sillimanite and garnet are common, so this part of the formation recrystallised under amphibolite facies conditions.

The amphibolite facies metamorphism in the Umanak gneiss and lower part of the Karrat Group outlasted the main phase of doming and gravity-induced folding in the area. Neither platy nor prismatic minerals show any deformation. Garnets in the Qeqertarssuaq Formation frequently have rolled cores mantled by featureless garnet, showing that crystallisation began during deformation and continued (or was resumed) after deformation had ceased.

There is a clear spatial relationship between increasing metamorphism in the Karrat Group and the proximity of the Umanak gneiss. This is best exemplified by the situation around the Kigarsima nappe in Kangerdluarssuk fjord. Along the lower flank of the nappe, which has carried gneiss and a thin mantle of Karrat Group metasediments over right-way-up Karrat Group, the metamorphic gradient is inverted.

Discussion and conclusions

In the foregoing it has been tacitly assumed that the Umanak gneiss represents a basement on which the sediments of the Karrat Group were deposited; a basement which was reworked and played an active role during the later development of the area. The evidence on which this interpretation rests is by no means unequivocal; the arguments may be summarised as follows.

In spite of transitions on a small scale, there is for the most part a striking contrast between the metasediments of the Karrat Group and the underlying gneisses. The boundary between these rock divisions is readily mappable over most of the area. The gneiss underlying the Karrat Group rocks in the central part of the area bears little resemblance to the gneiss derived from the lowermost part of the Karrat Group to the north. The thinning of the Qeqertarssuaq Formation to the south is therefore not due to 'gneissification' of the lower part of this formation.

The presence of anorthositic rocks in the gneisses in the southern part of the Umanak – Rinks Isbræ area suggests that these are Archaean, since anorthosites of the type in question are characteristic of the Archaean craton in Greenland, and on a world-wide scale seem to be confined to Archaean or reworked Archaean terrains (Windley, 1973, p. 326).

The structural disharmony between the Karrat Group and the Umanak gneiss is consistent with the suggestion that the latter is an older basement, but as has been pointed out, it has come to light that several of the recumbent folds in the gneiss owe their present shapes to late movements in the gneiss. This evidence is therefore less compelling than was at first thought.

It remains to be explained how the present shapes of the recumbent folds in the Umanak gneiss arose when the structure expressed by the base of the overlying Nukavsak Formation is a relatively simple pattern of domes. Most likely the recumbent, isoclinal folds are to some extent the result of modification of earlier structures which already, prior to the deposition of the Nukavsak Formation, were tight to isoclinal like the folds in much of the Archaean craton to the south. The final shaping of the folds could be the result of any of the following processes: (1) flattening and stretching, (2) horizontal differential movements resulting in simple shear deformation, and (3) flow folding; all three processes could well have acted more or less together, and both (1) and (3) are likely to have taken place in connection with the rise of the domes.

The following tentative chronology is suggested for the Rinkian of the Umanak – Rinks Isbræ area:

(6) Close of amphibolite facies metamorphism in the Umanak gneiss and lower part of the Karrat Group.
Development of the Kigarsima nappe.
Granite veining in the northern part of the area; late pegmatites.

(5) Updoming of the basement-cover interface, formation of gravity-induced angular folds and overfolds in the Nukavsak Formation, and final stages of the development of recumbent folds in the basement.
Amphibolite facies metamorphism in the basement and lower part of the Karrat Group, upper greenschist facies metamorphism in the remainder of the group.
Folding and boudinage of metabasites in the basement.

(4) Deposition of Karrat Group. ? ↕ Intrusion of basic dykes and sheets.
(Erosion)

(3) Extensive folding and deformation.

(2) Intrusion of granitic rocks.

(1) As yet undeciphered early development of the basement, with deposition of semipelitic to pelitic rocks, extrusion of basic pillow lavas, intrusion of anorthositic rocks, formation of gneisses.

It is probable that the K-Ar biotite ages of rocks in the Umanak – Rinks Isbræ area, which fall between 1870 and 1680 m.y., correspond to the close of phase 6 of the above succession. The main Rinkian deformation and metamorphism (phase 5) may be considerably older.

The Upernavik – Kraulshavn area

The Upernavik – Kraulshavn area is only known from one summer's reconnaissance mapping (Escher & Pulvertaft, 1968). Only the outlines of its geology can be given in the following account.

Stratigraphy

The Precambrian rocks in the Upernavik – Kraulshavn area can be divided in two main units, a gneiss complex which occupies mainly the northern part of the area, and a large porphyritic granite body (Prøven granite) in the south (fig. 101).

The gneiss complex

The gneisses can be grouped in two divisions – the red-brown gneiss and the grey gneiss. The grey gneiss appears to be structurally lower than the red-brown gneiss and is only seen in the northern part of the Upernavik–Kraulshavn area.

The red-brown gneiss has a remarkably uniform lithology. Where it is not migmatised it shows a lithology and type of banding that strongly recall the

Nukavsak Formation, and in some localities the same type of tight angular folding can be seen. This suggests that this division represents a highly metamorphosed flysch sequence and that it may even be the equivalent of the Nukavsak Formation which occurs in the southern part of the area flanking the Prøven granite. A thick horizon of quartzite is developed in the red-brown gneiss east of Upernavik. There is a single horizon with ultrabasic lenses but otherwise basic rocks are virtually unknown in this division. Occasional thin graphitic layers are contained within the gneisses; one near Upernavik has been mined in the past.

The grey gneiss is rather homogeneous and in many places nebulitic. Near the contact with the red-brown gneiss it locally grades into a leucocratic siliceous gneiss or quartzite. It is characterised by the presence of many basic and ultrabasic horizons.

The Prøven granite

The Prøven granite emerges from beneath the Tertiary basalts south-east of Prøven and occupies the entire country northwards as far as Upernaviks Isstrøm. The aerial extent of granite outcrop exceeds 2500 km². Along its south-eastern margin the body has more the character of a homogeneous biotite gneiss or augen gneiss than a granite. It is flanked by the Nukavsak Formation which, near the boundary, is intensely veined by concordant to sub-concordant leucogranite sheets. At the contact the metasediments dip under the homogeneous gneisses at *c.* 45°. The contact is transitional, the semipelitic and pelitic rocks becoming gradually recrystallised to coarser rocks devoid of banding.

For the greater part the Prøven granite is a rather uniform coarse-grained rock with potash feldspar megacrysts up to 4 cm long, locally reaching 10 cm in length and sometimes showing rapakivi texture. The characteristic mafic mineral is biotite; garnet appears locally and hypersthene is a common constituent in the north-west part of the body. Here the rock is better termed charnockite or enderbite according to the plagioclase/K feldspar ratio. In places the granite has a weak foliation, and sometimes there are well oriented inclusions of fine granular semipelite.

The north-western margin of the granite is not well defined. Migmatitic granulite facies gneiss rises in steeply flanked domes in the granite and in places there are sheets of granite in the gneisses. At the contact the gneisses almost invariably dip under the Prøven granite; it is clear that the Prøven granite occupies a higher structural position than the granulite facies gneisses (fig. 112).

Fig. 111. Isoclinal recumbent fold in the gneisses west of Giesecke Isfjord. Height of cliff 620 m.

In many places the Prøven granite is penetrated by irregular sheets and veins of coarse-grained white garnetiferous leucogranite. The same leucogranite forms the granitic component of the migmatitic granulite facies gneiss which it penetrates in thin lit-par-lit veins as well as big sheets.

Structure

The structural pattern throughout most of the Upernavik–Kraulshavn area is characterised by large recumbent isoclinal folds, domes and basins. It is thus very similar to the structural pattern found in other parts of the Rinkian mobile belt.

The best structures were seen between Giesecke Isfjord and Kraulshavn. In this area the grey gneisses and overlying red-brown gneisses are folded together into a succession of large isoclinal folds (fig. 111) which face consistently to the NNW. The dip is generally low and the limbs of the folds are almost flat-lying. In a few places it can be seen that the isoclinal folds are refolded by domes, basins and even by overturned structures. The contrast between the light coloured grey gneiss which forms the core of the folds and the surrounding darker red-brown gneiss makes these structures very conspicuous in the field.

Metamorphism

The Nukavsak Formation and homogeneous gneisses along the south-eastern margin of the Prøven granite

Fig. 112. Homogeneous Prøven granite (P) overlying moderately dipping granulite facies gneisses (G), east of Upernavik. Height of cliff 750 m.

have amphibolite facies mineral assemblages, but on its north-west side this granite is a typical granulite facies rock. It often contains antiperthitic plagioclase and hypersthene, and locally platy blue quartz. The rare basic to ultrabasic lenses consist mainly of hypersthene, diopside and plagioclase. North of Ussing Isfjord the gneisses contain no hypersthene and display characteristic amphibolite facies mineral assemblages. Around Kraulshavn sillimanite is very common in the gneisses, indicating a more aluminous composition.

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