Field work in the north of the Ivisârtoq region, inner Godthåbsfjord, southern West Greenland

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The programme of field investigations in the north of the Ivisârtoq region begun in 1981 by Chadwick & Crewe (1982) was continued in 1982. Julia Park began mapping the Taserssuaq granodiorite, its host rocks and the Ataneq fault in the north-west. Our team was joined by D. Bellur, Geological Survey of India, nominally as an assistant. In this report we present only summary notes of new findings relevant to the interpretation of the geometry and chronology of this segment of the Archaean crust in southern West Greenland. We use the established terminology for the Archaean rocks of the Godthåbsfjord region.

Akilia association

Previously unrecorded, extensive outcrops of the Akilia association were found in the north where they form important structural markers (fig. 14). Whilst banded quartz-magnetite rocks and silicate facies iron formations, amphibolites and ultramafic rocks are common, hornblende-biotite-garnet gneisses are especially abundant compared with Akilia occurrences elsewhere in the Godthåbsfjord region. Enclaves of Akilia rocks are abundant in Amîtsoq gneisses close to the Ataneq fault (fig. 14) where they may form up to 50 per cent of the outcrop.

Amîtsoq gneisses and Ameralik dykes

Amîtsoq gneisses are entirely of the pegmatite-banded multiphase type. Ameralik dykes are abundant in the Amîtsoq gneisses with A, B and C types (Chadwick, 1981) the most common. Ultramafic E type dykes up to 2 m thick occur in the north. Most Ameralik dykes are broadly concordant with banding in the host gneisses and generally thicker (5–20 m) in the north compared with those further south. This variation in thickness appears to be related to decrease in the degree of deformation of the dykes from south to north. This decrease in deformation of the dykes appears to continue progressively into the Isukasia area where they are labelled the Tarssartôq dykes (Nutman, 1982).

Malene supracrustal rocks

Malene supracrustal rocks mapped in central Ivisârtoq consist mainly of amphibolites with variably deformed pillow structure. Some pillows have hornblendite composition, but most are amphibolite, these compositions possibly corresponding to the komatiitic and tholeiitic varieties described by Hall (1980, 1981). Unambiguous younging criteria are preserved in outcrops north of the main Ivisârtoq ridge, but most of the pillowed amphibolites are intensely deformed with marked *LS* fabrics. The ultramafic pillowed amphibolites deform to ultramafic schists; pillowed amphibolites with epidote-diopside matrix and cores to the pillows deform to lenticular and banded amphibolites with gradations one to the other; and the more homogeneous pillowed amphibolites lacking epidote-diopside matrix deform to

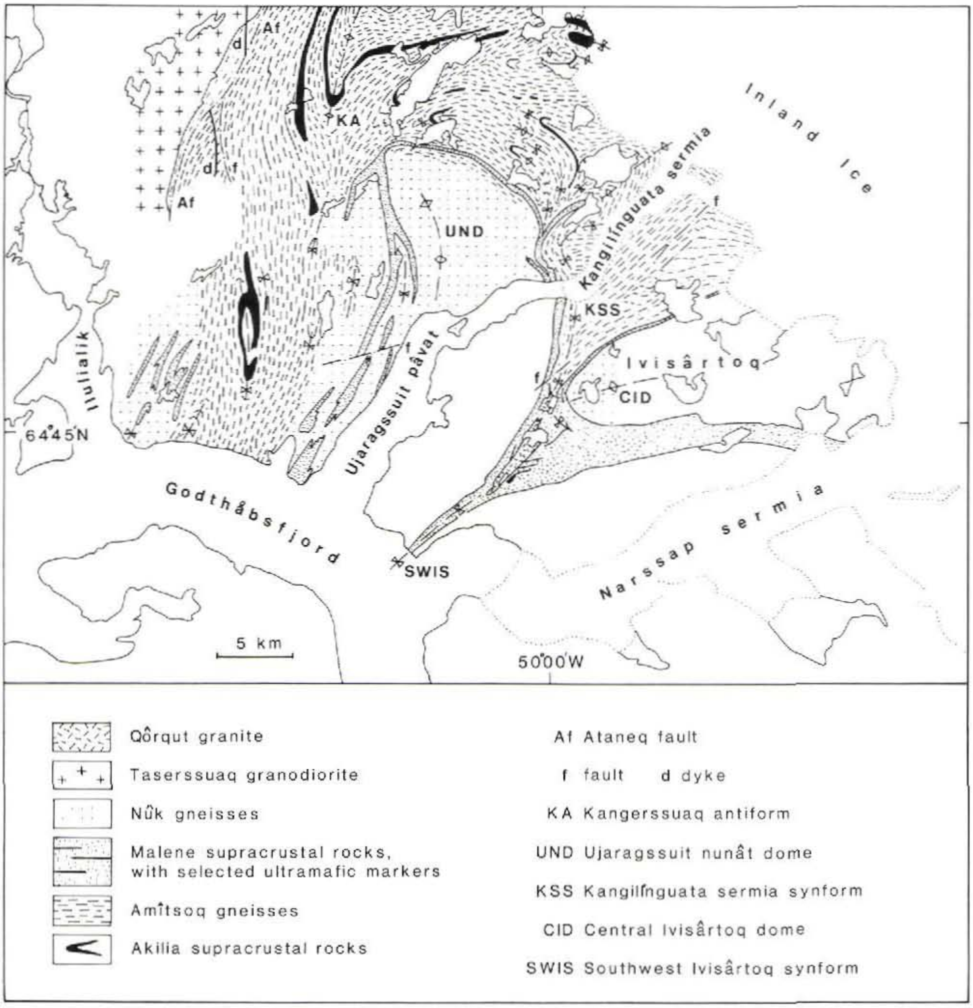

Fig. 14. Outline geological map of the north of the Ivisârtoq region based on field work in 1981 and 1982. The outcrop of Malene rocks south of the central Ivisârtoq dome is based on Hall (1981). Blank areas north of Narssap sermia and Ilulialik are to be mapped in 1983.

dark, homogeneous, schistose or flaggy amphibolites. Discordant amphibolites, some with feldspar aggregates, some with relict doleritic texture, occur locally in the deformed pillowed amphibolites. Sheets of metaperidotite, one forming a critical structural marker immediately east of the central Ivisârtoq dome (fig. 14), are more common than indicated by Hall (1981). Metasedimentary rocks are relatively common in south-west Ivisârtoq. Most are quartz-biotite schists, but some are garnetiferous like the Qilángârssuit Malene Gneiss of north-west Buksefjorden (Beech & Chadwick, 1980). Local intensely flattened quartzo-feldspathic sheets associated with these schists may be of Nûk affinity. Outcrops of Malene rocks south-east of Ilulialik (fig. 14) are dominated by garnetiferous quartz-rich gneisses with local sillimanite.

Nûk gneisses

Coastal outcrops on the north-west of Ujaragssuit pâvat (fig. 14) display an early dark phase of gneiss which is extensively invaded by younger pale homogeneous gneiss. Both types are pegmatite-banded and cut by locally abundant thin sheets of streaky gneiss. Pegmatite-banded grey gneisses with concordant sheets of amphibolite 30–50 m thick occupy most of the domal area (UND, fig. 14) north of Ujaragssuit pâvat. These thick sheets of amphibolite are especially abundant below the main Malene marker on the south-east of the dome, suggesting sill-like injection of the precursors of the grey gneisses into the original Malene amphibolite pile. Towards the core of the dome there is an increase in pegmatite and structural disorder. The grey gneisses are progressively absorbed by the pegmatite sheets and reduce in many instances to wisps. Amphibolite survives in the pegmatites as agmatite trains or isolated enclaves. Fragments of hornblendite are also common. The gneisses on the coast of Ujaragssuit pâvat and in the dome (UND) to the north are regarded as Nûk gneisses on the grounds of their concordant contacts (believed to be intrusive) with the Malene amphibolites and the absence of unambiguous Ameralik dykes.

Discordant and concordant sheets of grey homogeneous gneiss and associated white pegmatites are locally abundant in the Amîtsoq gneisses in the area south-east of Kangilínguata sermia. The sheets vary in thickness from a few centimetres to a few hundreds of metres. Many are parallel to fold axial surfaces of parasitic closures related to the major synform labelled KSS (fig. 14), but some have a similar relation with older fold closures. These gneisses have distinct *LS* fabrics, the *L* fabric being coaxial with folds and the regional mineral lineation. Their discordant relation and the presence of *LS* fabrics suggest the sheets are of Nûk affinity. Amîtsoq gneisses commonly become schlieric and progressively incorporated in these grey gneisses, the transformation being similar to that described from north of the dome at Ujaragssuit nunât (Chadwick & Crewe, 1982). Ameralik dykes, including the distinctive C AD types, survive as fragments in the composite gneisses. These composite gneisses are cut by undeformed granitic sheets and pegmatites regarded as part of the Qôrqut granite complex in the Ivisârtoq region. Gneisses within the western part of the central Ivisârtoq dome (CID, fig. 14) are pegmatite-banded like those in the Ujaragssuit nunât dome, but amphibolite sheets are not common. The paucity of amphibolite sheets may be more apparent than real because of poor exposure in the central western part of the central Ivisârtoq dome. Close to the boundary with the Malene amphibolites and ultramafic rocks surrounding the dome the gneisses are homogeneous with diffuse banding which appears to be of primary igneous origin.

Taserssuaq granodiorite

The Taserssuaq granodiorite (Allaart *et al.*, 1977) in the north-west of the Ivisârtoq region (fig. 14) is typically coarse to medium grained; in places it is porphyritic with feldspar megacrysts up to 4 cm long. Localised deformation has produced an *S* fabric in some parts of the granodiorite. Whilst the granodiorite is largely homogeneous, there are local variations including a dioritic mass about 200 × 500 m in size with transitional contacts. A solitary xenolith of interbanded granite, granodiorite and diorite was noted within the main body of the granodiorite. Other xenoliths are abundant (up to 80 per cent) near the boundary. These xenoliths include Amîtsoq gneisses, paragneiss which may be of either Akilia or Malene affinity, pyroxenites, doleritic amphibolites and coarse-grained gabbros. The Taserssuaq granodiorite has a diffuse boundary zone (0.5 to 1 km wide) with gneisses to the east (fig. 14). Within this zone the proportion of granodiorite increases westward at the expense of Akilia rocks, Amîtsoq and younger gneisses and pegmatites. The granodiorite within the zone is not deformed, except that there is a local *S* fabric which is itself deformed by younger shear zones. This diffuse boundary zone is interpreted as an intrusive contact. At two localities the granodiorite is fault-bounded with tectonic fabrics related to the faulting restricted to a zone about 2 m wide.

Sheets of leucocratic gneiss up to 100 m thick are abundant in a tract up to 3 km wide adjacent to the eastern boundary of the Taserssuaq granodiorite. They cut Amîtsoq gneisses and Ameralik dykes, but their affinity is uncertain. Contacts with the Amîtsoq gneisses are commonly diffuse. Some sheets contain feldspar augen and some are garnetiferous, but the sheets are rarely banded.

Qôrqut granite

Pale grey granite and associated pegmatites occur in large masses in the core of the synform in south-west Ivisârtoq (SWIS, fig. 14). They are locally garnetiferous. The granites have an *S* fabric and parallel diffuse pegmatite layering, both broadly parallel to the north-east trend of the synform. However, neither granite nor pegmatite have linear fabrics like the Nûk, Malene and Amîtsoq rocks in the Ivisârtoq region. The pegmatites cut grey gneisses (regarded as Nûk gneisses) containing enclaves of Amîtsoq gneisses. The granites and pegmatites in south-west Ivisârtoq are correlated with the Qôrqut granite on the basis of their lack of a linear fabric, their cross-cutting relations with older rocks, and their Rb-Sr whole rock isotopic age of 2437 ± 60 Ma as reported by Hall (1981). Similar granites and pegmatites occur in discordant sheets in parts of the Amîtsoq and Nûk gneisses in north-east Ivisârtoq. In some instances the pegmatites form large complex networks.

Dykes

Weakly migmatised amphibolite dykes cut Nûk and Amîtsoq gneisses in north-east Ivisârtoq, the dykes in turn being cut by pegmatites correlated with the Qôrqut granite. One of these dykes contains rimmed aggregates of white feldspar like those in C type Ameralik dykes. Its relations and their implications are discussed by Brewer *et al.* (this report). A discordant amphibolitic dyke trending due north cuts across Malene amphibolites and Qôrqut pegmatites in central Ivisârtoq, but it is intensely sheared on planes broadly parallel to major lithological boundaries. Dolerite dykes trending due north in north-east Ivisârtoq are cut by dolerite dykes trending about 060° and are displaced dextrally by 1.5 km on faults trending about 040° (fig. 14). A mafic amphibole-rich dyke trending N–S and varying in width from 50–150 m cuts the Taserssuaq granodiorite and its host gneisses (fig. 14). Dolerite dykes trending about 110°, varying in width from 0.5 to 15 m and containing abundant aggregates of white feldspar, some with reaction rims, are restricted to certain parts of the granodiorite. These dykes are cut by thin doleritic dykes trending about 090°.

The amphibolitic dykes trending N–S in central and north-west Ivisârtoq may be part of the early Proterozoic MD swarm of southern West Greenland like the dolerite dykes in Ivisârtoq. It would follow that some part of the movement on the Ataneq fault took place during or after the emplacement of the MD swarm.

Structure

East of the Ataneq fault (fig. 14) Amîtsoq gneisses and Akilia rocks have uniform, moderate dips to the east with a mineral or rodding lineation plunging gently south on foliation surfaces. In this part the Akilia association forms a thick, persistent marker folded in an antiform with the western limb overturned. This antiform is here called the Kangerssuaq antiform (KA, fig. 14). The eastern limb dips at moderate angles to the south. A prominent mineral lineation is coaxial with folds of all scales related to this antiform. The lineation and fold axes plunge to the south. Ameralik dykes are folded by the antiform and were deformed and migmatised prior to its development. The dykes cut earlier small-scale folds. The orientation of the eastern limb of the Kangerssuaq antiform suggests the antiform is related to the tight to isoclinal folds which swing round the north of the large dome labelled UND in figure 14.

Close to the edge of the Inland Ice immediately north of Kangilínguata sermia tight folds in Amîtsoq gneisses have sheets of grey gneiss and white pegmatite parallel to their fold axial surfaces. These sheets have distinct *LS* fabrics, *L* being coaxial with fold axes and ribbing in the gneisses and Ameralik dykes. These folds, with the gneiss and pegmatite sheets, swing round the antiformal closure in Amîtsoq gneisses just north of Kangilínguata sermia (fig. 14). The axial trace of this structure is continuous with the spur of Malene amphibolites trending north-east from the main Malene marker on the east limb of the Ujaragssuit nunât dome (fig. 14). The spur forms the south-east limb of a regional synformal closure in Amîtsoq gneisses (fig. 14; Chadwick & Crewe, 1982). Sheets of pegmatite are also parallel to the axial surfaces of folds parasitic to the antiform north of Kangilínguata sermia and there is a pronounced ribbing lineation coaxial with fold axes. A synformal closure complementary to this antiform occurs immediately south and its axial trace can be inferred to continue north-east mostly along the course of Kangilínguata sermia (fig. 14). To the south-west the axial trace swings south across the glacier and continues close to the strip of Malene rocks extending south from the glacier snout (fig. 14). This synformal trace is that of the main synformal closure in north-east Ivisârtoq and is hereafter labelled the Kangilínguata sermia synform (KSS, fig. 14). It is correlated with the 2*S* synform of Hall & Friend (1979, fig. 1), although its position is different from that on their map. The position of the Kangilínguata sermia synform axial trace close to the Malene marker on the western limb suggests that much of the Amîtsoq gneiss occupying the southern limb has been thinned or cut out by a slide on the western limb. The southern limb has also been thickened by injection of Nûk gneisses.

The distribution of Malene ultramafic sheets immediately west of the dome in central Ivisârtoq (CID, fig. 14) shows that a synformal closure, presumed to be the continuation of the Kangilínguata sermia synform, swings round the west of the central Ivisârtoq dome, a relation consistent with the interpretation of Hall & Friend (1979). There is evidence of local deformation of the regional hornblende lineation in the Malene rocks and isoclinal folds related to the earlier Kangilínguata sermia synform. The regional orientation of

Malene rocks in south-west Ivisârtoq suggests the presence of a large synformal closure, here labelled the south-west Ivisârtoq synform (SWIS, fig. 14), plunging north-east. This plunge is compatible with parasitic folds and the mineral lineation on the northern limb, but incompatible with the steeply plunging mineral lineation on the southern limb. The reason for this incompatibility is not clear. It is evident that the tectonic fabric had a long and complex development with *S* fabrics in the Malene rocks being initiated before the regional folds such as those marked UND, KSS and SWIS. The regional mineral and ribbing lineation which is parallel to stretched pillows in the Malene amphibolites is also believed to have had a comparable complex development, perhaps being initiated early in the tectonic history and then being progressively enhanced by later phases of deformation, although its presence in the sheets of grey gneiss parallel to fold axial surfaces in the Kangilínguata sermia synform suggests the lineation is relatively late. Folding of the Kangilínguata sermia synform and the generation of the south-west Ivisârtoq synform in central Ivisârtoq are regarded as part of a continuum of events associated with growth of the major domes (UND and CID of fig. 14), after the major regional emplacement of earlier phases of Nûk gneisses. Our interpretation of the regional structure is thus different from that of Hall & Friend (1979), except in respect of the detailed geometry of central Ivisârtoq. Our hypothesis that the regional structure of the Ivisârtoq region is controlled by doming (UND and CID) and consequent synformal pinching (KSS, SWIS and the synformal cusp north-east of UND) requires that an area of doming or regional uplift exists to the south (Brewer *et al.*, this report).

The Malene rocks had been deformed and migmatised before the development of the dome and synformal structures, but the relation between this early deformation and migmatisation and the folds in the Amîtsoq gneisses, including the Kangerssuaq antiform, in the north of the region is not clear. The contact between the Malene rocks and the Amîtsoq gneisses is ambiguous (Chadwick & Crewe, 1982), but on the basis of younging criteria in pillowed amphibolites in central Ivisârtoq it may be argued that the contact is a thrust with the Amîtsoq gneisses transported many kilometres to overlie a normal sequence of Malene rocks before Nûk injection and subsequent dome formation. The generation of nappes followed by doming occurred after comparable thrusting in north-west Buksefjorden (Chadwick & Nutman, 1979) and it is conceivable that the formation of nappes in the Ivisârtoq region also took place after thrusting, but positive identification of nappes has not been possible so far, although they may be represented by the Kangarssuaq antiform and other folds north-east of the Ujaragssuit nunât dome.

Tectonism and Nûk magmatism

The oldest Nûk gneisses appear to be confined mainly to the domes UND and CID (fig. 14), although some occur west of the Malene marker on the west limb of UND. They are pegmatite-banded grey gneisses whose magmatic precursors were emplaced as sheets into Malene amphibolites which probably had marked tectonic *S* fabrics with mainly horizontal orientation as suggested by the scale of the extensive sheets of amphibolite below the main Malene marker on the east of the Ujaragssuit nunât dome. It is also probable that the Amîtsoq gneisses had been thrust over the Malene rocks in the north-east of the Ivisârtoq region prior to the emplacement of the early Nûk magmas. The growth of the Ujaragssuit nunât dome may have been accompanied by further development of Nûk pegmatites as suggested by the abundance of pegmatite in its core north of Ujaragssuit pâvat. Development of the Kangilínguata sermia synform (KSS) and some earlier folds in the east was accompanied by injection of grey gneiss and pegmatite sheets along planes parallel to fold axial surfaces. The injection of abundant pegmatite and potash metasomatism in the Ujaragssuit nunât dome may be related to the sheet injection in Kangilínguata sermia synform. The homogeneous grey gneiss with diffuse layering around the rim of the central Ivisârtoq dome may also be an expression of this phase. Injection of Nûk gneisses thus appears to be part of a continuum of tectonothermal events in the later part of the Archaean evolution of the Ivisârtoq region. Whilst injection of the post-tectonic Qôrqut granite and related pegmatites in central Ivisârtoq was controlled to some extent by pre-existing structure in the sense that they are confined to the core of the south-west Ivisârtoq synform, further north-east on the southern limb of the Kangilíngua sermia synform and in the area north-east of the Ujaragssuit nunât dome described by Chadwick & Crewe (1982) the granite and pegmatite sheets appear to have a random pattern.

The Ataneq fault

The positions of the main fault and an associated splay are shown in figure 14, but other faults occur parallel to the main fracture. At least 4 km of dextral strike displacement has taken place on the Ataneq fault in north-west Ivisârtoq as indicated by a mafic amphibolite dyke (fig. 14). Deflections of fabric consistent with this displacement are also evident in the gneisses close to the fault. The dextral movement appears to have taken place after major ductile displacements on the Ataneq and related faults. These earlier movements gave rise to mylonites a few centimetres thick and protomylonites up to 10 m thick. Most of the mylonite fabrics dip about 40°E broadly parallel to foliation in Amîtsoq gneisses extending east to the Kangerssuaq antiform (KA, fig. 14). The orientation of slickencrysts on the mylonitic *S* fabrics suggests thrusting from east to west with the transport vector pitching 70°–80°S. The abundance of distinct sheets of mylonite and protomylonite along the Ataneq fault and in the gneisses immediately east of the fault indicates slip occurred on a number of shear zones. Mylonitic rocks have not been seen in the Taserssuaq granodiorite suggesting most of the ductile displacement took place before its emplacement. A complex history of ductile movements is indicated by variations in mylonite development and local folding of mylonite fabrics. Later brittle movements are indicated by minor faults and joints. Many joints contain epidote, and feldspars in the host rocks are commonly altered, the normal white grains being coloured pink. This epidotisation and colour change in feldspars is common throughout much of the Ivisârtoq region. Dolerite dykes trending about 100° terminate abruptly at the Ataneq fault, but the time of emplacement relative to fault movement is uncertain.

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Provisional results of isotope investigations into quartzo-feldspathic rocks from Kangiussap nunâ, Ivisârtoq sheet, southern West Greenland

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The geology of Kangiussap nunâ has been described by Walton (1976), Allaart *et al.*, (1977) and more recently, following 1:20000 mapping, by Coe & Robertson (1982) (see also Brewer *et al.*, this report). A heterogeneous banded gneiss believed to be Amîtsoq is intruded by multiphase Nûk gneiss. Coe & Robertson (1982) recognised five phases of Nûk gneiss (Nûk 1–5). These are cut by undeformed to weakly foliated granites and pegmatites which were judged to be of Qôrqut age (Coe & Robertson, 1982).

This report presents the results of Rb-Sr whole rock-analyses and provisional Pb isotope results on representative samples of Nûk 1 to 4 and Qôrqut granite (terminology of Coe & Robertson, 1982). These samples were collected during field mapping in 1981 as part of the Ivisârtoq project for the Geological Survey of Greenland at the University of Exeter.

Rb-Sr ratios were determined by X-ray fluorescence spectrometry at the University of Oxford. Sr and Pb isotopes were measured in the same laboratories on VG Micromass 30 and Isomass 54E mass spectrometers, respectively. The generous assistance of P. N. Taylor and S. Moorbath is gratefully acknowledged.