Formation. The conglomerate is overlain by black bituminous mudstones of the Kangilia Formation (Fig. 113).

Geological age. The oysters and other bivalves in the matrix of the conglomerate indicate a Danian age (Birkelund 1965). The fauna has species in common with the *Thyasira* Member of the Kangilia Formation of Rosenkrantz (1970), here defined as the Eqalulik Formation, and the conglomerate was referred to the Lower to Middle Danian by Rosenkrantz (1970). Dinocysts from the mudstone matrix also suggest a Danian age. Kennedy *et al.* (1999) referred the ammonites to the early Maastrichtian. The age of the Oyster–Ammonite Conglomerate Bed is constrained by its Danian fossils and the early Late Danian age of the Agatdal Formation, which overlies the Kangilia Formation.

Correlation. The bed is referred to the Kangilia Formation based on the general Danian age and the lack of volcaniclastic material (the presence of which characterises the Eqalulik Formation) in both the conglomerate and the overlying mudstone.

Quikavsak Formation

new formation

History. The strata comprising the Quikavsak Formation as defined here were briefly described by Steenstrup (1874 p. 79) and later in detail by Koch (1959) who included them in his Quikavsak Member of the Tertiary Upper Atanikerdluk Formation. The strata are now established as a separate formation. A major, fluvial channellised sandstone unit that Koch (1959 fig. 5) previously included in the top of the Atane Formation at Quikassaap Kuua is now tentatively also included in the Quikavsak Formation. At Nassaat, a tributary on the south-eastern side of Agatdalen, a poorly exposed conglomerate unit that had been assigned to the Sonja member (Agatdal Formation) by Rosenkrantz (1970) and to the Quikavsak Member by Koch (1959) is here re-assigned to the Quikavsak Formation.

Dam (2002) suggested a division of the Quikavsak Formation into four members reflecting various depositional stages during infill and drowning of the incised valley system. Dam's three lower members – the Tupaasat, Nuuk Qiterleq and Paatuutkløften Members – are defined formally below. The Asuup Innartaa Member is no longer recognised, and the deposits on Nuussuaq are now included in either the Eqalulik or the Atanikerluk Formations whereas the deposits on Disko are now referred to the Kussinerujuk Member of the Itilli Formation (see below).

Name. The member is named after the stream of Quikavsaup kûa (now spelled Quikassaap Kuua) near Atanikerluk (Fig. 40). The spelling of the name is taken from Koch (1959).

Distribution. The formation is exposed along the south coast of Nuussuaq, from Nuuk Killeq in the west to Saqqaqdalen in the east. On central Nuussuaq, the formation is exposed at Nassaat (Fig. 2).

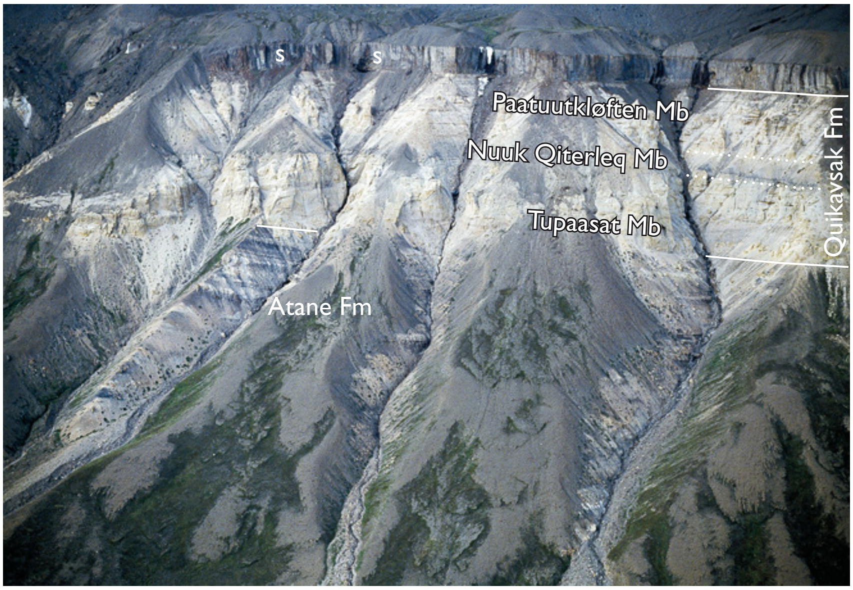


Fig. 97. The type locality of the Quikavsak Formation, east of Nuuk Qiterleq on the south coast of Nuussuaq (for location, see Figs 2, 40). The Quikavsak Formation overlies the Atane Formation and is overlain by a very thin Eqalulik Formation and hyaloclastite breccias of the Vaigat Formation. A volcanic sill (**S**) has been intruded between the Quikavsak and the Eqalulik Formations. The thickness of the Quikavsak Formation in this outcrop is *c.* 180 m.

On Svartenhuk Halvø, on the east slope of Firefjeld, a thin (30 m) Paleocene conglomeratic unit is present between the Itilli Formation and the hyaloclastic rocks of the Vaigat Formation (Fig. 73; J.G. Larsen & Pulvertaft 2000). This unit may be correlated with either the Agatdal Formation or the Quikavsak Formation.

Type section. Originally, Koch (1959) chose the exposures at the stream of Quikassaap Kuua as the type locality for his Quikavsak Member (Fig. 40). At this locality, however, only two of the members of the Quikavsak Formation are exposed (Tupaasat and Nuuk Qiterleq Members) and the formation has an atypical appearance (Fig. 100). The best exposures and the most complete development of the formation occur between Paatuut and Nuuk Killeq, south Nuussuaq. The type section is located on the coastal slope just east of Nuuk Killeq below the mountain Point 1580 (Figs 6, 97, 98, 99A; A.K. Pedersen *et al.* 1993). The type section is located at 70°20.75´N, 53°08.75´W.

Reference sections. Reference sections occur at Ivisaannguit, Paatuut and Quikassaap Kuua (Figs 40, 99B, 100, 108).

Thickness. The channellised nature of the deposits forming the Quikavsak Formation results in highly variable thicknesses. The formation is up to 180 m thick at the type locality. At Ivisaannguit it is up to 116 m thick, on the west side of Ataata Kuua it is up to 135 m, on the east side of Ataata Kuua below the mountain of Ivissussat Qaqqaat it is more than 100 m, at Paatuut up to 162 m and at Quikassaap Kuua it is up to 70 m thick. Between these sections, the formation is only a few metres thick or is absent altogether.

Lithology. Along the south coast of Nuussuaq the formation is divided into three lithological units that are given the rank of members (Dam & Nøhr-Hansen 2001; Dam

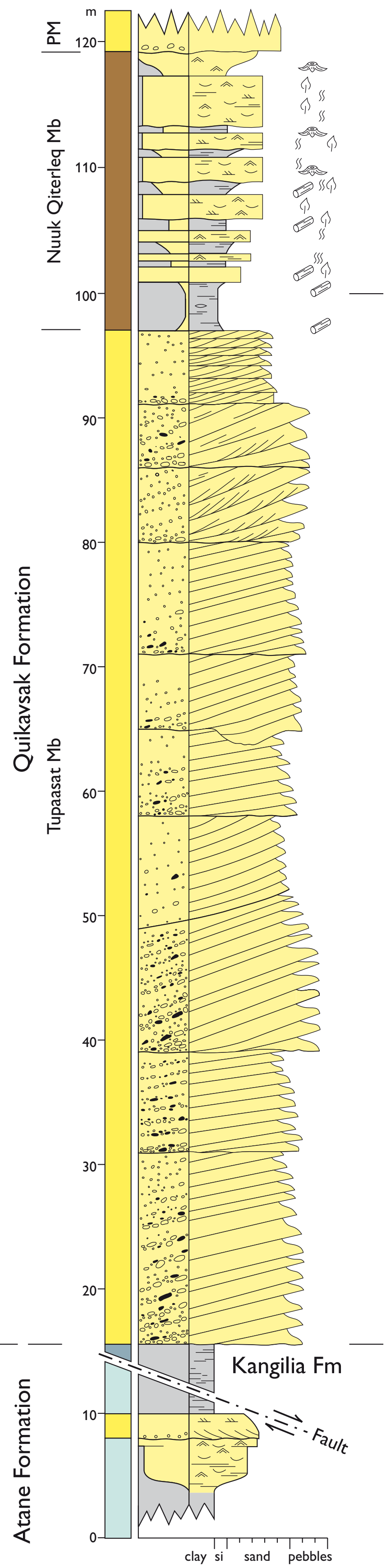
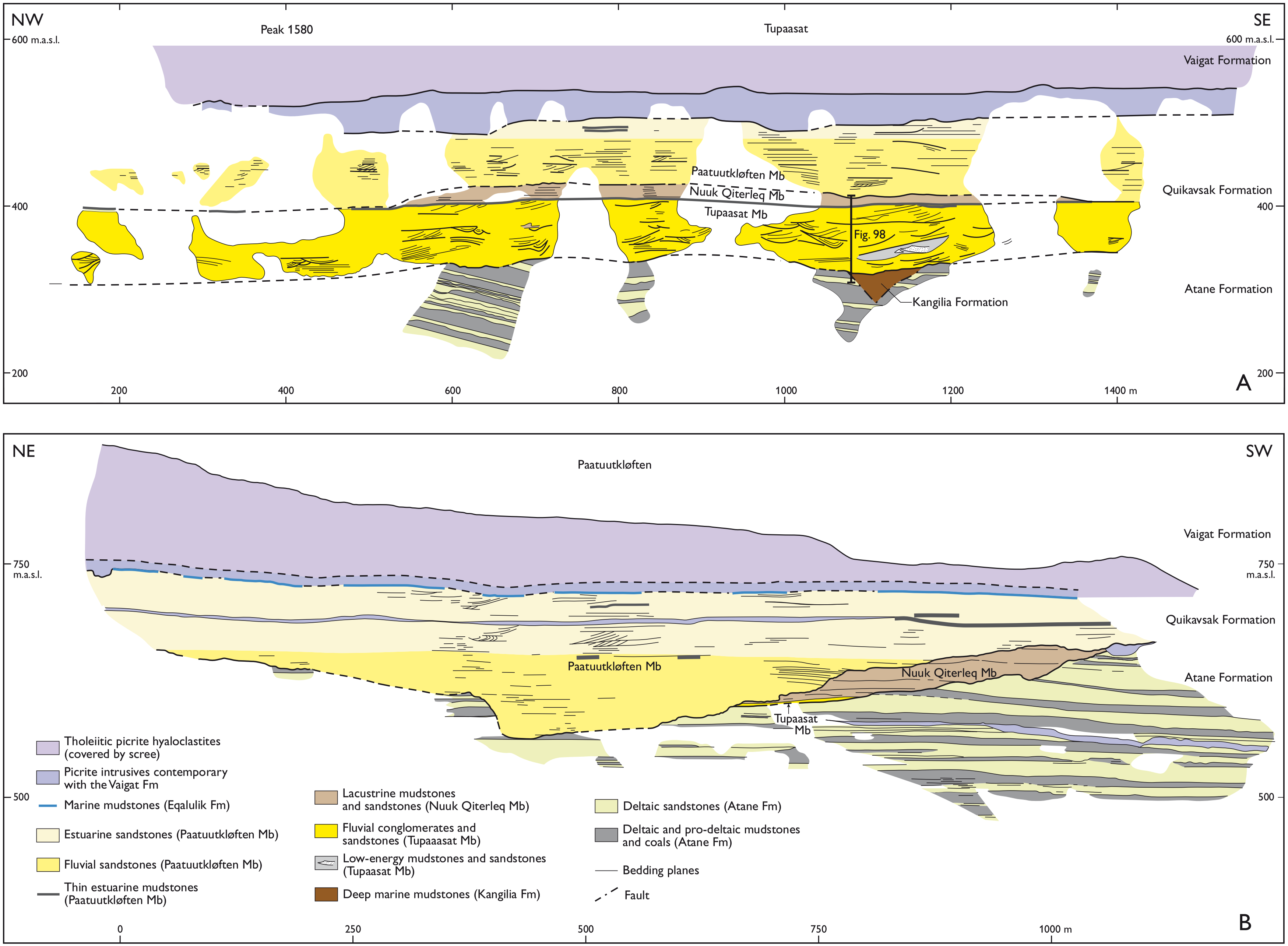


Fig. 98. Type section of the Quikavsak Formation (and the Tupaasat and Nuuk Qiterleq Members) at Tupaasat, east of Nuuk Qiterleq; for location, see Figs 2, 6, 97. The upper member of the formation (**PM**, Paatuutkløften Member) has not been measured at this locality. The lenticular mud-rich body illustrated on Fig. 99A just southeast of the section line is absent in this section, probably due to erosion at the charred base at 39 m. Modified from Dam & Nøhr-Hansen (2001). Note that the position of this section was erroneously stated to be at Ivisannguit in Dam (2002). For legend, see Plate 1.



NW
SE
600 m.a.s.l.
Peak 1580
Tupaasat
Vaigat Formation
Quikavsak Formation
Atane Formation
Paatuutkløften Mb
Nuuk Qiterleq Mb
Tupaasat Mb
Fig. 98
Kangilia Formation
400
200
600
800
1000
1200
1400 m
A
NE
SW
Paatuutkløften
750 m.a.s.l.
500
Paatuutkløften Mb
Nuuk Qiterleq Mb
Tupaasat Mb
0
250
500
750
1000 m
B
Tholeiitic picrite hyaloclastites (covered by scree)
Picrite intrusives contemporary with the Vaigat Fm
Marine mudstones (Eqalulik Fm)
Estuarine sandstones (Paatuutkløften Mb)
Fluvial sandstones (Paatuutkløften Mb)
Thin estuarine mudstones (Paatuutkløften Mb)
Lacustrine mudstones and sandstones (Nuuk Qiterleq Mb)
Fluvial conglomerates and sandstones (Tupaasat Mb)
Low-energy mudstones and sandstones (Tupaasat Mb)
Deep marine mudstones (Kangilia Fm)
Deltaic sandstones (Atane Fm)
Deltaic and pro-deltaic mudstones and coals (Atane Fm)
Bedding planes
Fault

Fig. 100. Reference locality of the Quikavsak Formation at Quikassaap Kuua (see Fig. 40 for location). This locality was selected by Koch (1959) as the type locality of his Quikavsak Member. The channellised sandstone is now referred to the Tupaasat Member of the Quikavsak Formation (for explanation, see text).

2002). The lower, markedly erosional unit dominated by coarse-grained sandstones succeeded by a middle unit comprising sand- and silt-streaked mudstones and sandstones with numerous *in situ* and drifted remains of trees. The upper unit also has an erosional base and consists of medium- to coarse-grained sandstones arranged in an overall fining- and thinning-upward succession, locally with a basal boulder conglomerate bed. For detailed descriptions, see members below.

Fossils. The sandy parts of the formation are rich in coal fragments and pieces of coalified wood. The fine-grained parts of the formation are rich in clay ironstone with plant fossils, sideritic silty shale with plant fossils, mostly as impressions, and *in situ* coalified tree trunks. Plant fossils belong to the 'Upper Atanikerdluk A' flora of Heer (1883a, b); fossil insects and ostracods have also been described (Koch 1959). At the top of the section at Paatuut, about 5 m below the basalts, a few marine molluscs have been found (Koch 1959). Early Paleocene oysters (*Ostrea* sp.) have been reported immediately west of Paatuutkløften and east of Nuuk Killeq (Koch 1959). Palynomorphs are common, but only few marine dinocysts are present.

Depositional environment. The Quikavsak Formation represents fluvial to estuarine deposition in a series of fault-controlled, incised valley systems that formed during two phases of uplift of the Nuussuaq Basin (Dam & Sønderholm 1998; Dam & Nøhr-Hansen 2001; Dam 2002). The mudstone member overlying the basal sandstone member in the type section (Fig. 98) is probably related to a quiescent period between the tectonic events resulting in the development of low-energy depositional (lacustrine) areas within the valleys.

Boundaries. The lower boundary of the formation is a major erosional unconformity formed during valley incision, cutting at least 190 m down into the underlying deposits (Figs 99, 109). East of Ataata Kuua, the unconformity separates Turonian – Lower Campanian deltaic sandstones and mudstones of the Atane Formation from the coarse-grained deposits of the Quikavsak Formation. The contact with the underlying Atane Formation is generally easily recognised with the exception of the locality at Quikassaap Kuua where the boundary relationships are somewhat enigmatic (see below under Tupaasat Member). On the west slope of Ataata Kuua and westwards to Ivisaannguit and in the type section,

Facing page:
Fig. 99. Photogrammetrically measured sections of the incised valley fills of the Quikavsak Formation. **A**: Longitudinal section of the Tupaasat and Paatuukløften incised valleys in the area around the type section (see Figs 97, 98). **B**: Cross-section of the Paatuutkløften incised valley from Paatuutkløften (see Fig. 105). Note that the Kangilia Formation is bounded by faults, and that the Atane Formation is also faulted. Most of the Tupaasat Member and the Nuuk Qiterleq Member were removed by erosion prior to deposition of the Paatuutkløften Member. For location of sections, see Figs 2, 40. Modified from Dam (2002; it should be noted that the figure captions for figs 3B and 4 in this paper are switched).

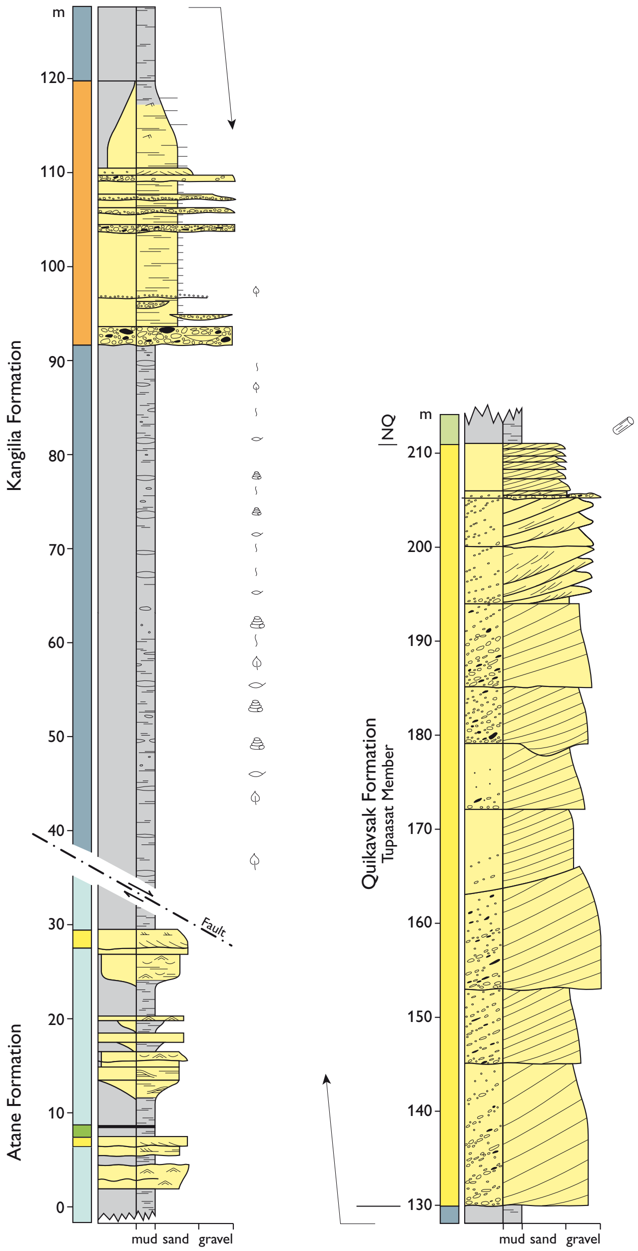


Fig. 101. Generalised sedimentological log from Ivisaannguit on the south coast of Nuussuaq (for location, see Fig. 40). The sandstones and conglomerates of the Kangilia Formation are similar to those seen at Ataa (Fig. 91). At this locality, the Kangilia Formation has a faulted contact with the Atane Formation and is erosionally truncated by the Quikavsak Formation. **NQ**, Nuuk Qiterleq Member. For legend, see Plate 1.

the Quikavsak Formation cuts down into mudstones of the upper Maastrichtian – Lower Paleocene Kangilia Formation (Figs 14, 15, 98, 101).

West of Paatuut, the formation is overlain by marine mudstones of the Eqalulik Formation whereas east of Paatuut it is succeeded by syn-volcanic lacustrine deposits referred to the Atanikerluk Formation.

Geological age. The fauna and flora are not age-diagnostic but a Danian age is indicated by the stratigraphic position between the Kangilia Formation, of Danian age on southern Nuussuaq, and the overlying Eqalulik Formation of Danian to Selandian age (Fig. 16; Piasecki *et al.* 1992; Nøhr-Hansen *et al.* 2002.

Correlation. The Quikavsak Formation deposits can be correlated to the submarine canyon deposits of the Agatdal Formation exposed on central Nuussuaq (Koch 1959; Dam & Sønderholm 1998) and occurring in the subsurface in the GRO#3 well (Fig. 67) and the GANE#1 well (Fig. 119).

Subdivision. The Quikavsak Formation is divided into three members: the Tupaasat, Nuuk Qiterleq and Paatuutkløften Members (Fig. 99).

Tupaasat Member

new member

History. Strata now referred to the Tupaasat Member were first but only briefly described by Steenstrup (1874 p. 79). The member was described in detail by Koch (1959) and referred to as the lower part of the Quikavsak Member (Upper Atanikerdluk Formation). That part of the section at Quikassaap Kuua described by Koch (1959 p. 17, fig. 5) as "cross-bedded quartz sandstone of a considerable thickness" and assigned by him to the Atane Formation, is now referred to the Quikavsak Formation (see Fig. 100).

Name. The member is named after the headland of Tupaasat just west of Ataata Kuua.

Distribution. The member is exposed along the south coast of Nuussuaq as the fill of an incised valley system extending from Nuuk Qiterleq in the west to Saqqaqdalen in the east where it occurs on the western slope of Saqqaqdalen close to the Vaigat strait (Figs 40, 129; Koch 1959; Pulvertaft 1989a, b; A.K. Pedersen *et al.* 2007a). The Tupaasat Member is not present in all outcrops of the Quikavsak Formation. At some localities it was partly or entirely eroded away prior to deposition of the Paatuutkløften Member (see Figs 99B, 109).

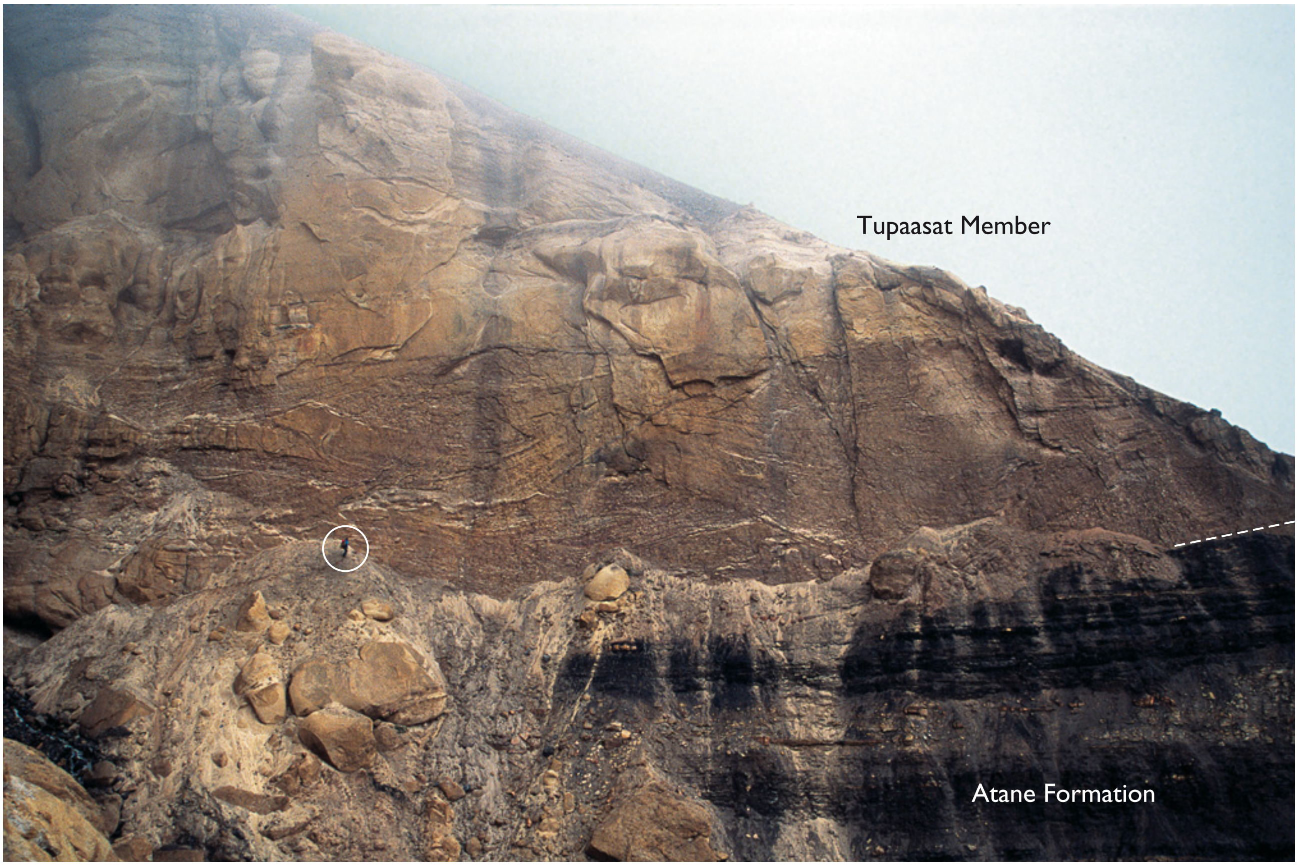


Fig. 102. Giant-scale, cross-bedded conglomerates and sandstones of the Tupaasat Member (Quikavsak Formation). Encircled person for scale. From the coastal slope between Tupaasat and Nuuk Qiterleq (for location, see Fig. 2).

Type section. The thickest deposits and the best exposure of the member occur between Tupaasat and Nuuk Qiterleq, in the coastal slope below the mountain Point 1580 (Figs 6, 98, 99, 102). This exposure is designated as the type section. The type section is located at 70°20.75´N, 53°08.75´W.

Reference sections. There are several well-exposed sections along the south coast of Nuussuaq, e.g. in the coastal cliffs around Ivisaanguit (Dam 2002 fig. 4) and at Quikassaap Kuua (Figs 40, 100).

Thickness. The member is 78 m thick in the type section, at least 80 m at Ivisaannguit, up to 7 m in Paatuutkløften, and *c*. 20 m at Quikassaap Kuua (Figs 40, 100).

Lithology. At the type locality, the lower part of the Tupaasat Member consists of giant-scale trough cross-bedded, parallel-bedded and structureless pebbly to cobbly, very coarse-grained sandstone. In the lower part of the member, each trough set is up to 30 m in thickness (Figs 98, 99, 102, 103), but set thickness decreases upwards to less than 0.5 m at the top concomitant with a fining-upward trend; the sandstones are, however, distinctly different from the cross-bedded medium- to coarse-grained sandstones of the Paatuutkløften Member (Dam 2002). Pebbles are well rounded and consist of quartz (80%), gneiss and granite (10%), metasediments (7%) and chert (3%). Within the pebbly sandstones in the type section area, an up to 10 m thick unit of mudstone rich in detrital mica is intercalated with lenses of sandstone. The mudstone is bounded at the top by an erosional unconformity giving rise to the lenticular shape of the shale. The shale is succeeded by cross-bedded pebbly sandstones.

Around Ivisaannguit, the member has a similar development to that in the type section. In the eastern part of these exposures, the member is only up to 15 m thick. Towards the west, the thickness of the member increases dramatically to at least 80 m where it crosses an Early Paleocene fault scar (Dam 2002 fig. 4).

Fig. 103. Giant-scale, cross-bedded conglomerates and sandstones of the Tupaasat Member. Encircled person for scale. Arrows indicate dip of major foresets. From the coastal slope above Ivisaannguit (for location, see Fig. 40).

In Paatuutkløften and at the spur between the coastal escarpment and Ippigaarsukkløften, the Tupaasat Member consists of a 7 m thin unit of pebbly, coarse- to very coarse-grained sandstones and a pebble to cobble conglomerate (Figs 99B, 104).

On the eastern slope of Quikassaap Kuua, a 20 m thick set of cross-bedded medium- to coarse-grained sandstone is present. It is well consolidated and forms a vertical cliff (Fig. 100). This cross-bedded sandstone unit was included in the Atane Formation by Koch (1959) in spite of the stronger similarity to the lower part of the Quikavsak Member farther west than to the fluvial sandstones of the Atane Formation. This assignment may have been based on the presence of a small unconformity, possibly associated with a fossil podsol profile that separates the sandstones from the overlying heterolithic deposits, which he referred to as the Quikavsak Member but are here assigned to the Nuuk Qiterleq Member of the Quikavsak Formation.

Fossils. Fragments of coal and pieces of coalified wood are common in the member.

Depositional environment. The conglomerates and sandstones of the Tupaasat Member form a characteristic suite of very thick sandstone beds deposited by major bedforms related to catastrophic flows. The flows were confined to incised fluvial valleys formed during major tectonic uplift of the basin (Dam *et al.* 1998a; Dam 2002). From the Tupaasat Member facies alone it is not possible to determine whether deposition took place in a subaerial or a submarine environment. The overlying sediments, how-

Fig. 104. Tupaasat Member conglomerate in Paatuutkløften (for location, see Fig. 99B). Hammer for scale.

ever, have a fluvio-lacustrine origin, which makes a subaerial environment most likely for the Tupaasat Member.

Boundaries. The lower boundary is a major erosional unconformity that follows the base of the incised valley systems. It cuts across faults that bring Lower Paleocene mudstones of the Kangilia Formation against mid-Cretaceous deltaic deposits of the Atane Formation (Figs 98, 99A). The unconformity reflects major tectonic uplift of the basin (Dam 2002).

Where the Nuuk Qiterleq Member is present, the upper boundary is gradational and non-erosional (Figs 97, 98). At other localities, the Tupaasat Member is erosionally truncated by the Paatuutkløften Member (Fig. 99).

Geological age. The Tupaasat Member is referred to the Early Paleocene (Danian), its age being bracketed by data from the Kangilia Formation below and the Nuuk Qiterleq Member above (Dam 2002; Nøhr-Hansen *et al*. 2002).

Nuuk Qiterleq Member

new member

History. Strata now referred to the Nuuk Qiterleq Member are equivalent to the Quikavsak Member as described by Koch (1959) from the type section at Quikassaap Kuua. Moreover, the Nuuk Qiterleq Member includes the middle, very fossiliferous unit of the Quikavsak Member described elsewhere in the area by Koch (1959).

Name. The member is named after the headland Nuuk Qiterleq (Fig. 2).

Distribution. The member is locally exposed along the south coast of Nuussuaq as the fill of an incised valley system extending from Nuuk Qiterleq in the west to Atanikerluk in the east (Fig. 2). It is not recognised in all outcrops of the Quikavsak Formation due to erosion preceding deposition of the succeeding Paatuutkløften Member.

Type section. The member is well exposed between Tupaasat and Nuuk Qiterleq. The type section is the same as that for the Tupaasat Member (Figs 97–99). The type section is located at 70°20.75´N, 53°08.75´W.

Reference sections. Reference sections occur in Paatuutkløften and at Quikassaap Kuua (Figs 99B, 100).

Thickness. In the type section the member is 23 m thick, at Ivisaannguit 3–6 m, at Paatuut up to 42 m and at Quikassaap Kuua up to 50 m. The thickness is mainly dependent on the depth of erosion into the member prior to deposition of the overlying sandstones of the Paatuutkløften Member (Fig. 105).

Lithology. In the type section and in Paatuutkløften, the Nuuk Qiterleq Member is composed of up to 6 m thick coarsening-upward successions, composed of silt- and

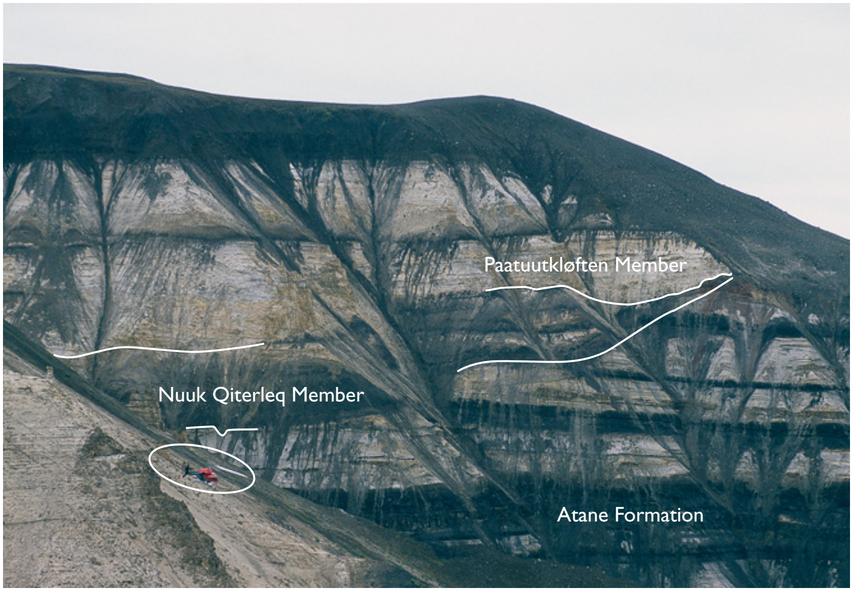


Fig. 105. Nuuk Qiterleq Member erosively overlain by the Paatuutkløften Member in Paatuutkløften (see Fig. 99B). Helicopter (encircled) for scale.

Fig. 106. **A**: Thin coarsening-upward successions in the Nuuk Qiterleq Member composed of silt- and sand-streaked mudstones passing upwards into fine- to medium-grained sandstones. Person for scale. From the type locality near Nuuk Qiterleq (for location, see Fig. 2). Arrows indicate the location of *in situ* coalified tree trunks. Note the upper, sharp, erosional boundary with the Paatuutkløften Member. **B**: *In situ* vertical, coalified tree trunk from the type section of the Nuuk Qiterleq Member. Pencil for scale (arrowed).

sand-streaked mudstones grading upward into fine- to medium-grained sandstones (Fig. 106A). Incipient ripples as well as wave and current ripples and parallel lamination are widespread. *In situ* vertical coalified trees and drifted tree trunks and plant fossils are very common (Fig. 106B). At Ivisaannguit, at Paatuut and at Ippigaarsukkløften, the member is dominated by mudstones with thin sand-streaks. A single, sharply based sandstone bed occurs at Ivisaannguit.

At Quikassaap Kuua, the member consists of interbedded siltstones and graded, occasionally parallel- laminated, very fine-grained to very coarse-grained sandstones (Fig. 107). This interbedded facies alternates with lenticular beds with erosional bases consisting of normally graded, medium- to very coarse-grained trough, cross-bedded sandstones arranged in thinning-upward successions up to *c*. 50 cm thick. The interbedded siltstones and sandstones are rich in plant fossils, clay ironstone concretions, *in situ* vertical coalified tree trunks, drifted coalified tree trunks and finely disintegrated coal fragments.

Fossils. The Nuuk Qiterleq Member is very rich in plant fossils and contains most of the species known from the Quikavsak Formation. The fossil flora from this member and from the lower part of the overlying Naujât Member (Atanikerluk Formation) at Atanikerluk and a few additional localities is known as the 'Upper Atanikerdluk A' flora of Heer (1883a) who recognised 282 species, some of which have been revised by Brown (1939), Seward (1939), Chaney (1951) and Koch (1963). Koch described the Lower Paleocene flora in the Agatdalen area where he recognised 27 species, of which 19 species were recognised by him as also occurring in the Quikavsak Formation.

Depositional environment. Sediments of the Nuuk Qiterleq Member were deposited in various environments within an incised valley system. The stacked coarsening-upward cycles in the type section and in Paatuutkløften were formed by repeated progradation of shoreface or bay-head deltas into a lacustrine environment (Dam 2002).

The deposits at Quikassaap Kuua include lenticular fining-upward successions of sandstones deposited in minor fluvial channels, interbedded with siltstones and graded, very fine-grained to very coarse-grained gravelly sandstones deposited in interchannel areas. The thin graded sandstone sheets were probably deposited during periods of intense overbank flooding.

Boundaries. The lower boundary is placed at the lithological change from pebbly coarse-grained sandstones of the Tupaasat Member to the fine-grained deposits of Nuuk Qiterleq, rich in plant fossils (Fig. 99). At most localities, the lower boundary is non-erosional; at Quikassaap Kuua, however, the Nuuk Qiterleq Member overlies an erosional surface (Koch 1959).

Fig. 107. Interbedded siltstones and sandstones of the Nuuk Qiterleq Member on the western slope of Quikassaap Kuua (for location, see Fig. 40). This section was previously the type section of the Quikavsak Member of Koch (1959).

At most localities, the upper boundary is with the Paatuutkløften Member (Figs 99, 106). At Quikassaap Kuua, the member is overlain by dislocated (landslipped) mudstones of the Atanikerluk Formation (Koch 1959).

Geological age. All the plants are interpreted as Danian in age (Koch 1963).

Paatuutkløften Member

new member

History. Strata now referred to the Paatuutkløften Member were first described and figured as the Quikavsak Member by Koch (1959) along the south coast of Nuussuaq in the Paatuut area (Koch 1959 figs 20–25), the Ataata Kuua area (Koch 1959 figs 26–30) and at the localities between Tupaasat and Nuuk Qiterleq and on central Nuussuaq at Nassaat (Koch 1959 fig. 37). The strata were described in detail by (Dam *et al.* 1998a; Dam & Sønderholm 1998; Dam 2002).

Name. The member is named after the Paatuutkløften ravine (Fig. 40).

Distribution. The Paatuutkløften Member is exposed along the south coast of Nuussuaq as the fill of an incised valley system, exposed from Nuuk Qiterleq in the west to Ippigaarsukkløften in the east and also at Nassaat on central Nuussuaq (Figs 2, 40).

Type section. The eastern slope of Paatuutkløften (Figs 99B, 105, 108). The base of the type section is located at 70°15.27′N, 52°40.65′W.

Reference sections. Reference sections occur on the western slope of Ippigaarsukkløften (Figs 108, 109), at Ivissussat Qaqqaat on the east side of Ataata Kuua (Fig. 110), in the south-west-facing cliffs above the west side of Ataata Kuua (Fig. 14) and between Tupaasat and Nuuk Qiterleq below the mountain Point 1580 (Figs 6, 97, 98, 99; A.K. Pedersen *et al.* 1993).

Thickness. The member is 145 m thick in the type section. Thicknesses in the reference sections are 158 m at Ippigaarsukkløften, more than 110 m at Ivissussat Qaqqaat, 110 m in the coastal cliffs above Ataata Kuua, up to 25 m at the coastal section above Ivisaannguit and 78 m in the section between Tupaasat and Nuuk Qiterleq. The exposures at Nassaat are too poor to estimate the thickness of the member.

Lithology. At Ivissussat Qaqqaat and Ataata Kuua the member is initiated by conglomerates composed of gneiss pebbles and boulders (Fig. 110). This is followed by monotonous successions of light grey, well-sorted, dominantly planar cross-bedded, medium- to very coarse-grained pebbly sandstones that are present at all localities (Fig. 111). These are distinctly different to the succession characterising the Tupaasat Member (Dam 2002). There is a general overall upward decrease in grain size, clast size and set thickness; thin mudstone beds are occasionally present in the uppermost part of the member. Coal clasts, finely disseminated coal fragments and sideritic mudstone clasts are common. Penecontemporaneous deformation structures are widespread in some beds.

Along the south coast of Nuussuaq between Nuuk Qiterleq and Ippigaarsukkløften, the sandstones become

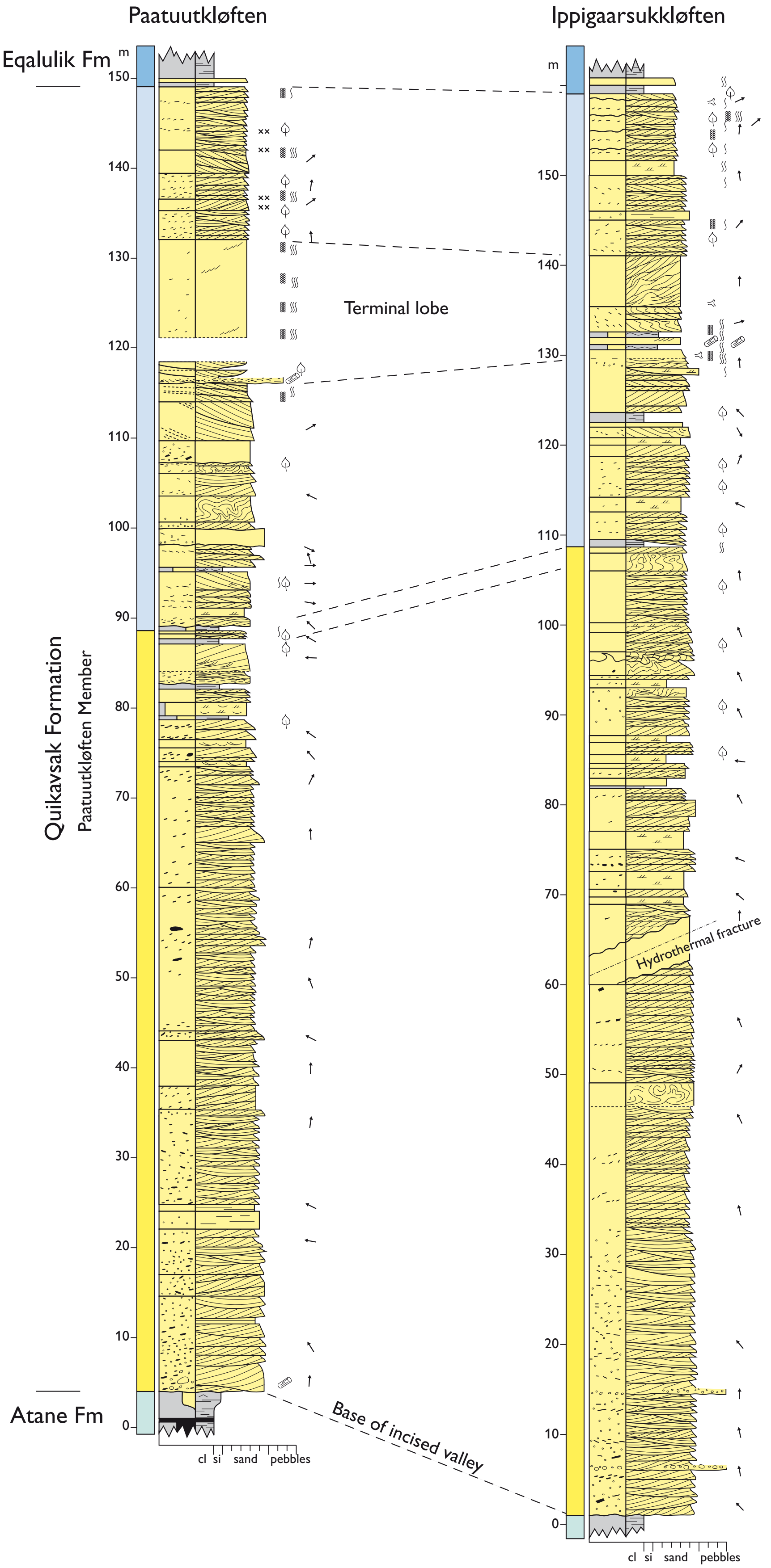


Fig. 108. Type and reference sections of the Paatuutkløften Member at Paatuutkløften and Ippigaarsukkløften, respectively (for location, see Fig. 40; for legend, see Plate 1). The dashed lines indicate correlative surfaces between the two sections.

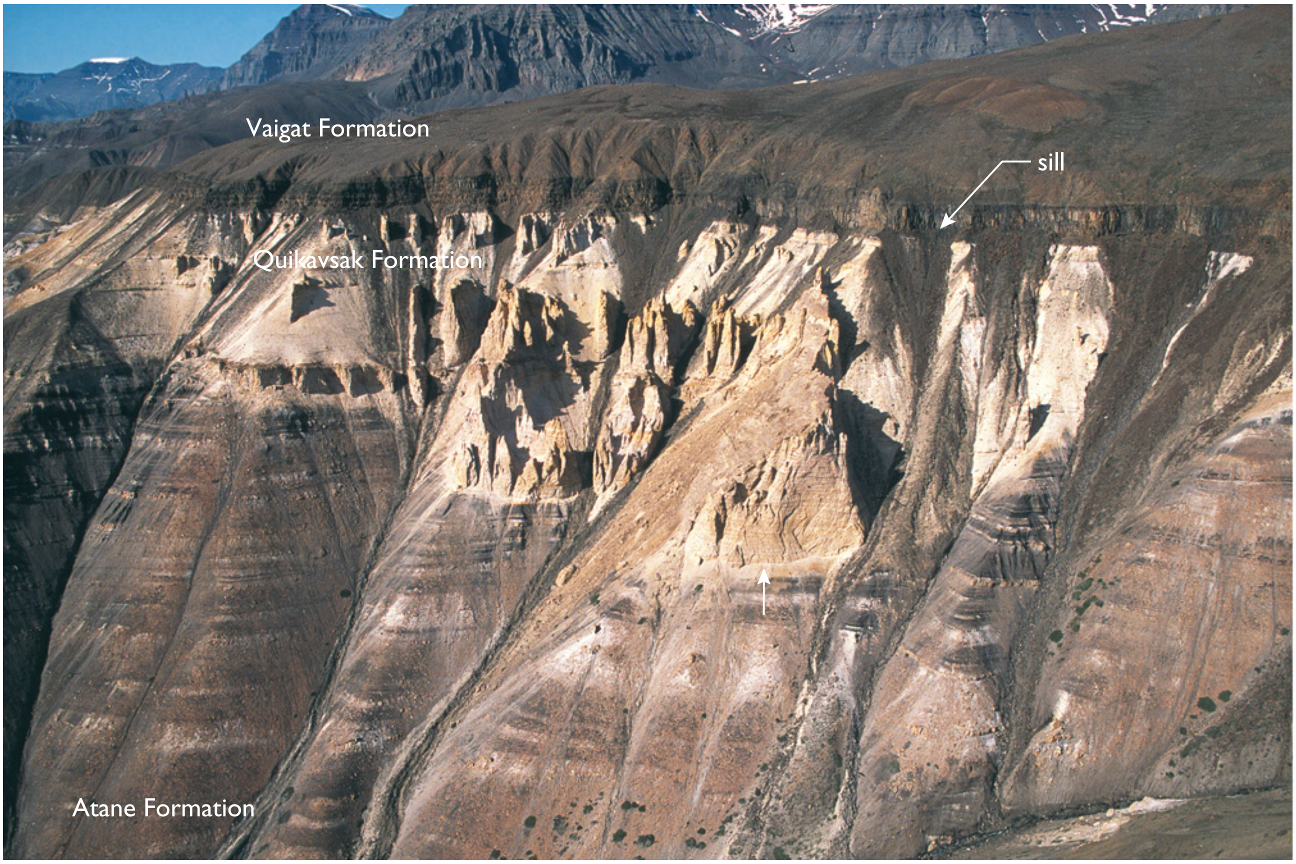


Fig. 109. Paatuutkløften Member as exposed in the Ippigaarsukkløften section (for location, see Fig. 40). The sandstones of the Paatuutkløften Member fill a valley incised into deltaic deposits of the Atane Formation (see Fig. 108). Thickness of valley fill is *c.* 180 m; the white arrow indicates the base of the reference section shown in Fig. 108.

light orange in the upper part of the member and cross-beds show double mud drapes and reactivation surfaces draped by mudstone clasts. Locally the cross-bedding is bidirectional. The sandstones frequently show convolute bedding; coal fragments, sideritic mudstone clasts and concretions are common. Thin mudstone beds with plant debris and heavily bioturbated sandstones occur in the upper part of the succession.

Fossils. Few recognisable plant fossils are present in the mudstones of the member. On the spur between the western slope of the Ippigaarsukkløften ravine and the coastal slope, about 5 m below the basalts, a few Danian marine molluscs have been found (Koch 1959). Danian oysters (*Ostrea* sp.) have been found immediately west of Paatuutkløften and east of Nuuk Killeq (Fig. 2; Koch 1959). These oysters were most probably derived from sandstones in the uppermost part of this member. Trace fossils are common to abundant at most localities in the upper part of the member. They include *Ophiomorpha nodosa*, *Ophiomorpha* isp., *Diplocraterion parallelum* and *Thalassinoides* isp. (Fig. 108).

Depositional environment. The sediments of the Paatuutkløften Member were deposited in an incised valley system formed after an episode of renewed Early Paleocene faulting. The valley system seems to follow the system generated prior to the deposition of the Tupaasat Member, resulting in considerable or in some cases complete erosion of the earlier deposits within the incised valleys. Deposition of the lower part of the member took place in a fluvial environment during a period of rapidly rising sea level, high river discharge and high sedimentation rates (Koch 1959; Dam & Sønderholm 1998; Dam 2002). The upper part of the member is characterised by a change in colour, by sedimentary structures typical of tidal activity and by intense bioturbation, indicating a change to a tidal estuarine environment during infilling of the valleys (Dam & Sønderholm 1998).

Fig. 110. Basal gneiss-clast conglomerate of the Paatuutkløften Member at Ivissussat Qaqqaat (east slope of Ataata Kuua; for location, see Fig. 40). Person for scale.

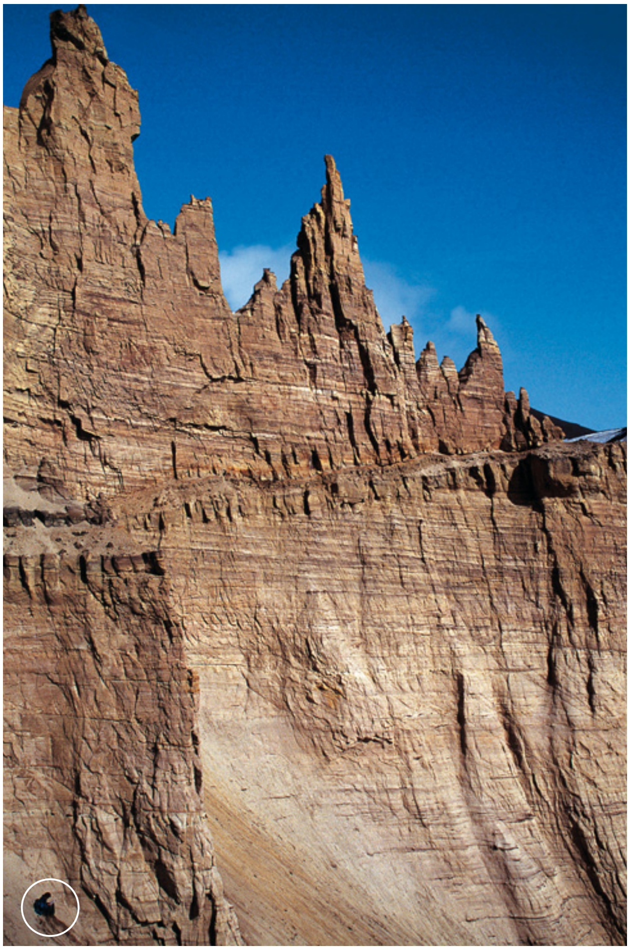


Fig. 111. Uniformly cross-bedded fluvial sandstones of the Paatuutkløften Member at Ippigaarsukkløften (for location, see Fig. 40). The apparent discontinuity in the middle of a section is due to hydrothermal alteration (see Fig. 108). Encircled person for scale.

Boundaries. An erosional unconformity separates the sandstones of the Paatuutkløften Member from the underlying incised valley deposits of the Nuuk Qiterleq or Tupaasat Members (Figs 97, 99, 105). In some cases, the Paatuutkløften Member is incised directly into the Kangilia or Atane Formations suggesting either that the previous deposits within the valley system were completely eroded away or that new valleys were eroded locally (Figs 14, 99, 109, 110). The sandstones of the Paatuutkløften Member are abruptly overlain by mudstones of the Eqalulik Formation (Figs 108, 112).

Geological age. The age of the Paatuutkløften Member is bracketed by the Danian age of the underlying Kangilia Formation and the latest Danian to Selandian age of the overlying Eqalulik Formation (see p. 137), suggesting that the age of Paatuutkløften Member is late NP3–NP4 (Nøhr-Hansen *et al.* 2002).

Correlation. The Paatuutkløften Member has been correlated with marine deposits of the Agatdal Formation on central Nuussuaq (Koch 1959; Dam & Sønderholm 1998), and with the Agatdal Formation in the GANE#1 and GRO#3 wells (Nøhr-Hansen *et al.* 2002).

Fig. 112. The sharp boundary between estuarine sandstones of the Paatuutkløften Member and the mudstones of the Eqalulik Formation above. Hammer (left) for scale. From Ippigaarsukkløften (for location, see Fig. 40).

Agatdal Formation

revised formation

History. The Agatdal Formation was established by Rosenkrantz (in: Koch 1959 pp. 75–78) to encompass Upper Danian marine mudstones, sandstones and conglomerates found in the Agatdalen area on central Nuussuaq; these sediments were further described by H.J. Hansen (1970), Rosenkrantz (1970) and Henderson *et al.* (1976). In some papers, the formation is referred to as the Agatdalen Formation.

The Agatdalen area was the key study area for the Nûgssuaq Expeditions led by A. Rosenkrantz because of the rich fossil content of the sediments (see 'Previous work'). Focus was on the fossil assemblages, and the various outcrops (sections) were only shown schematically and described provisionally. The component lithological units of the section were assigned to individual members resulting in a complex lithostratigraphic terminology. Four members were recognised within the small area of outcrop: the Turritellakløft, Andreas, Sonja and Abraham Members. Schematic sections from the localities in the Agatdalen area are shown in Rosenkrantz (1970 figs 4, 5). The outcrops in the Agatdalen area are discontinuous, and because many of the sandstone and conglomerate units are channellised – and lateral facies changes are therefore pronounced – the members are difficult to correlate and map in detail (Figs 113, 114). A possible correlation between the outcrops of the Agatdal Formation is shown in Plate 3. Furthermore, the members cannot be recognised outside the type area and therefore the three lower members are no longer treated as formal units. They are, however, treated as informal members below in order to facilitate correlation between the new data presented here and the older literature and fossil records (see Plate 3).

The Agatdal Formation as defined here is entirely prevolcanic. Thus, the Abraham Member, which is synvolcanic, is now included in the new Eqalulik Formation (see below). Rosenkrantz (1970) referred other synvolcanic marine sediments found on Nuussuaq to the tuffaceous *Thyasira* and *Propeamussium* Members (abandoned here) of the Kangilia Formation. In Agatdalen, the Turritellakløft Member, from which tuffs are not reported, overlies the *Propeamussium* Member (Rosenkrantz 1970 fig. 5). The correlation between the pre- and synvolcanic members of the Kangilia and Agatdal Formations of Rosenkrantz is not well explained.

Strata assigned to the Agatdal Formation (Sonja Member) at Nassaat north-east of Agatdalen (Fig. 2) by Rosenkrantz (1970 fig. 4c, d) are here assigned to the Quikavsak Formation, following Koch (1959). The tuffaceous deposits of the Abraham Member are coeval with the volcanic Asuk Member of the Vaigat Formation and are therefore now included in the Eqalulik Formation (see p. 137). A sandstone unit underlying the pillow breccias at Kangilia on the north coast of Nuussuaq was tentatively assigned to the Agatdal Formation by H.J. Hansen (1970), Rosenkrantz (1970) and Dam & Sønderholm (1998); this unit is regarded here as forming part of the Eqalulik Formation.

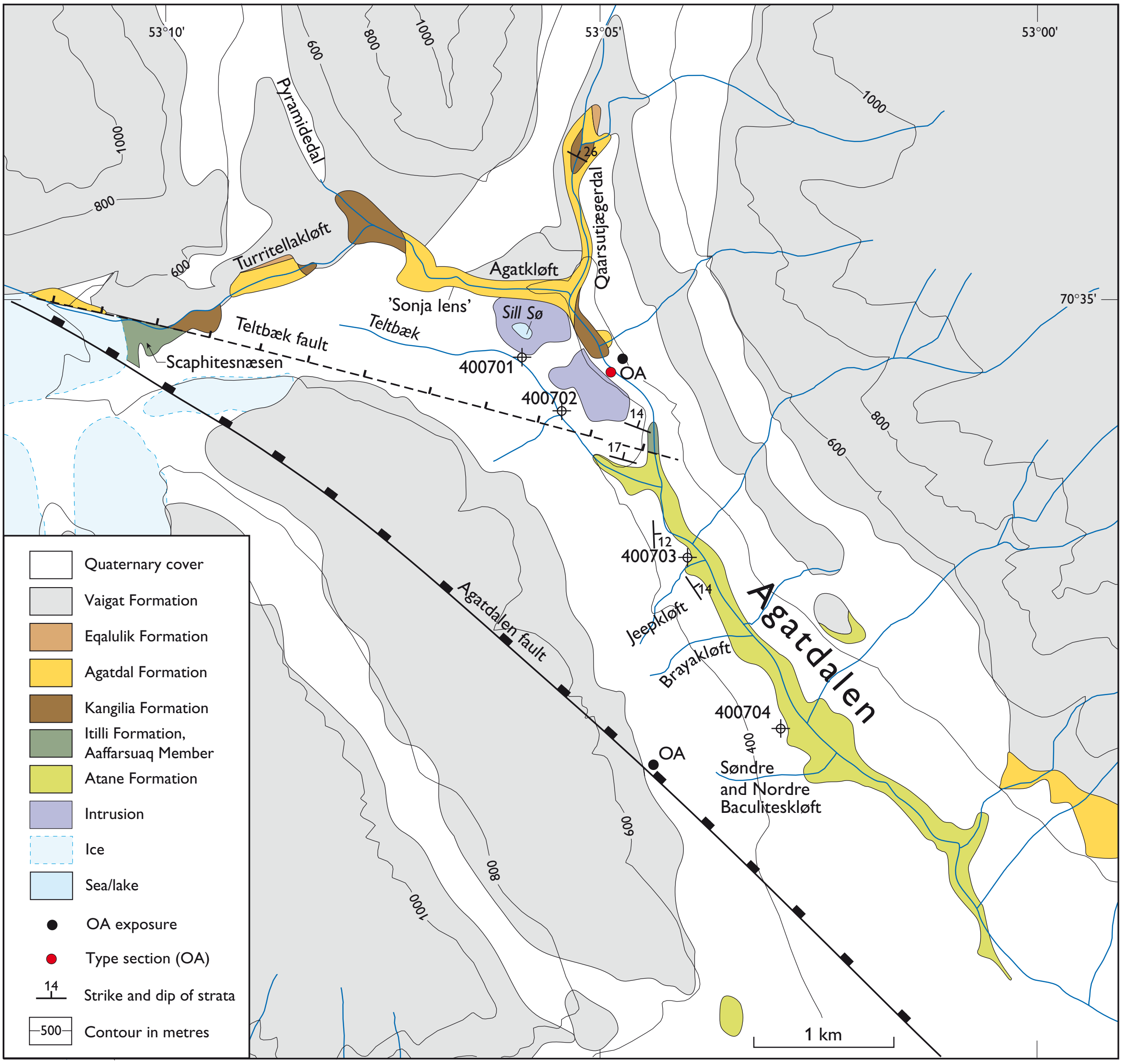


Fig. 113. Geological map of the Agatdalen area. The positions of the four shallow wells drilled by GGU in 1992 (GGU 400701–400704) are shown. Exposures of Oyster–Ammonite Conglomerate Bed (**OA**) shown with dots. From Dam *et al.* (2000) based on Rosenkrantz *et al.* (1974). Turritellakløft is also named Turritelladal on some maps. For location, see Fig. 2.

Subsurface strata, here assigned to the Agatdal Formation, were first cored in the GANE#1 well drilled by grønArctic Energy Inc. at Eqalulik on western Nuussuaq in 1995 (Fig. 65). A thick succession of marine Paleocene sandstones and conglomerates was drilled in 1996 by the GRO#3 exploration well south-east of the Kuussuaq river delta (Figs 9, 65, 67). This succession was referred to the Quikavsak Formation by Christiansen *et al.* (1999), but is here referred to the Agatdal Formation.

Name. The formation is named after the Agatdalen valley on central Nuussuaq.

Distribution. Outcrops of the Agatdal Formation are only known from the Agatdalen area (Fig. 113; Dam *et al.* 2000). From subsurface data (GRO#3, GANE#1 and GANE#1A wells), the formation is known also to be present on western Nuussuaq, west of the Kuuganguaq–Qunnilik Fault.

Fig. 114. Type locality of the Agatdal Formation in Turritellakløft (Rosenkrantz 1970; for location, see Fig. 113). The section is approximately 80 m high. In the present paper, the Agatdal Formation is not subdivided, but the formally abandoned 'Turritellakløft Member' and 'Andreas Member' are shown to provide a link to Rosenkrantz (1970). The Agatdal Formation is overlain by a thin development of the Abraham Member which is part of the Eqalulik Formation. For measured section, see Plate 3 (section 1).

The Turritellakløft Member and the Abraham Member of Rosenkrantz (1970) were described from the western end of the Turritellakløft gorge and Qaarsutjægerdal (Figs 113–115, Plate 3; H.J. Hansen 1970), whereas the Andreas Member was only recognised in Turritellakløft (Figs 113, 114, Plate 3). The Sonja Member of Rosenkrantz (1970) is only known from a section in Agatkløft, 2 km east of Turritellakløft (Figs 116, 117, Plate 3).

On Svartenhuk Halvø, on the east slope of Firefjeld, a thin (30 m) Paleocene conglomeratic unit is present between the Itilli Formation and the hyaloclastic rocks of the Vaigat Formation (Fig. 73; J.G. Larsen & Pulvertaft 2000). This unit may be correlated with either the Agatdal Formation or the Quikavsak Formation.

Type section. The type section of the Agatdal Formation is at the so-called 'Store Profil' (or 'Big Section') in Turritellakløft in the north-western end of Agatdalen (Fig. 114, Plate 3, section 1; Rosenkrantz 1970 fig. 5; Henderson *et al.* 1976 fig. 312). The type section is located at 70°35.01´N, 53°08.02´W.

Reference sections. Reference sections occur on the southern slopes of Agatkløft and on the eastern slope of Qaarsutjægerdal (Figs 115, 116, 117, Plate 3).

In the subsurface, a complete section through the formation was encountered in the GRO#3 well from 718 m to 423 m (Fig. 67). No cores were taken but a complete suite of well logs is available (Kristensen & Dam 1997). The upper part of the Agatdal Formation was drilled and fully cored in the GANE#1A well from 706.7 m to 601.5 m (Fig. 119).

Thickness. The formation varies considerably in thickness from 65 m in the type section to 18 m in Qaarsutjægerdal (Plate 3). In the GRO#3 well, the formation is approximately 250 m thick (excluding igneous intrusions; Fig. 67).

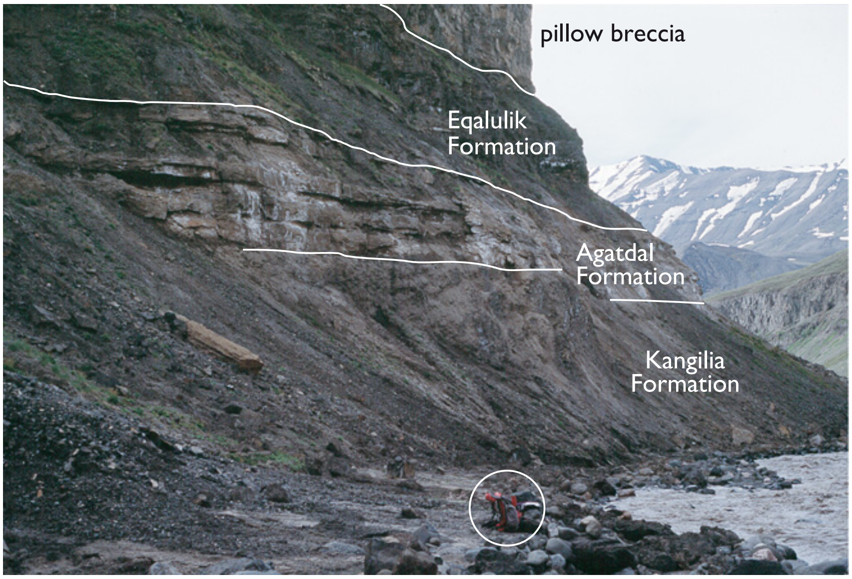


Fig. 115. Thin development of the Agatdal Formation in Qaarsutjægerdal (for location, see Fig. 113). Sandstone beds of the Agatdal Formation overlie mudstones of the Kangilia Formation with marked angular unconformity. The Agatdal Formation is overlain by the Abraham Member of the Eqalulik Formation. The exposed section below the pillow breccias is 21 m thick. For measured section, see Plate 3 (section 4).

Lithology. In the Agatdalen area, the Agatdal Formation comprises mudstones with several thick, lenticular conglomeratic and sandstone units (Figs 114–117, Plate 3) that Rosenkrantz (1970) had already recognised to be partly laterally equivalent.

The Agatdal Formation, as exposed in the junction between Agatkløft and Qaarsutjægerdal, is characterised by a major, fining-upward succession composed of a basal conglomerate unit grading upwards into alternating arkosic sandstones, conglomerates and mudstones with marine fossils and plant remains (Plate 3). The basal conglomerate unit can be followed laterally for about 1 km, but disappears rapidly towards the south-east along the Agatdalen river (Figs 113, 116, 117, Plate 3). The conglomerates also seem to wedge out towards the north-west in Agatkløft. The clasts are pebble to boulder grade and are composed of gneiss. The conglomerates form amalgamated beds up to 7 m thick, or alternate with clast-rich, coarse-grained sandstones. The sandstone beds of the overlying succession usually show normal grading and both parallel- and cross-lamination. Sandstone streaks are common in the mudstones interbedded with the sandstone beds.

In the Turritellakløft section, the Kangilia Formation is unconformably overlain by dark grey to black, sand-streaked mudstones with sandstone lenses and sheets which form the base of the Agatdal Formation (Fig. 114, Plate 3; Rosenkrantz 1970). The lower part of the formation here consists of thinly interbedded mudstones, siltstones and sandstones. The mudstones show graded, parallel lamination. The sandstone beds are parallel- and cross-laminated. Trace fossils are common (J.M. Hansen 1980b).

Upwards, the sandstone beds become thicker and occur as sheets and lenses with erosional bases. The beds are parallel laminated or show normal grading from coarse-grained to fine-grained sand. Locally the sandstones are highly fossiliferous (predominantly *Turritella* sp.). Intraformational mudstone and sandstone clasts are common. Loose slabs show a preferred orientation of *Turritella* shells; this parallel orientation indicates that the shells were current-worked and may serve as palaeocurrent indicators.

In the upper part of the Turritellakløft section is a channellised unit of well-sorted, very coarse-grained, tabular to wedge-shaped, cross-bedded sandstone (Fig. 114). The top of the Agatdal Formation is a 1.5 m thick gravelly, very coarse-grained sandstone bed. Body and trace fossils are very rare in these sandstones.

In Qaarsutjægerdal, a matrix-supported conglomerate bed occurs at the base of the formation (Fig. 115, Plate 3). It is succeeded by well-sorted, fine- to medium-grained sandstones, with few mudstone interbeds. Locally the sandstones show parallel- and low-angle cross-lamination. Bioturbation is intense at the top of the section where *Ophiomorpha* isp. and *Planolites* isp. are common. The sediments are highly fossiliferous; *Turritella* sp. is particularly numerous and the shells show a preferred parallel orientation.

In the GANE#1 well, the Agatdal Formation consists of a thick, fining-upward succession composed of a lower sandstone unit grading upwards into a heterolithic unit.

Fig. 116. Basal conglomerate unit of the Agatdal Formation south of the junction between Agatdalen and Agatkløft (for location, see Fig. 113). Note how the conglomerate pinches out towards the left (south). Section is approximately 13 m high. For measured section, see Plate 3 (section 3).

The cored succession in the GANE#1 and GANE#1A wells consists of amalgamated, thickly bedded, coarse- to very coarse-grained sandstones with normally graded beds in places alternating with thinly interbedded sandstones and mudstones (Fig. 119). The upper heterolithic part of the formation consists of mudstones, thinly interbedded sandstones and mudstones, amalgamated sandstones grading upwards into thinly interbedded sandstones and mudstones and muddy sandstones. Probable scape burrows are observed locally (Dam 1996b).

Fossils. The Agatdal Formation is the most fossiliferous of the marine units in West Greenland, with more than 500 described macrofossil species (see also 'Previous work' above).

Marine fossils in the mudstones (the former Turritellakløft Member) include gastropods, bivalves, scleractinian corals, fish, ostracods, coccoliths and foraminifera (Bendix-Almgreen 1969; Rosenkrantz 1970; Szczechura 1971; J.M. Hansen 1976; Kollmann & Peel 1983; Petersen & Vedelsby 2000). Dinocysts are rare (J.M. Hansen 1980b).

The sandstones of the former Andreas Member are very poor in fossils in the Turritellakløft section, whereas certain levels in Qaarsutjægerdal are very fossiliferous. *Turritella* sp. is particularly common, but other gastropods together with bivalves, scleractinian corals and spines of echinoids have also been found in the member (Rosenkrantz 1970; Floris 1972; Kollmann & Peel 1983; Petersen & Vedelsby 2000). Wood and fragments of leaves and fruits have been collected in this member in Qaarsutjægerdal (Koch 1963, 1972a, b).

The sandstones and conglomerates of the former Sonja Member are generally poor in marine fossils but locally contain a very rich marine fauna, known mainly from the 'Sonja lens'. The lens was originally 7 m long and 0.7 m thick but was completely excavated by Rosenkrantz and his co-workers. The fauna from this bed is dominated by bivalves and gastropods, but also includes scleractinian corals, octocorals, asteroids, crinoids, echinoids, serpulids, brachiopods, bryozoans, scaphopods, crustaceans, fish, foraminifera, coccoliths and palynomorphs (Bendix-Almgreen 1969; H.J. Hansen 1970; Rosenkrantz 1970; Szczechura 1971; Floris 1972; Perch-Nielsen 1973; Henderson *et al.* 1976; J.M. Hansen 1980b; Kollmann & Peel 1983; Collins & Wienberg Rasmussen 1992; Petersen & Vedelsby 2000). Moreover, the Agatdal Formation contains a well-preserved macroflora (Koch 1963). On western Nuussuaq, however, no determinable macrofossils have been found in the Agatdal Formation.

Dinocysts are common in samples from the GRO#3 and GANE#1 wells (Nøhr-Hansen 1997b, c; Nøhr-Hansen *et al.* 2002). The trace fossils *Ophiomorpha* isp. and *Planolites* isp. are locally common (see above).

Depositional environment. In the Agatdalen area, the macrofossils are indicative of a relatively shallow-water, marine depositional environment, such as a lower shoreface or inner shelf environment (Petersen & Vedelsby 2000). In contrast, the sedimentary facies are interpreted to reflect deposition in a deep-water slope environment.

Fig. 117. Exposure of the Agatdal Formation in Agatkløft (for location, see Fig. 113; for measured section, see Plate 3 (section 2)). The section is approximately 50 m high and, together with the basal conglomerate unit shown in Fig. 116, was referred to the 'Sonja Member' by Rosenkrantz (1970). The completely excavated Sonja Lens was part of this section. According to H.J. Hansen (1970) the succession is capped by 6 m of concretionary mudstone (covered by scree during the authors' visit in 1992) underlying volcanic pillow breccias and a sill.

The mudstone-dominated units were deposited from dilute turbidity currents in an unconfined slope setting where the sandstone interbeds possibly represent splay deposits from nearby submarine channels. The thick lenticular, conglomeratic sandstones were deposited by high- and low-density turbidite currents in submarine slope channels. The fossils found in these units must therefore have been transported, but probably only over short distances, as they are not worn or fragmented.

The presence of basement boulders in the conglomerate close to the base of the formation implies fluvial transport from areas east of the Ikorfat fault system (A.K. Pedersen *et al.* 1996 fig. 6). The conglomerates were thus probably deposited in a submarine canyon in front of a major delta at the mouth of the coeval incised fluvial valley system represented by the Quikavsak Formation.

Palynological and geochemical investigations of the GRO#3 and GANE#1 wells also indicate a marine depositional environment (Bojesen-Koefoed *et al.* 1997; Nøhr-Hansen 1997c) and the sediments record deposition dominated by high-density turbidity currents. The thickness of the formation in the GRO#3 and GANE#1 wells and the overall geological setting suggests that deposition took place in a major submarine canyon system on a fault-controlled slope (Dam 1996b; Kristensen & Dam 1997). The small, fining-upward cycles in the upper, heterolithic part of the canyon fill were deposited in small turbidite channels.

Boundaries. Where the lower boundary is exposed in the Agatdalen area the Agatdal Formation rests unconformably on the Kangilia Formation (Figs 113, 115, Plate 3). The Agatdal Formation is overlain by the Eqalulik Formation (Figs 113–115, 119, Plate 3) or locally by volcaniclastic breccias of the Vaigat Formation.

In the GRO#3 well the lower boundary is probably an erosional unconformity separating coarse- to very coarse-grained sandstones of the Agatdal Formation from heterolithic deposits of the Kangilia Formation below (Fig. 67). The upper boundary is placed at the base of the reworked volcaniclastic sediments or tuffs of the Eqalulik Formation (Fig. 67).

Age. Most fossil groups indicate a Paleocene (Late Danian) age for the formation (Fig. 16; Bendix-Almgreen 1969; H.J. Hansen 1970; Rosenkrantz 1970; Szczechura 1971; Kollmann & Peel 1983; Collins & Wienberg Rasmussen 1992). The coccolith assemblage indicates a *Chiasmolithus danicus* zone age (NP 3 Zone; Perch-Nielsen 1973). The co-occurrence of the foraminifera *Globoconusa daubjergensis* and *Globigerina compressa* indicates a P1c plankton zone age for the Agatdal Formation (H.J. Hansen 1970; Berggren *et al.* 1995; Olsson *et al.* 1999) which corresponds to a late NP3 – early NP4 age. In the GRO#3 well, dinocysts and nannofossils indicate an age not younger than nannoplankton zone NP4 (Late Danian or Early Selandian; Nøhr-Hansen 1997c; Nøhr-Hansen *et al.* 2002).

Correlation. The age of the Agatdal Formation suggests that it is coeval with the major incised valley systems of the Quikavsak Formation on southern Nuussuaq and with most of the upper part of the Kangilia Formation on the north coast of Nuussuaq (Figs 11, 15, 16; Nøhr-Hansen et al. 2002). The basal unconformity described between the Agatdal and Kangilia Formations in the Agatdalen area may be due to either condensation or nondeposition of nannoplankton zones NP1 and NP2 in the type section of the Kangilia Formation.

Eqalulik Formation

new formation

History. Deposits now assigned to the Eqalulik Formation embrace the marine synvolcanic strata below the basalts of the West Greenland Basalt Group (Hald & Pedersen 1975) that contain volcaniclastic sandstones and tuffs. On the north coast of Nuussuaq and on central Nuussuaq, these strata have previously been assigned to the *Thyasira* and *Propeamussium* Members of the Kangilia Formation (Rosenkrantz 1970) and the Abraham Member of the Agatdal Formation (Rosenkrantz 1970). However, the *Thyasira* and *Propeamussium* Members are considered inappropriate as they were established solely on the basis of the faunal content. The use of these two members as defined by Rosenkrantz (1970) is now abandoned and the strata included in the new Eqalulik Formation.

On the south coast of Nuussuaq, a thin unit of marine black shale including bioturbated sandstone beds below the volcaniclastic breccias of the Vaigat Formation was referred to the Asuup Inatartaa Member of the Quikavsak Formation by Dam (2002) but is here included in the Eqalulik Formation. Strata previously mapped as unnamed Paleocene (Tertiary) on the north coast of Nuussuaq east of the Ikorfat fault, in the region around the Tunorsuaq valley, and in the Itilli and Aaffarsuaq valleys are now assigned to the Eqalulik Formation.

Name. After Eqalulik, a lake close to the location of the GANE#1 drill site on western Nuussuaq (Fig. 65).

Distribution. The formation is widely distributed below the hyaloclastites of the Anaanaa and Naujánguit Members of the Vaigat Formation (West Greenland Basalt Group) and, although it is generally poorly exposed, it has been recognised at many localities on Nuussuaq (Piasecki *et al.* 1992), locally on the north coast of Disko, and locally on Svartenhuk Halvø (Fig. 73; J.G. Larsen & Pulvertaft 2000). On the north coast of Nuussuaq, the formation has been recognised both east and west of the Ikorfat fault. It is present in the Tunorsuaq valley and has been locally observed in the Itilli and Aaffarsuaq valleys (Floris 1972). West of Ataa on the south coast of Nuussuaq, the formation forms a thin unit dominated by marine mudstones below the hyaloclastites of the Vaigat Formation. East of Ataa, it is sandwiched between the sandstones of the Quikavsak Formation and overlying non-marine mudstones referred to the Naujât Member of the Atanikerluk Formation (see also Koch 1959 pp. 78–79).

Type section. The outcrop section at Kangilia where the Eqalulik Formation conformably overlies the Kangilia Formation is very poorly exposed (Figs 74, 87, 118). A complete, well-preserved section through the formation was cored from 598 m to 496.5 m in the GANE#1 well (Figs 65, 119) and this is therefore chosen as the type section (Fig. 119). The cores are stored at GEUS in Copenhagen. The GANE#1 well is located at 70°28.25´N, 54°00.40´W.

Reference section. Reference sections occur on central Nuussuaq in Agatdalen (Plate 3) and Aaffarsuaq (Fig 83), and on the south coast of Nuussuaq at Ippigaarsukkløften (Fig. 120).

In the GANK#1 well, a reference section was cored from 333 m to 114.9 m (Fig. 121), and the formation was also cored in the sidetrack well GANK#1A from 332.9 m to 218.6 m. The cores are stored at GEUS.

Fig. 118. Exposure of the Eqalulik Formation overlying the Kangilia Formation at Kangilia. The photo shows the lower *c.* 20 m of the formation; for location, see Fig. 74.

Thickness. On the north coast of Nuussuaq, the formation ranges from 100 to 160 m thick, in Agatdalen it is approximately 12 m thick (H.J. Hansen 1970), and in Aaffarsuaq it is less than 20 m in thickness. In the GANE#1A well, the formation is 102 m thick and it is 218 m thick in the GANK#1 well. The very variable thickness of the formation is the result of varying proportions of tuffaceous material (the presence of which defines the formation) and intensive loading and deformation of the mudstones by prograding thick lobes of submarine basaltic breccia beds.

Lithology. The formation comprises mudstones, tuff beds and volcaniclastic sandstones; the latter lithologies are essential to the definition of the formation (Fig. 122). Internal structures in the mudstones cannot be recognised due to poor exposure. The thicker sandstone units consist of amalgamated graded beds composed of fine- to very coarse-grained, volcaniclastic sandstones with scattered pebble-sized volcanic and mudstone clasts. Parallel lamination, current cross-lamination and dish structures have locally been observed within the graded beds. In some areas volcanic material may constitute up to 25% of the section (A.K. Pedersen 1978) and fossils are common (Rosenkrantz 1970; Floris 1972). The tuff beds are up to 7 m thick at Kangilia, and tuff beds up to several metres thick are also seen in Danienkløft (Tunorsuaq) and in Koralkløft (Ilugissoq; Figs 2, 74). Most of these tuff beds contain scleractinian corals; these are without preferred orientation, but only slightly worn (Floris 1972).

In the GANE#1 well the formation consists of mudstones, interbedded quartz-rich, siliciclastic and volcaniclastic sandstones and mudstones, muddy sandstones and chaotic beds (Dam 1996b). Volcanic clasts and rounded basement pebbles and angular mudstone rip-up clasts are common, and concretions and plant debris are locally present (Fig. 119). Several thinning- and fining-upward successions have been recognised in the core. These are sharply based and consist of amalgamated normally graded, very coarse- to coarse-grained sandstone beds passing upwards into thinly interbedded sandstones and mudstones. Occasionally the sandstone beds are internally stratified, showing parallel-lamination or cross-lamination, dish structures and soft sediment folds. Sandstones are occasionally burrowed and escape burrows

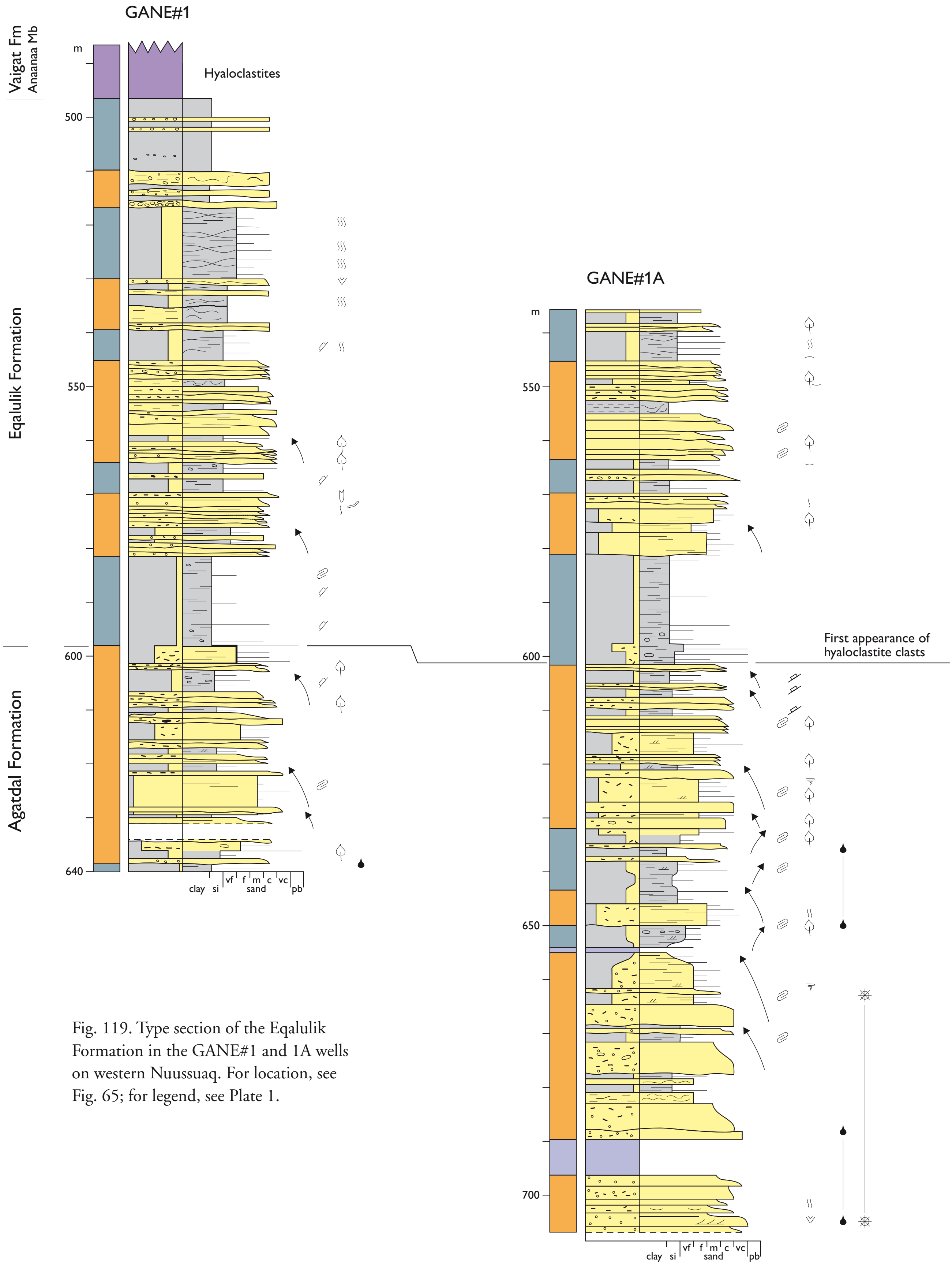


Fig. 119. Type section of the Eqalulik Formation in the GANE#1 and 1A wells on western Nuussuaq. For location, see Fig. 65; for legend, see Plate 1.

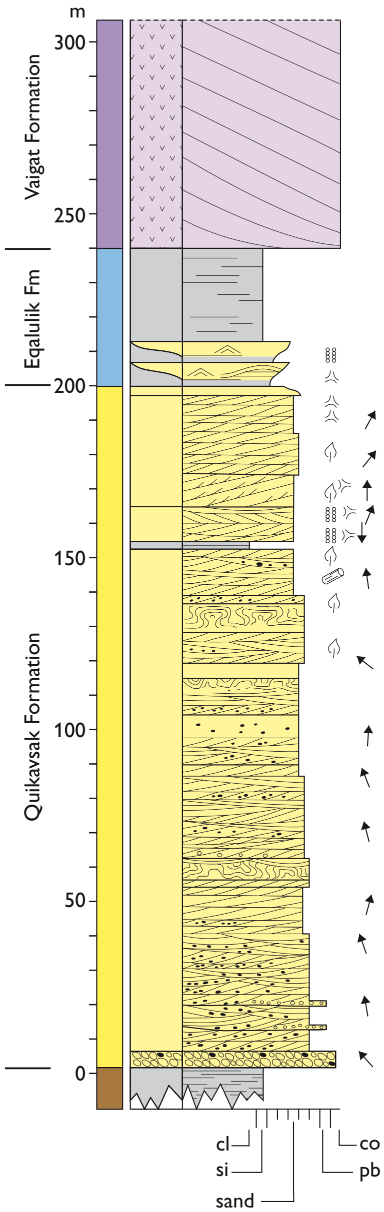


Fig. 120. Reference section of the Eqalulik Formation overlying the Paatuutkløften Member (Quikavsak Formation) at Ippigaarsukkløften on southern Nuussuaq (for location, see Fig. 40). The upper part of the Eqalulik Formation comprises fine-grained, tuffaceous mudstones deposited at water depths up to 700 m, as demonstrated by the height of the foresets in the overlying and laterally equivalent hyaloclastite breccias. Modified from Dam & Nøhr-Hansen (2001). For legend, see Plate 1.

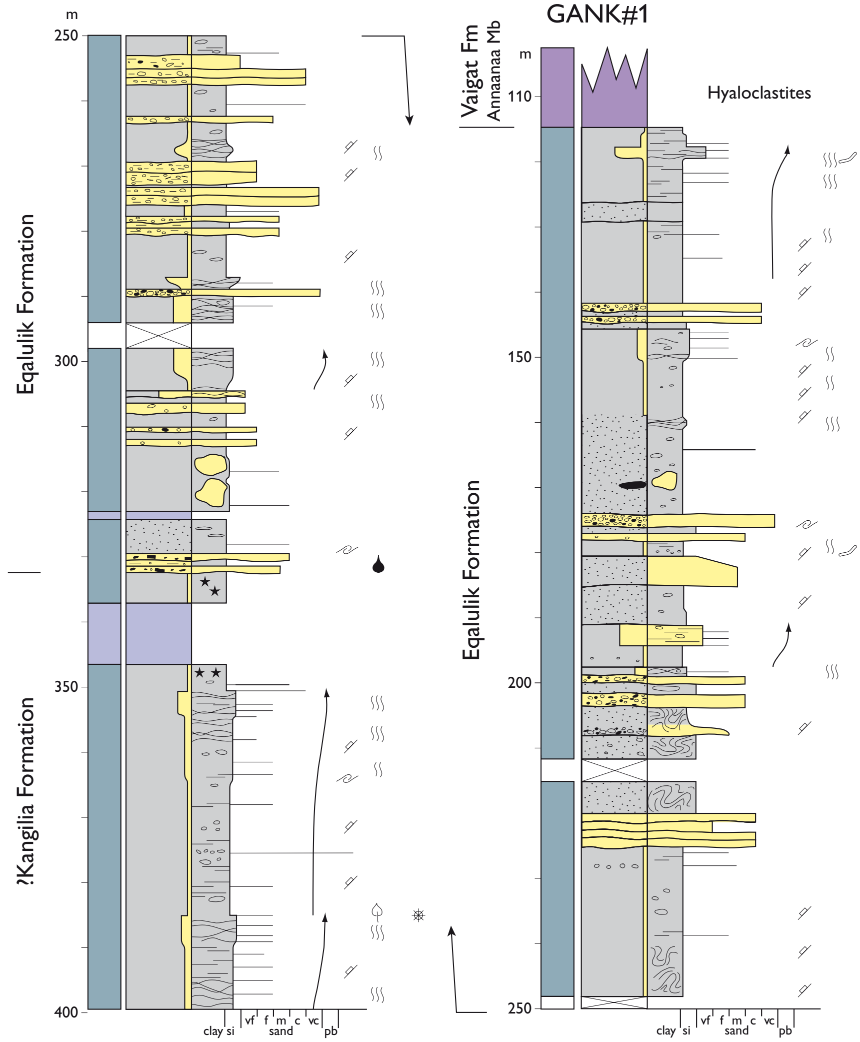
are present in a few beds. Mudstone laminae show normal grading. The chaotic beds in the GANE#1 well consist of homogenised mudstones with evenly scattered sand grains, granules, volcanic clasts and concretions. The beds are interbedded with structureless muddy sandstones and slumped mudstones showing contorted bedding (Fig. 119; Dam 1996b).

Fossils. The formation has yielded a very rich fauna, particularly in the Kangilia section where the concretions in the mudstones include gastropods, bivalves, corals, echinoderms and nautiloids, and also foraminifera, crinoids and serpulids. The bivalve *Thyasira (Conchocele)* aff. *T. conradi* (Rosenkrantz) and the pectinid *Propeamussium ignoratum* Ravn are especially common in the concretions together with a large thick-shelled *Echinocorys, Hercoglossa groenlandica* (Rosenkrantz) and stems of *Isselicrinus groenlandicus* Wienberg Rasmussen (Rosenkrantz 1970; Henderson *et al.* 1976; Kollmann & Peel 1983; Petersen & Vedelsby 2000). A fish fauna is also represented in the concretions (Bendix-Almgreen 1969) and scleractinian corals and coccoliths have been reported from the volcaniclastic sandstones (Floris 1972; Jürgensen & Mikkelsen 1974). Some corals are attached to tuff clasts, indicating that this was their original substrate. Their random orientation suggests, however, that they are redeposited, but as they are only slightly worn, transport distances must have been short (Floris 1972). A sparse nannoplankton and dinocyst flora is present at most localities (Piasecki *et al.* 1992; Nøhr-Hansen *et al.* 2002), including the mudstones at the base of the volcanic breccias of the Vaigat Formation along the south coast of Nuussuaq. The trace fossils *Planolites* isp. and *Helminthopsis horizontalis* have been recognised in the GANE#1 and GANK#1 cores (Dam 1996b, c).

Depositional environment. The macrofossils and the dinocysts indicate a marine depositional environment. Based on the height of the overlying foresets in the hyaloclastite breccias, the water depth can be estimated to have been up to 700 m (A.K. Pedersen *et al.* 1993). The sandstones are interpreted as the deposits of waning stage high- to low-density turbidity currents. However, tuff layers deposited from suspension have also been recorded (A.K. Pedersen *et al.* 1989). Volcanism started from eruption centres in the north-western and western part of the region erupting directly into a deep marine environment covering large parts of Nuussuaq and northern Disko. The fossiliferous volcaniclastic sandstones and tuffs represent the distal bottomsets of major hyaloclastite beds of the Vaigat Formation (A.K. Pedersen 1985), the result of sediment gravity flows that transported volcanic detritus and fossils into deeper water.

Boundaries. The lower boundary is placed at the base of the first volcaniclastic sandstones or tuffs. This bound-

Fig. 121. Well reference section of the Eqalulik Formation in the GANK#1 well. For location, see Fig. 65; for legend, see Plate 1.



ary is, however, difficult to place in the field since outcrops are generally very poor in these mudstone-dominated successions. Along the north coast of Nuussuaq and in the Tunorsuaq valley, a conspicuous change in the colour of bottom sediment in small streams draining the local lithologies has been observed to occur at a distinctive level high in the sections. In the lower part of the sections, the stream-bed sediments are ochreous whereas this colouring is not present at higher levels; this change may reflect the sulphide content in the mudstones of the two formations and thus aid localisation of the formation boundary. If so, the mudstones of the Kangilia Formation were deposited in a poorly oxygenated, deep-water environment in contrast to the Eqalulik Formation where more oxygenated conditions could have resulted from intermittent disturbance of bottom waters by progradation of volcanic breccias.

The upper boundary is generally placed at the base of the West Greenland Basalt Group, at the base of the major hyaloclastic foreset beds of the Vaigat Formation or at sills situated along the base of the Vaigat Formation (Hald & Pedersen 1975; A.K. Pedersen *et al.* 1993). On southern Nuussuaq, however, between Ataa and Ippigaarsukkløften (Fig. 40), the marine conditions prevailing during deposition of the Eqalulik Formation were succeeded by lacustrine environments, and consequently the Eqalulik Formation is overlain by non-marine shales of the Atanikerluk Formation (A.K. Pedersen *et al.* 1996; G.K. Pedersen *et al.* 1998).

Geological age. The Eqalulik Formation is visibly diachronous, reflecting the progressive eastward progradation of the hyaloclastite fans which are very well exposed along the slopes overlooking the south coast of Nuussuaq

Fig. 122. Fossiliferous, volcaniclastic sandstones of the Eqalulik Formation at Danienrygge. Pencil (encircled) and person for scale.

(A.K. Pedersen *et al.* 1993). However, the biostratigraphic resolution is in most cases not good enough to resolve this diachronism. The macrofauna at the type locality and on central Nuussuaq indicates an Early Danian age (Rosenkrantz 1970; Floris 1972; Henderson *et al.* 1976). The coccolith assemblage has been related to the NP3 nannoplankton zone by Jürgensen & Mikkelsen (1974); however, new dinocyst and nannoplankton data indicate an NP4 – possibly base NP5 zone age (latest Danian – early Selandian; Nøhr-Hansen *et al.* 2002). $^{40}Ar/^{39}Ar$ age determinations of the volcanic rocks of the Anaanaa Member (Vaigat Formation) overlying the Eqalulik Formation yield an age of 60.7 ± 1.0 (recalculated from Storey *et al.* 1998).

Correlation. On the basis of dinocyst markers, the strata in the type section can be correlated with the volcanic hyaloclastites of the Anaanaa and Naujánguit Members of the Vaigat Formation in the north-western part of the basin (Nøhr-Hansen *et al.* 2002). The tuffs of the Abraham Member (see below) have a unique composition with graphite and native iron that allows them to be correlated with the volcanic Asuk Member (A.K. Pedersen *et al.* 1989).

Subdivision. The volcaniclastic sediments in Agatdalen and Qilakitsoq will continue to be assigned to a separate member, the Abraham Member, because of their unique geochemical composition which permits correlation of the sediments with the volcanic Asuk Member of the Vaigat Formation.

Abraham Member

revised member

History. The Abraham Member was established by Rosenkrantz (in: Koch 1959 pp. 75–78) as the uppermost member of the Agatdal Formation, but is now included in the Eqalulik Formation on the basis of the characteristic content of volcaniclastic material.

Name. After Abraham Løvstrøm from Niaqornat, who for 30 years was a member of Rosenkrantz's expeditions to Nuussuaq (Fig. 7).

Distribution. The Abraham Member is known from two localities in the northernmost part of the Agatdalen valley (Fig. 113) and from the Qilakitsoq area in the Aaffarsuaq valley (Fig. 82).

Type section. The type section of the Abraham Member is in Turritellakløft at the northern end of Agatdalen (Fig. 113, 114, Plate 3, section 1). The type section is located at 70°35.01′N, 53°08.02′W.

Reference section. A reference section occurs in 'Ravine 4' east of Qilakitsoq (Figs 82, 83).

Thickness. The thickness of the Abraham Member is approximately 12 m in the type section, 10 m in Qaersutjægerdal in Agatdalen and 10–20 m at Qilakitsoq.

Lithology. The Abraham Member consists of black and grey sandy mudstones intercalated with fossiliferous reworked volcaniclastic sandstones and basement pebble conglomerates (Figs 114, 115, Plate 3). Volcanic material may constitute up to 25% of the section (A.K.

Pedersen 1978). The beds are usually structureless, but cross-bedding has been recognised locally. Volcaniclastic sandstones also occur as thin streaks in the mudstones and may include spherules of volcanic glass or tuff with a distinct chemical composition known only from the Asuk Member erupted from the Ilugissoq graphite andesite volcano (A.K. Pedersen 1985; A.K. Pedersen & Larsen 2006). In the lower part of the member, the mudstones are very dark, fossiliferous and rich in concretions. At one horizon, *in situ* corals are present in small bioherms, 10–20 cm high and less than 1 m wide (Plate 3, section 4). This horizon can be followed for more than a kilometre on the eastern bank of Qaersutjægerdal. The content of volcaniclastic sandstones increases upwards in the section.

Fossils. A sparse but diverse marine fauna and flora has been recorded from the Abraham Member, comprising scleractinian corals, echinoids, bivalves, gastropods, crustaceans, fish remains and palynomorphs (Bendix-Almgreen 1969; Rosenkrantz 1970; Floris 1972; Kollmann & Peel 1983; Piasecki *et al.* 1992; Petersen & Vedelsby 2000).

Depositional environment. The macrofossil content in the lower part of the member indicates a marine depositional environment. However, an increase up-section in terrestrially derived palynomorphs indicates that the environment became increasingly brackish with time.

Sedimentary structures in the volcaniclastic sandstones indicate deposition from turbidity currents. The corals suggest a shallow water (50?–80 m) marine environment in a warm temperate climate (Floris 1972), but where the corals were redeposited the water depth may well have exceeded 80 m.

Boundaries. A sharp lithological boundary occurs between the sandstones of the Agatdal Formation and the interbedded mudstones and volcaniclastic sandstones of the Abraham Member (Figs 114, 115). At Qilakitsoq and in the northern part of Agatdalen, the Abraham Member is succeeded by hyaloclastites of the Naujánguit Member, whereas in the eastern part of Agatdalen the Abraham Member is succeeded by hyaloclastites of the Tunoqqu Member (A.K. Pedersen 1978; Piasecki *et al.* 1992; A.K. Pedersen, personal communication 1999).

Geological age. As for the Eqalulik Formation, i.e. latest Danian to early Selandian.

Correlation. The geochemical correlation of the Abraham Member with the hyaloclastites of the Asuk Member of the Vaigat Formation (A.K. Pedersen 1978, 1985; A.K. Pedersen & Larsen 2006) ties these isolated outcrops to the mapped volcanic succession on the south coast of Nuussuaq (A.K. Pedersen *et al.* 1993).

Atanikerluk Formation

new formation

History. The Atanikerluk Formation comprises the synvolcanic non-marine sediments in the Nuussuaq Basin; in the eastern part of the basin, it includes almost all the sediments overlying the Atane Formation (Fig. 16). It is divided into five members (Fig. 123), which are correlated to members in the volcanic Vaigat and Maligât Formations (Fig. 131). The intra- and post-volcanic sediments of the Nuussuaq Basin are not included in the Nuussuaq Group and are therefore not discussed here.

Koch 1959		This paper		
Nuussuaq		Nuussuaq	Disko	
Upper Atanikerdluk Formation	Point 976 Member	Assoq Member	Assoq Member	Atanikerluk Formation
	Aussivik Member			
	Umiussat Member	Umiussat Member	Umiussat Member	
	Naujât Member	Naujât Member	Pingu Member Akunneq Member Naujât Mb	
	Quikavsak Member	Quikavsak Formation	Not present	

Fig. 123. Lithostratigraphical subdivisions of the synvolcanic, non-marine deposits of the Nuussuaq Basin.