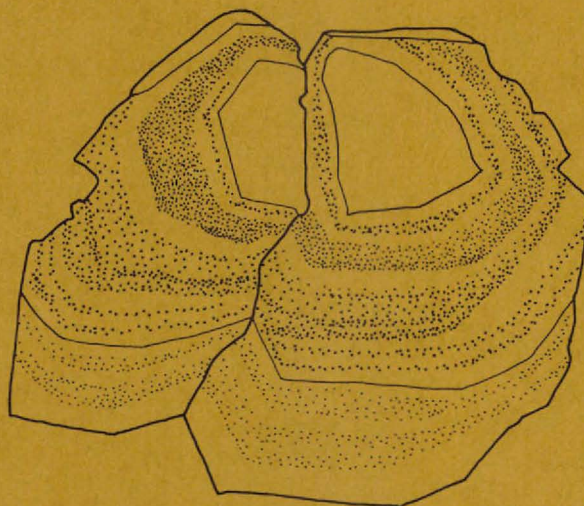


Stratabound scheelite and stratiform tourmalinites
in the Archaean Malene supracrustal rocks,
southern West Greenland

P. W. U. Appel and A. A. Garde




Grønlands Geologiske Undersøgelse

(The Geological Survey of Greenland)

Øster Voldgade 10, DK-1350 Copenhagen K

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An outline map of Greenland, showing the island's irregular coastline and several smaller islands to the north and east. The map is drawn with a simple black line on a white background.

Stratabound scheelite and stratiform tourmalinites
in the Archaean Malene supracrustal rocks,
southern West Greenland

P. W. U. Appel and A. A. Garde

Abstract

The Malene supracrustal rocks form large enclaves in the late Archaean Nûk gneisses within an area of at least 36 000 km² on the west coast of Greenland, and have been repeatedly deformed and metamorphosed under amphibolite facies conditions. Stream sediment sampling has shown that scheelite occurs in the supracrustal enclaves throughout the area. It occurs stratabound in amphibolites, micaceous quartzites, siliceous cordierite-bearing metasediments and tourmalinites.

A detailed geological map has been made of the central part of Store Malene mountain close to Nuuk. Banded metavolcanic Malene amphibolites and siliceous cordierite-bearing metasediments contain stratiform tourmalinites, often with appreciable scheelite, in addition to common accessory tourmaline. The tourmalinites predate the earliest recognisable phase of deformation as well as prominent simple pegmatites.

The tourmaline probably originated as primary sea floor precipitates, and the primary or diagenetic tourmaline crystals were later overgrown with tourmaline during metamorphism. The scheelite and tourmaline are probably syngenetic and of submarine exhalative origin, and boron complexes may have played a role in transporting tungsten in hot brines.

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Contents

Introduction	5	Timing of deformation, metamorphism and pegmatite intrusion at Store Malene.....	11
General geology	5	Tourmaline and tourmalinites	12
Geology of Store Malene.....	6	Field relationships	12
General geology	6	Petrography	13
Malene metasediments and intercalated thin amphibolites	6	Chemistry of the tourmalinites	16
Malene amphibolites.....	8	Chemistry of tourmaline	16
Pegmatites	8	Scheelite occurrences	18
Structural and metamorphic evolution of the Store Malene area	9	Genesis of the tourmaline and the tourmalinites	20
Pre-pegmatite deformation	9	Genesis of the scheelite	23
Post-pegmatite deformation	10	Acknowledgements.....	24
Microtextures in metasediments and amphibolites .	10	References	24

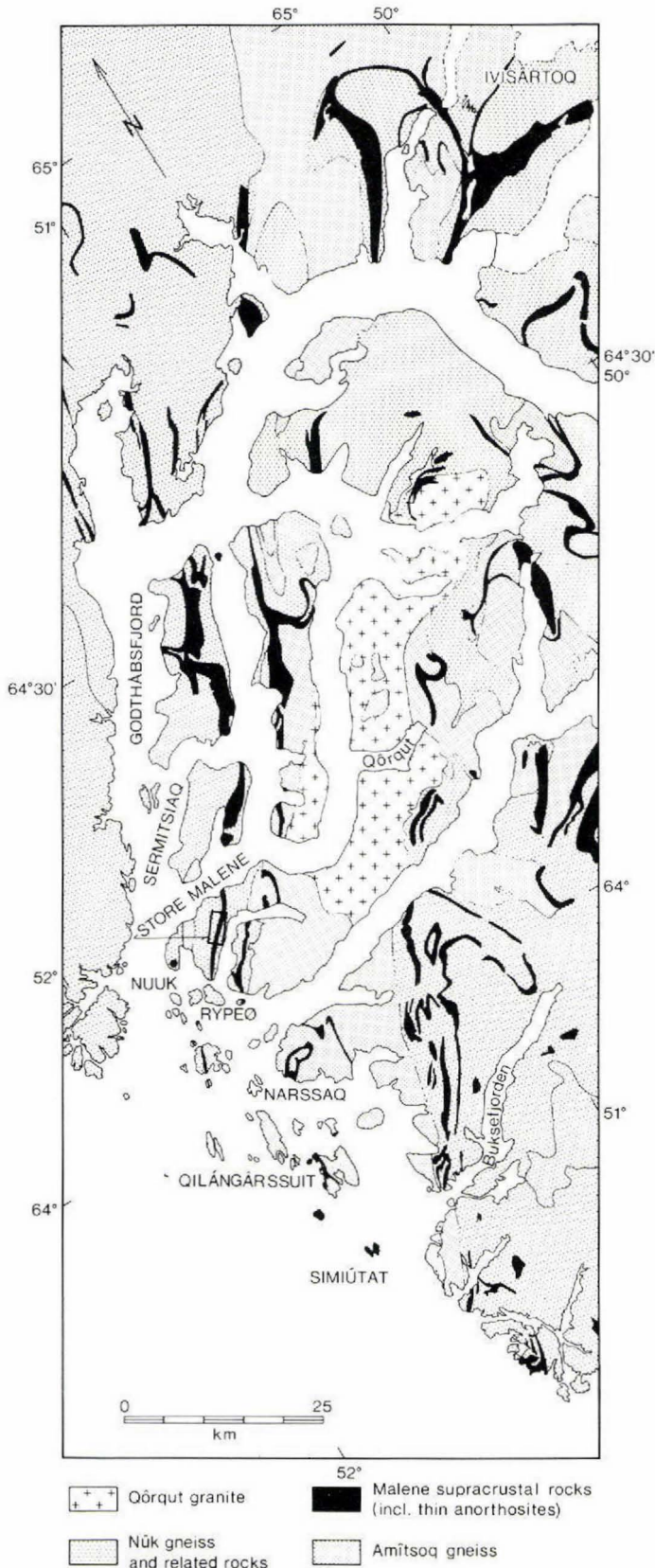


Fig. 1. Simplified geological map of the Godthåbsfjord area. The location of Plate 1 at Store Malene is indicated.

Introduction

Until recently tourmaline and scheelite occurrences were mostly regarded as being of granitic pedigree. It has, however, been increasingly recognised that both minerals also occur stratabound in geologic settings which strongly indicate syngenetic relationships, and with submarine exhalative origins (Ethier & Campbell, 1977; Höll & Maucher, 1967; Maucher, 1965; Slack *et al.*, 1984; Taylor & Slack, 1984; Plimer, 1980, 1983a). Recently, the suggestion that tourmaline can be a primary mineral precipitated on the sea floor gained further support from the discovery of fine-grained tourmaline in Archaean stromatolites in the Swaziland sequence, Barberton Mountain Land (Byerly *et al.*, 1986). The concept of tungsten precipitation in subaqueous environments has also been substantiated by the discovery of tungsten-rich sea-floor manganese nodules (Kunzendorf & Gwozd, 1984).

Stratabound tourmaline is frequently associated, and is co-genetic, with stratabound massive sulphide deposits (Ethier & Campbell, 1977; Taylor & Slack, 1984; Plimer, 1980, 1983a). Furthermore, stratabound scheelite and/or tin deposits are often associated with tourmaline-rich rocks (Plimer, 1983b). It has thus been suggested that tourmaline can be used as a guide in pro-

specting for stratabound scheelite and/or tin and/or stratabound massive sulphide deposits (Taylor & Slack, 1984; Plimer, 1983b). While this is undoubtedly true, there is one major problem in using tourmaline as a tracer mineral in that it is very difficult (and sometimes virtually impossible) to recognise fine-grained tourmaline in a dark coloured rock during field work, and because tourmalinites may even be mistaken for amphibolites. Future field work may reveal that tourmalinites are not as rare as hitherto believed.

In 1982 scheelite was found in the Godthåbsfjord area (Appel, 1983a). During the following years the presence of a tungsten province in southern West Greenland was revealed (Appel, 1986a) and a close association between tourmaline and scheelite established (Appel, 1985a). During the field season of 1985 the Department of Mineral Resources (P. W. U. A.) and Department of Precambrian Geology (A. A. G.) of the Geological Survey of Greenland (GGU) carried out a joint project to produce a detailed stratigraphic and structural map of a small area of Malene supracrustal rocks (Plate 1); this included further investigation of the scheelite-bearing horizons found in this part of the supracrustal belt and the discovery of the scheelite-bearing tourmalinites.

General geology

The first major event in the Archaean history of the Godthåbsfjord area was the deposition of the Isua supracrustal rocks *c.* 3800 Ma ago (Moorbath *et al.*, 1975; see Nutman, 1986 for further references). The main outcrop of these supracrustal rocks is at Isukasia approximately 150 km north-east of Nuuk, where they form a *c.* 15 km wide arcuate enclave within the slightly younger Amitsoq gneiss. Similar, but smaller, supracrustal remnants, the so-called Akilia association enclaves, are found in the Amitsoq gneisses throughout the Godthåbsfjord area. The Isua-Akilia rocks comprise basic and acid metavolcanic rocks together with thin horizons of carbonates and metapelites (Nutman *et al.*, 1983). Copper sulphides, stratabound tourmaline and scheelite were observed associated with an iron-formation in these supracrustal rocks (Appel, 1979, 1980, 1985b).

The next major event in the Nuuk area was the deposition of some of the Malene supracrustal rocks and the subsequent intrusion of a large anorthosite complex

(fig. 1). Both these units postdate the intrusion of the Amitsoq gneisses, but their exact ages are unknown. Apparently some of the Malene rocks also postdate the Nûk gneisses (L. Schiøtte, personal communication, 1987), see below. The supracrustal rocks form extensive outcrops up to several hundred metres wide and several kilometres long throughout the Nuuk area. The Store Malene mountain north-east of Nuuk, which has been studied in detail by the present authors, is the type locality for the Malene supracrustal rocks (McGregor, 1973). The Malene supracrustal rocks and the anorthosites were deformed and metamorphosed 2800–3000 Ma ago, contemporaneously with the emplacement of the Nûk gneisses (Moorbath & Pankhurst, 1976; Taylor *et al.*, 1980). The last major rock-forming event in the Nuuk area was the intrusion of the Qôrqt granite complex (Friend *et al.*, 1985) *c.* 2550 Ma ago, which formed by anatexis of the older gneisses. See also Bridgewater *et al.* (1976), Chadwick & Coe (1983) and McGregor *et al.* (1986) for general accounts of the geology in the region.

Geology of Store Malene

General geology

Malene supracrustal amphibolites and metasediments at the Store Malene mountain c. 5 km east of Nuuk are characterised by several horizons of tourmalinites, scheelite-bearing rocks and rust zones with pyrrhotite and small amounts of chalcopyrite. The area has been subjected to repeated late Archaean deformation and amphibolite facies metamorphism, as well as massive pegmatite injection.

Store Malene mountain consists of late Archaean (c. 3000–3050 Ma) Nûk tonalitic orthogneisses, which are intercalated with early Archaean (c. 3750 Ma) Amitsoq gneisses of similar composition, and Malene supracrustal rocks with a supposed age intermediate between those of the Amitsoq and Nûk gneisses. The contacts between the Nûk and Malene rocks at Store Malene are tectonic or strongly modified by shearing, whereas there is ample evidence that the Nûk gneisses intruded Malene units elsewhere in the Godthåbsfjord area.

The central part of Store Malene was mapped at a scale of 1:7500 (Plate 1). The field mapping was supplemented by geological photogrammetry at GGU and the Institute of Surveying and Photogrammetry, Copenhagen, using both conventional vertical aerial photographs and 24 × 36 mm colour slides taken by A. A. G. with an ordinary hand-held small frame camera (Dueholm & Garde, 1986).

Along the ridge of the mountain the supracrustal rocks form a c. 500 m thick, NE–SW striking tectonic segment, dipping at moderate to steep angles to the north-west (Plate 1), and bounded by Nûk gneisses on both sides. The lower half of the supracrustal segment is composed of pelitic, Mg and Al-rich siliceous paragneisses intercalated with thin volcanic amphibolites, whereas the upper half consists of a variety of mafic metavolcanic rocks and minor intermediate volcanosedimentary rocks. It is not known whether the sequence is inverted or right way up, since no primary way-up criteria have been found. Tourmaline-bearing rocks and tourmalinites are characteristic components of the metasedimentary as well as the metavolcanic rocks within the central part of Store Malene (Plate 1).

Metavolcanic and pelitic Malene rocks in the vicinity of Store Malene, which may once have been part of the same original volcanosedimentary pile, have been described in detail from the islands of Qilángårssuit in the Buksefjorden area south of Godthåbsfjord (Beech & Chadwick, 1980) and from southern Rypeø immediately south of Store Malene (Dymek *et al.*, 1983). Recent U-Pb ion probe age determinations of single zircon

grains from quartz-rich clastic Malene metasediments on western Rypeø indicate an age of deposition after c. 2800 Ma (L. Schiøtte, personal communication, 1987). It therefore appears that the Malene rocks comprise at least two units, one of which postdates Nûk magmatism.

In the Malene rocks on the island of Simiutat and in the Narssaq and Ivisârtoq areas (fig. 1) inconspicuous horizons of iron-formation occur. A peculiar feature of this iron-formation is its high content of trace elements notably tungsten, molybdenum, tin, copper and zinc (Appel, in press).

Malene metasediments and intercalated thin amphibolites

Rocks of sedimentary origin form the lower, north-east half of the supracrustal segment of Store Malene (Plate 1). They are intercalated with very thin bands of dark green, often garnet-bearing, amphibolites which are considered to be metamorphosed basic tuffs (see below).

A large proportion of the metasediments is exposed on steep south-east facing mountain sides with difficult access, and it has not been possible to subdivide the metasediment lithologies throughout the area shown on Plate 1. Precise correlation is complicated by internal isoclinal folds which have repeated part of the sequence. In addition, the most competent siliceous members located between more ductile micaceous schists have been disrupted and pulled apart during deformation.

The metasediments include a variety of schists and gneisses in shades of pale yellowish grey, grey, brown-grey and brown weathering colours. There are biotite-rich pelitic schists, anthophyllite-cordierite-bearing magnesian schists, and siliceous, magnesian and aluminous paragneisses rich in cordierite and quartz.

Biotite schists predominate both in the lower part of the supracrustal segment and towards its middle, where they alternate with amphibolites. The biotite schists are generally fine to medium-grained, grey-brown, with variably intense schistosity. They vary in composition and may grade into quartz-rich semipelites. Garnet is common as large flattened crystals, locally up to several centimetres in size. Common mineral parageneses are biotite–quartz–plagioclase ± K-feldspar and biotite–garnet–quartz–plagioclase. Rounded (?detrital) zircons, euhedral tourmaline, apatite and magnetite are common accessories. In thin section quartz and feldspar form thin fine-grained layers separated by biotite (-garnet)-rich layers. In many instances late muscovite and

chlorite have grown along the axial plane cleavage of D_2 folds (see below) discordant to the F_1 foliation.

The magnesian, aluminous and siliceous rocks occur mainly in the central area of the metasediments in the lower part of the supracrustal segment and are less persistent laterally than the biotite schists. Their colour varies from ash-grey to yellowish grey (cordierite- and sillimanite-bearing rocks), and brown-grey (anthophyllite-cordierite \pm garnet-bearing rocks). They are generally coarser and more homogeneous than the biotite schists, and normally have a gneissic layering rather than a schistose fabric. Local, very coarse-grained paragneisses contain steel grey cordierite augen several centimetres in diameter in the siliceous matrix.

The paragneisses are characterised by quartz segregations parallel to the planar fabric, ranging in thickness from a few millimetres to a centimetre. These segregations predate the injection of the pegmatites as well as the latest (D_2) phase of deformation, and seem to have formed at the peak of the earliest phase of metamorphism (M_1 , see below). In the most silica-rich, quartz-cordierite gneisses, these segregations form a distinct undulating, lensoid layering affected by post-segregation deformation. Common peak-metamorphic parageneses are anthophyllite-cordierite-biotite-quartz-tourmaline \pm plagioclase, cordierite-biotite-sillimanite-quartz-tourmaline \pm plagioclase \pm garnet, and cordierite-biotite-quartz, in addition to almost pure quartzite. Tourmaline is very common, particularly in the cordierite-anthophyllite paragneisses where it is often a rock-forming phase. It typically occurs throughout the rock along narrow zones or as thin (millimetre scale) layers with preferred orientations parallel to the foliation, in patterns similar to those often formed by sillimanite or anthophyllite. Tourmaline is concentrated locally in larger tourmalinite lenses and trains of lenses (see below).

Textures in thin section show two successive stages of deformation. In cordierite-bearing rocks, cordierite typically forms smeared-out lensoid aggregates, one to several millimetres in size, often surrounded by thin sheaths of chlorite and set in a matrix dominated by strained quartz. Prismatic crystals of anthophyllite, sillimanite and/or tourmaline, which are concentrated in closely spaced layers, are frequently fractured and pulled apart as a result of D_2 deformation after the peak of metamorphism.

Thin dark green bands of homogeneous, fine to medium-grained amphibolite often very rich in red-brown garnet occur throughout the metasediments. The amphibolites are normally only about 20 cm thick or less, but a few are up to several metres thick. They are persistent laterally and appear to be concordant with

lithological layering in the metasediments. Their boundaries with the metasediments are well-defined but typically blurred and gradational over a few centimetres. They consist of dark green hornblende (1–2 mm in size, c. 60 per cent of the rock) and andesine-labradorite plagioclase (An_{40-65}), variable amounts of euhedral or flattened garnets with inclusions of quartz and magnetite, minor diopside and interstitial quartz. They are often found in the immediate vicinity of tourmaline-rich metasediments and tourmalinites, whereas they only rarely contain scheelite. The amphibolites are of volcanic origin and may have been mafic tuffs.

The amphibolite bands reveal small isoclinal folds which are otherwise difficult to detect in the massive and uniform quartz-cordierite gneisses. The folds appear to be contemporaneous with larger D_2 isoclinal folds (see below and fig. 2) which postdate pegmatite injection. In the hinge zones of these folded amphibolites



Fig. 2. Cliff-face with isoclinally folded pegmatites (bounded by heavy lines) and metasediments in the lower part of the Malene segment. Locality A on Plate 1. The folds are almost symmetrical with nearly horizontal axes and are SE-vergent. View towards north-east.

the garnets are rotated and flattened parallel to the axial surfaces. In nearby folded tourmalinites individual tourmaline prisms are bent and partially reorientated parallel to the fold axes. The D_2 folding therefore postdated not only garnet but also tourmaline growth.

Malene amphibolites

The upper part of the Malene segment consists of various amphibolites. The lowermost thick amphibolites, which occur in the middle of the segment, are intercalated with members of biotite (-garnet) metasedimentary schists, which are lacking higher up in the segment towards the north-west. The amphibolites are strongly deformed with a well-developed foliation; no way-up criteria or primary features (such as pillowed structure) other than lithological layering features have been identified with certainty.

The amphibolites are mafic, fine-grained, foliated hornblende-plagioclase rocks with hornblende predominating over plagioclase; they may grade into almost pure hornblendites. The greater part of the amphibolites are ramified with abundant centimetre scale layers, lenses and subconcordant veinlets of diopside accompanied by plagioclase, sphene, garnet, calcite, local scapolite and secondary epitaxial epidote.

The amount of calc-silicate rocks in the amphibolites at Store Malene is large but variable, and it has not been possible to present more than a qualitative indication of calc-silicate amphibolites (Plate 1). There are several zones of irregularly striped, pale green and white diopside-plagioclase (-epidote) rocks which contain thin layers and boudins a few centimetres in size of black fine-grained hornblendite. These zones alternate with amphibolite *sensu stricto* where subordinate, centimetre-sized calc-silicate lenses and veinlets only amount to 5–10 per cent of the rock. The calc-silicate and amphibolite *sensu stricto* zones have lateral extents of tens to hundreds of metres and thicknesses an order of magnitude less. Obviously the deformation must have strongly modified their original geometry.

In amphibolites rich in calc-silicate minerals, local thin (1–3 cm) layers of calcite marble are screened from amphibolite *sensu stricto* by reaction rims a few centimetres thick of diopside, calcic plagioclase and sphene (and rarely scapolite). We believe that the calc-silicate rocks are products of metamorphic reactions between primary mafic volcanic rocks and intercalated carbonates, the latter still locally preserved as impure marble. The marble or calc-silicate banded amphibolite association may have been derived from either pillowed basalt flows or breccias extruded onto pelagic calcareous

sediments, or drusy carbonate filling cavities between and within pillows (Garrison, 1972).

At Store Malene there are occasional lensoid bodies of homogeneous amphibolite up to 50 m thick. In the least deformed varieties a medium-grained spotted texture of hornblende crystals set in a plagioclase matrix is discernible. These rocks are interpreted as former gabbroic sills.

Near the middle of the supracrustal segment where the amphibolites alternate with biotite-garnet schists, there are two distinct rusty hornblende- and iron-rich amphibolite horizons. They are characterised by quartz-banding on a scale of centimetres, abundant red-brown garnet, often very high contents of tourmaline (see below), magnetite, ilmenite and lesser pyrrhotite. Small calc-silicate lenses may be present but are not typical.

At the top of the supracrustal segment, near the north-eastern end of the mapped area, there is a horizon of pale grey amphibolite mainly composed of magnesium-rich amphibole and plagioclase.

Ultramafic rocks occur only at the upper boundary of the supracrustal segment, where they form a thin (1–3 m) layer of green schist at the tectonic contact with the Nûk gneiss. This schist consists of varying proportions of tremolite/actinolite, orthoamphibole, antigorite and talc. An isoclinally folded body of metaperidotite and dunite with tectonic contacts with the host gneiss is situated 400 m north-west of the supracrustal segment; it probably represents the unaltered equivalent of the ultrabasic schist.

Within the amphibolites there are several thin (0.2–2 m) persistent beds of pale grey intermediate gneiss. The rocks are homogeneous, fine-grained, and consist of approximately equal proportions of quartz and plagioclase (An_{20} , optical determinations) with *c.* 5 per cent evenly dispersed biotite, occasionally minor K-feldspar or small garnets, and accessory zircon and ilmenite. Sulphides are absent. The pale grey gneiss beds do not resemble any of the metasedimentary lithologies that form the lower half of the segment, and their composition and mode of occurrence as thin persistent markers within the mafic volcanic rocks suggest they were intermediate pyroclastic rocks.

Pegmatites

Large pegmatites are prominent in the central part of Store Malene where they stand out as ridges within the Malene rocks along the crest of the mountain (Plate 1, fig. 3). All the pegmatites of mappable size appear to belong to the same phase. They owe their present complicated outcrop patterns to dextral shear, folding and faulting superimposed on their intrusive shapes (see be-



Fig. 3. Malene supracrustal rocks and deformed pegmatites at Store Malene. View towards north-east.

low). The following sections deal with the relations of the pegmatites to the supracrustal rocks (in particular the tourmaline-bearing rocks) and the structural and metamorphic evolution of the Store Malene area. It is argued that the pegmatites postdate the tourmalines.

The pegmatites consist of coarse-grained quartz, alkali feldspar, biotite and local muscovite, but lack tourmaline and scheelite. The pegmatites reach lengths of about one kilometre and are as much as 100 m in thickness. They are commonly crushed. They were intruded mainly as inclined sill-like tabular bodies parallel to lithological layering in their hosts, particularly along sheared boundaries between markedly different lithologies. Preferred locations are along the lower contact between supracrustal rocks and gneiss, along boundaries of competent siliceous and cordierite-rich members in the lower part of the supracrustal segment, and

between micaceous metasediments and amphibolites in the middle of the segment. These relations suggest that the pegmatite sills were intruded into active shear zones between layers with contrasting competence.

In addition to the sills there are irregular transgressive pegmatite bodies and dykes, which emerge from the sills and are contemporaneous with them. These pegmatites cut the lithological layering and well-developed foliation in their hosts, but the pegmatites themselves are also deformed and in many places isoclinally folded (see below). There are several examples of pegmatites that cut tourmalinites and tourmaline-bearing metasediments and amphibolites. Their intrusive contacts with both supracrustal rocks and Nük gneisses and their discordant relations with the well-developed foliation show that they postdate the first major events of deformation (D_1) in the area (see below).

Structural and metamorphic evolution of the Store Malene area

Pre-pegmatite deformation

The general structure of the outer Godthåbsfjord – Kobbefjord area is described by McGregor (1973) who interpreted the main supracrustal segment at Store Malene as an overturned isoclinal synform. See also geological map sheet 64 V.1 S, Qôrqt (McGregor, 1984).

Store Malene mountain is composed of a slice of supracrustal Malene rocks c. 500 m thick sandwiched between Nük gneisses, which trends NE–SW through the peninsula and dips 45–65° to the north-west. Along the coast of Kobbefjord south-east of the main supracrustal

segment there is a second band of Malene amphibolite c. 50 m thick, bounded to the south-east by Amitsoq gneiss at the coast. Several other slices of Malene amphibolite and ultrabasic rocks less than 20 m thick occur in the vicinity of the north-western boundary of the main Malene segment (Plate 1).

The tectonic intercalation of Malene rocks and gneisses was accompanied by D_1 deformation and isoclinal, perhaps multiple, folding on a scale of kilometres (McGregor, 1973), development of penetrative foliation (F_1) and upper amphibolite grade metamorphism (M_1).

The presence of widespread deformed pegmatites at Store Malene enables a distinction to be made between pre- and post-pegmatite deformation (D_1 and D_2). The pegmatites cut well-foliated amphibolites and metasediments, sometimes at right angles (Plate 1). The pegmatites are also discordant to an intra-Nûk homogeneous amphibolite dyke *c.* 200 m north-west of the main supracrustal segment, which cuts a thin Malene amphibolite sheet and Nûk gneiss at a low angle (Plate 1). These relations show that the pegmatites postdate the tectonic intercalation of supracrustal rocks and gneisses and isoclinal folding during D_1 deformation, as well as the development of a penetrative foliation (F_1) and accompanying high amphibolite facies metamorphism (M_1).

Post-pegmatite deformation

Deformation continued after pegmatite injection. Tight and isoclinal folds with wavelengths ranging from a few centimetres to about 100 m are common within the Malene segment; their patterns vary depending on their structural position. Most of these folds postdate the pegmatites.

In the present lower part of the Malene segment there are many tight and isoclinal, symmetrical or almost symmetrical post-pegmatite folds; an unusually large example is visible in fig. 2 (locality A, Plate 1). Fold axes in this area plunge $0-20^\circ$ to $015-040^\circ$ (Plate 1). Higher up in the segment the folds are generally asymmetric and Z-shapes predominate (viewed down plunge to the north-east, figs 4-5), indicating shear in the direction W-NW to E-SE. These folds also deform the pegmatites.

There is a characteristic series of large asymmetric Z folds along the north-west boundary of the Malene supracrustal segment (localities B-E on Plate 1). Their

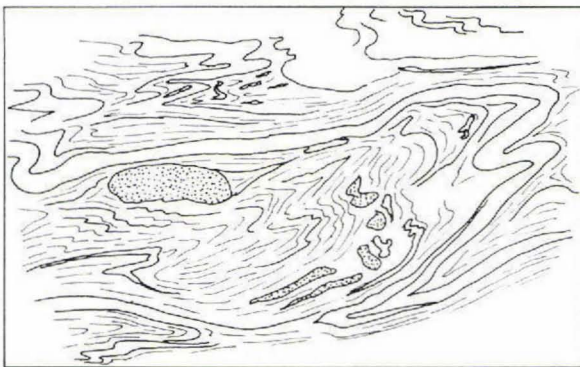


Fig. 4. Tight asymmetric Z folds in Malene metasediments, minor pegmatites and boudinaged dark green amphibolite (stippled). Vertical, *c.* 3 m high exposure viewed towards north-east.

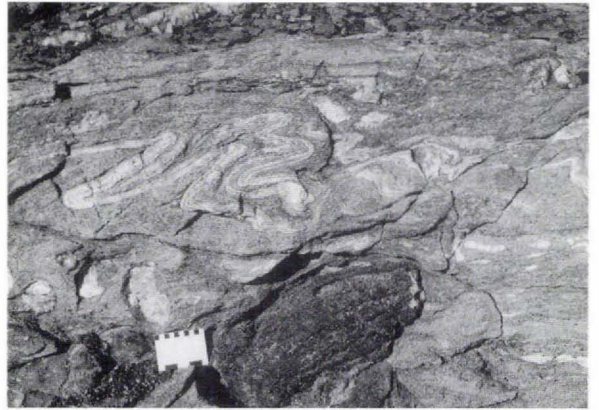


Fig. 5. Boudinaged tourmalinite (dark, on both sides of scale) in Malene metasediments showing minor folds, Store Malene. Scale is 10 cm.

axes plunge $40-60^\circ$ to *c.* 300° . These folds are located at the north-western ends of the thickest transgressive pegmatites and are interpreted as dextral shear folds. Apparently the thick and competent pegmatites prevented shearing within the supracrustal strata they cut, and the folding took place where strain locally accumulated at the contact between gneiss and supracrustal rocks just outside the pegmatites.

Further away from the thick pegmatites, progressive dextral shear within the upper part of the supracrustal rocks has resulted in rotation and internal deformation of thinner transgressive pegmatites (e.g. localities F-H, Plate 1) into their present curved and roughly N-S trends. They are also locally offset by small dextral faults (localities F-G). The original orientation of the transgressive pegmatites seems to have been E-W, an orientation preserved in the little deformed south-eastern ends of the thickest transgressive pegmatites. The E-W orientation is consistent with an interpretation of the transgressive pegmatites as giant tension gashes, responding to dextral shear.

It follows from the foregoing that the post-pegmatite deformation (D_2) had a significant component of simple shear, most apparent in the upper part of the Malene segment (cf. small-scale internal Z folds and associated small dextral faults, asymmetric folds at the upper contact between supracrustals and gneiss and curved, deformed pegmatites). The nature of the D_1 deformation is more uncertain.

Microtextures in metasediments and amphibolites

Microtextures in thin sections support the field evidence of two high-grade tectonometamorphic events (D_1-M_1 , D_2-M_2) which were followed by partial local

static retrogression (M_3). In general the parageneses from the first event (of highest metamorphic grade) survived well and were only partly retrogressed during the M_2 and M_3 events. Metasedimentary rocks with two successive parallel foliations (F_1 , F_2) have been described above, and it was noted that tourmaline belongs to the earlier one. The second event produced distinct, closely spaced S -surfaces parallel to the earlier foliation.

The effects of two successive tectonometamorphic events are also clearly illustrated by the thin garnet-amphibolite sheets in the metasediments. Their field relations (see above) show that D_2 deformation and folding postdate both garnet and tourmaline growth. One of these amphibolites is a c. 30 cm thick band occurring in garnet-biotite schists at a locality where no folds occur. In thin section (GGU 288231) green hornblende and plagioclase in equal amounts form a well-foliated fine-grained matrix containing approximately equidimensional garnets up to 1 cm in diameter. The garnets contain small inclusions of quartz and magnetite which are arranged in parallel trains forming an angle of c. 90° with the hornblende-plagioclase foliation. The outermost millimetre of these trains curves 90° into parallelism with the matrix foliation, so that the trains of inclusions have sigmoidal shapes. The first and longest

stage of garnet growth (M_1) seems to have taken place under pure shear strain (apparently during D_1 deformation) when the garnets incorporated trains of inclusions parallel to matrix F_1 foliation. The strain then changed to simple shear (D_2), during which the garnets were rotated 90° and the (M_2) rims grew with their curved trains of inclusions. No M_2 recrystallisation of the matrix was observed.

Within the thick amphibolites there are lithologies with contemporaneous garnet and tourmaline. A rusty amphibolite (GGU 288248) contains hornblende, garnet, tourmaline, plagioclase (An_{42} , optical determination), magnetite, quartz, and minor secondary biotite, epidote, chlorite and muscovite. The amphibolite is compositionally banded with 1–2 mm thick quartz-rich layers and thicker hornblende-plagioclase-magnetite layers. Garnets occur in the latter and are flat ellipsoidal in shape, c. 5–10 mm long and strongly deformed. Corroded, zoned tourmaline prisms are associated with garnets which locally completely enclose them, such that the tourmaline prisms form flat aggregates. This texture shows that tourmaline was contemporaneous with or earlier than garnet and belongs to the (pre-pegmatite) M_1 paragenesis.

Timing of deformation, metamorphism and pegmatite intrusion at Store Malene

Recent age determinations of single zircon grains from clastic Malene rocks at western Rypeø (L. Schjøtte, personal communication, see above) indicate that the late Archaean evolution in Godthåbsfjord is more complicated than hitherto believed.

No age determinations have been carried out at Store Malene itself. Presuming that the supracrustal segment at Store Malene predates the Nûk gneisses with which it is tectonically intercalated, we propose the following correlation between events at Store Malene and in the Godthåbsfjord area. Zircons from Nûk gneisses at Nuuk have yielded ages of 2980 and 2940 Ma (Baadsgaard & McGregor, 1981). Rb-Sr whole rock ages of Nûk gneisses in the outer Godthåbsfjord area range from 2980 to 2770 Ma (Taylor *et al.*, 1980). These ages probably reflect strontium rehomogenisation during various stages of late Archaean deformation and recrystallisation of the gneisses. The latest, so-called 'straight-belt' Archaean deformation event, described from Nuuk by McGregor *et al.* (1983) postdated the intrusion of Qârusuk granitic dykes at south-eastern Bjørneøen,

which have yielded an age of 2660 Ma (U-Pb zircon concordia intercept age, Baadsgaard & McGregor, 1981). The Qôrqt granite complex (Friend *et al.*, 1985) which was emplaced about 2550 Ma ago (Moorbath *et al.*, 1981), is unaffected by, and therefore younger than, the straight-belt deformation.

Correlation of the late Archaean evolution of the Store Malene area with that in Godthåbsfjord hinges on the timing of D_2 deformation and partial M_2 recrystallisation. Because of its proximity to Nuuk and its similar north-eastern trend this deformation is considered to be contemporaneous with the straight-belt deformation in Nuuk town, i.e. about 2660 Ma and hence older than the Qôrqt granite complex. Accordingly the deformed pegmatites at Store Malene are regarded as pre-Qôrqt. The preceding sillimanite-grade high amphibolite facies metamorphism probably dates back to the peak of metamorphism following the intrusion of the Nûk tonalitic gneisses about 3000 Ma ago (see also Dymek, 1978, 1984).

Tourmaline and tourmalinites

Field relationships

Tourmaline is widespread in the Malene supracrustal rocks, occurring as disseminated grains in metasediments and banded amphibolites, and in concentrations as tourmalinites.

Accessory tourmaline in the metasediments is common, mostly as scattered subhedral, often corroded grains in quartzites, micaceous quartzites, quartz-cordierite rocks, and sillimanite-cordierite rocks. In some of the sillimanite-cordierite-rich metasediments thin tourmaline-bearing layers are found with more than 5 per cent tourmaline, and they can be traced continuously for well over a hundred metres along strike. In the immediate vicinity of the Qôrqut granite due east of Store Malene and on Store Malene tourmaline is also found as sub- to euhedral crystals up to 20 cm in size in a peculiar type of metasediment which consists only of biotite and tourmaline in layers up to 1 m wide. Tourmaline in biotite schists rarely amounts to more than 5 per cent.

Tourmaline is found in the banded amphibolites as scattered, millimetre sized, disseminated, anhedral grains which are commonly concentrated in thin layers parallel to the banding. Sulphide-rich horizons with up to 30 per cent sulphides, mainly pyrrhotite and chalcopyrite, occur in the amphibolites and contain small amounts of tourmaline. The tourmalines in the amphibolites are often inconspicuous and difficult to recognise in the field. Tourmaline-bearing banded amphibolites have been found throughout the Malene supracrustal rocks in the Godthåbsfjord area. In these banded amphibolites tourmaline rarely makes up more than a few per cent of the rocks, with the exception of thin tour-



Fig. 6. Tourmalinite (dark) interlayered with Malene cordierite schist and with minor folds, Store Malene. Scale is 10 cm.

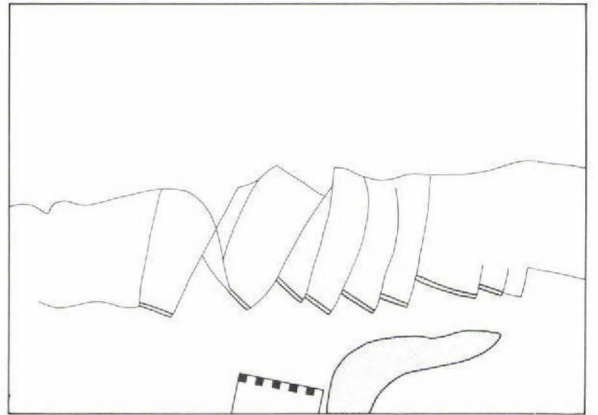
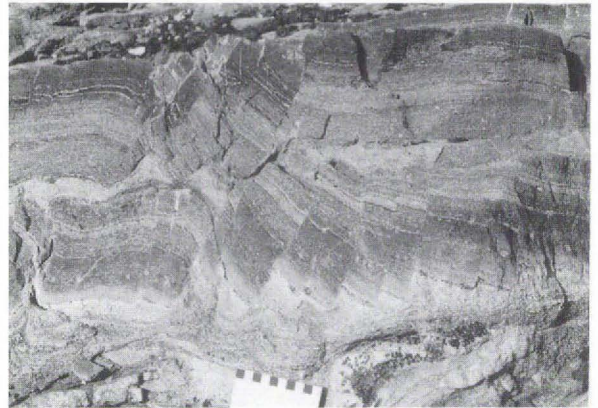


Fig. 7a-b. Tourmalinite layer about 5 mm thick along the lower side of a competent layer of greenish Malene garnet amphibolite, jointed and rotated by D_2 deformation. In the lower right is seen a quartz-veined scheelite-bearing tourmalinite. Tourmalinites are dotted on fig. 7b. Scale is 10 cm. Store Malene.

maline-rich layers where the tourmaline content reaches up to 60 per cent (Appel, 1985a).

Several layers of tourmalinite have been found in the Store Malene area (Plate 1). This rock type consists of over 50 per cent tourmaline together with quartz, plagioclase, sometimes scheelite, and minor pyrrhotite and chalcopyrite. The tourmaline is black in hand specimen, with a grain size of up to a few centimetres. The tourmalinites occur as lithostratigraphic horizons mainly in cordierite-anthophyllite-bearing metasediments (figs 6, 7).

The tourmalinites, which can be traced intermittently for more than a kilometre, pinch and swell along strike and are locally up to 2 metres wide. Some of the tourmalinites have been cut by quartz veins up to a few centimetres wide (fig. 8) and by pegmatites. No sedimen-

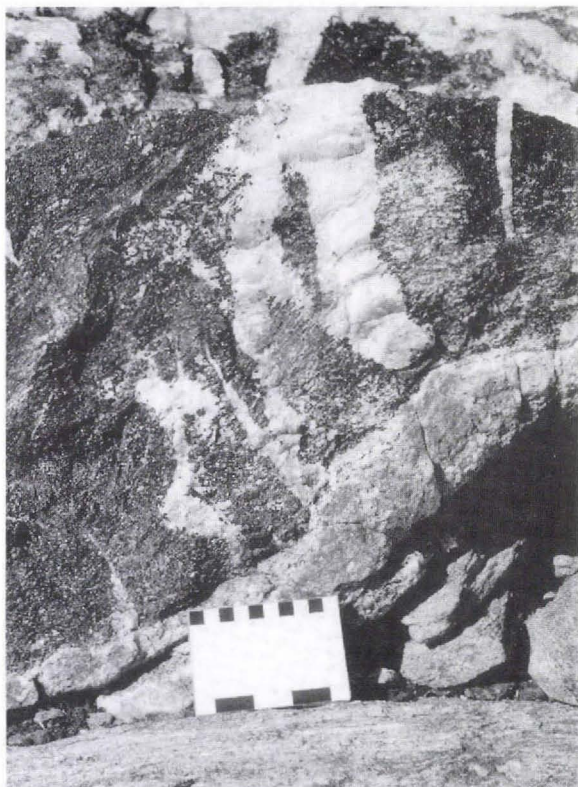


Fig. 8. Barren quartz veinlets intruding scheelite-bearing tourmalinite, Store Malene. Scale is 10 cm.

tary structures, such as bedding, or slump structures, have been found in the tourmalinites, as has been reported from tourmalinites in the Broken Hill area, Australia (Plimer, 1983a). The tourmalinites are deformed by the D_1 and D_2 events together with the host metasediments (figs 6, 7) and locally have a pronounced lineation.

The most prominent tourmalinite horizon occurs within an ash-grey unit of cordierite-anthophyllite-rich siliceous gneiss near the base of the supracrustal rocks east of locality A (Plate 1). Another occurs in brown biotite-garnet schist close to the middle of the segment. As already mentioned, the tourmalinites are often intimately associated with dark green, often garnet-rich amphibolite bands, either in direct contact with them or within a few metres above or below them.

Although the large majority of the tourmalinites in the Malene supracrustal rocks are stratiform, some are discordant (fig. 9). These discordant tourmalinites are up to a few metres long and up to about 10 cm wide. They are generally irregular, pinching and swelling in the amphibolites. The discordant tourmalinites consist of black tourmaline together with plagioclase and local minor amounts of quartz. The discordant tourmalinites were folded by the D_2 event, and were probably mobilised during the peak of M_1 metamorphism.

Petrography

In thin section the tourmaline is generally green to bluish green, locally with a brownish green tinge. It is commonly zoned, a feature which is particularly well developed in the tourmalinites and to a lesser extent in the amphibolites. Most of the tourmalines in the metasediments are homogeneous.

Tourmaline in the tourmalinites is mostly subhedral, with a sub- to euhedral bluish core surrounded by a dark greenish rim (fig. 10). This inner rim often consists of very thin concentric lamellae (fig. 11). In many tourmalines the inner rim is in turn surrounded by a light greenish outer rim which is mostly homogeneous, but sometimes has diffuse concentric lamellae (fig. 11). Tiny adjacent grains of tourmaline have frequently coa-



Fig. 9. Discordant, folded tourmalinite veins (white with dark clusters, left, top of picture and right of hammer) in Malene amphibolite, Store Malene.



Fig. 10. Subhedral bluish tourmaline rimmed by dark greenish tourmaline. Plane polarized light. (GGU 329926).



Fig. 12. Rimmed tourmaline broken up into smaller fragments. Plane polarized light. (GGU 329926).



◀ Fig. 11. Bluish subhedral tourmaline core rimmed by a dark greenish inner rim of concentric lamellar tourmaline, which is in turn rimmed by a light green diffuse lamellar outer rim of tourmaline. During the growth of the inner rim, the tourmaline was broken up by deformation and subsequently 'healed' by dark greenish tourmaline. Plane polarized light. (GGU 329926).

lesced during the formation of the outer tourmaline rims. In the tourmalinites there are small but consistent differences in chemical composition between the bluish core and the rims of the tourmalines (see below).

Subsequent to the growth of the inner rims, the tourmalinites were deformed, probably during D_2 , as a result of which many of the tourmaline grains were broken up into smaller fragments (fig. 12). The tourmalines in the tourmalinites are often extensively replaced by silicates such as plagioclase, quartz and biotite, the replacement clearly postdating the inner rims of the tourmaline (fig. 13). The time relationship between the replacement and deformation is ambiguous. Some replacement took place after the deformation (fig. 18), but some appears to have taken place before or during



Fig. 13. Replacement of rimmed tourmaline by plagioclase. Plane polarized light. (GGU 329926a).

deformation. Figure 11 depicts an unusual example of early deformation (possibly D_1) of tourmaline. A bluish tourmaline core is rimmed by dark greenish lamellar tourmaline. During the formation of the dark greenish rim, the tourmaline was broken up, but the two parts were welded together by dark greenish tourmaline. Subsequently the welded grain was rimmed by light greenish slightly lamellar tourmaline. Most of the tourmaline grains, however, were broken up after formation of the light greenish outer rim.

A very thin rim of secondary (? M_3) tourmaline formed locally (fig. 14) after the latest D_2 deformation. This secondary tourmaline is light green to light bluish in colour and apparently also postdates the replacement of tourmaline by plagioclase.

In amphibolites and in hornblendites most tourmalines display a weak zoning with homogeneous bluish cores surrounded by homogeneous green rims. However, only minor differences in chemical composition

between the cores and rims were reported by Appel (1985a). This lack of chemical zonation has been confirmed by the present investigation (see below). The zoned tourmalines are in equilibrium with hornblende and garnet and belong to the M_1 parageneses.

Tourmaline in micaceous quartzites, mica schists and siliceous cordierite-bearing metasediments are generally anhedral and display no zoning (fig. 15). The tourmalines are often poikiloblastic with abundant inclusions of quartz, and have often been extensively replaced by quartz (fig. 15). Tourmaline has been found as small inclusions in garnets within micaceous quartzites, and locally the tourmaline inclusions have a parallel alignment, as described in an earlier section.

The association of scheelite and tourmaline so often encountered in the field is also frequently found on a microscopic scale, where tourmaline occurs together with scheelite and often also with magnetite (fig. 16). Scheelite and tourmaline are also frequently intergrown (Appel, 1985a).



Fig. 14. Secondary tourmaline on rimmed and broken up tourmaline, detail from fig. 12. Plane polarized light. (GGU 329926).



Fig. 15. Poikiloblastic tourmaline enclosing quartz and partly replaced by quartz in a mica schist. Plane polarized light. (GGU 329877).



Fig. 16. Tourmaline associated with scheelite (mottled, high relief) and magnetite in an amphibolite. Plane polarized light (GGU 329866).

Chemistry of the tourmalinites

Three tourmalinite samples from Store Malene have been analysed for major and trace elements (Table 1). In spite of the numerous papers dealing with tourmalinites and the numerous microprobe analyses of tourmalines in tourmalinites, no whole rock analyses of tourmalinites have been published, apart from one analysis of an early Archaean tourmalinite in the Isua supracrustal belt, West Greenland (Appel, 1983b). The chemistry of the Malene tourmalinites compares fairly well with the Isua tourmalinite with the exception of magnesium contents, which are high in the Malene tourmalinites compared with the Isua tourmalinite.

Chemistry of tourmaline

Tourmalines have been analysed with the microprobe at the Geological Institute, University of Copenhagen. It has been argued that some boron evaporates due to the heat of the beam during microprobe analysis (Ethier & Campbell, 1977). To refute this several analyses were

carried out on the same spots and the results were identical within analytical error.

The analysed tourmalines are from tourmalinites, tourmaline-bearing amphibolites and mica schists together with tourmalines from a quartz tourmaline pegmatite from Sermitsiaq (fig. 1). A total of 488 analyses were made. The results are shown in Tables 2–3 and are plotted in fig. 17 together with microprobe analyses of Malene tourmalines from a previous study (Appel, 1985a). The microprobe analyses reveal that the Malene supracrustal tourmalines have a chemical composition which is markedly different from granite related tourmalines (Table 2, fig. 17). On the contrary, their Na_2O , CaO , FeO and MgO contents resemble those of tourmalines of submarine exhalative origin elsewhere (Ethier & Campbell, 1977; Slack, 1982; Plimer, 1983a; Taylor & Slack, 1984). The analyses also show that there are only small differences in composition between different tourmaline grains within each sample; these differences are non-systematic. In several Malene amphibolites and mica schists the tourmalines display little or

Table 1. Major and trace element compositions of three tourmalinites, from Store Malene

GGU Sample No.	329880	329918	329926
SiO ₂	39.49	45.14	42.26
TiO ₂	0.68	0.65	0.54
Al ₂ O ₃	29.41	27.91	27.62
FeO*	6.92	4.29	4.98
MnO	0.02	0.04	0.03
MgO	7.13	5.53	8.28
CaO	2.38	4.91	1.77
Na ₂ O	1.14	3.06	2.58
K ₂ O	0.06	0.11	0.79
P ₂ O ₅	0.08	0.02	0.32
B ₂ O ₃	4.9	2.0	4.2
l.o.i. (980°C)	2.91	1.84	2.81
	95.12	96.13	96.18

Trace elements ppm

Ni	160	89	210
Co	26	22	31
Cr	50	68	50
As	7	2	1
Ba	10	74	300
Au	210	5	5
Zr	30	33	280
V	150	162	142
Cu	180	7	3
Ga	30	19	32
Sr	220	320	750
Sn	10	6	10

The elements Si, Ti, Al, Fe, Mn, Mg, Ca, K and P were analysed by XRF on glass discs. Na was analysed by wet chemical methods. Ba, Zr, V, Cu, Ga, Sn, Sr and B were analysed by spectrographic methods and the remaining elements in Table 1 by induced neutron activation. Loss on ignition (l.o.i.) was determined after heating the samples to 980°C. The most likely explanation for the low sums is that water in the tourmaline was not completely removed during ignition.

Fig. 17. Tourmaline compositional plot Na₂O – FeO – MgO, CaO – FeO – MgO. The hatched area shows the compositional field of granite-related tourmalines. The area enclosed by the stippled line shows the compositional field of tourmalines of submarine exhalative origin from Ethier & Campbell (1977), Plimer (1983a, b), Taylor & Slack (1984) and Henry & Guidotti (1985). Dots and circles are coexisting cores and rims of zoned tourmalines in tourmalinites. Triangles are tourmalines from amphibolites. Crosses are tourmalines from mica schists. Inverted triangles are secondary tourmaline rims. Square indicates pegmatitic tourmaline.

no zoning and are homogeneous within analytical error or with very small core-rim differences (e.g. sample 329784 in Table 2). Examples of homogeneous tourmalines are shown in Table 2 and in Appel (1985a). The microprobe analyses further indicate that there is only minor variation in chemical composition of tourmalines from one tourmalinite to the next (fig. 17) and from one mica schist to the next, whereas there is considerable compositional variation in tourmalines hosted in different amphibolites. Tourmalines in the mica schists are generally more magnesium-rich (dravitic) than in the amphibolites (fig. 17).

Three tourmaline grains from two tourmalinites showing a particularly well preserved zoning were analysed along traverses from the bluish cores to the peripheries of the outer light greenish rims. Only one set of results is presented (Table 3, fig. 18) because the variations in the three analysed zoned tourmalines were found to be similar. The bluish core is homogeneous and shown as a straight line in fig. 18. This homogeneity of the cores has been confirmed by analysing tens of tourmaline grains. There is a pronounced change in chemical composition across the border between the core and the inner rim. The contents of FeO, MgO, TiO₂ and CaO increase whereas Na₂O, Al₂O₃ and SiO₂ decrease. Outwards through the inner rim there are small differences in chemical composition between the individual thin lamellae, especially in FeO. Across the border between the inner and the outer rim there is a

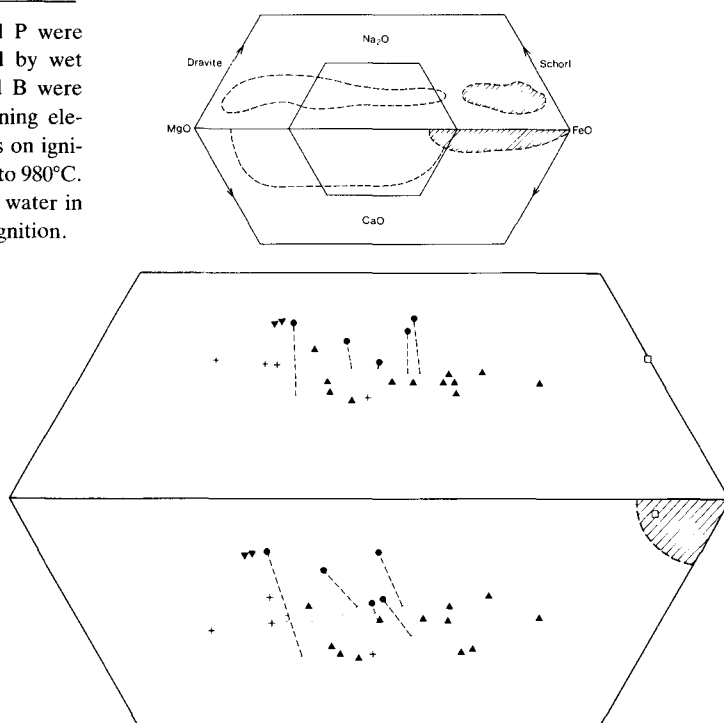


Table 2. Microprobe analyses of tourmalines from amphibolites, mica schists

GGU Sample No.	329926			329882			329926A			329926			329880			329784			329878			329877		
No. of analyses	Core (20)		Rim (19)	Average Range		(46)	Rims (33)		Rims (33)	Average Range		Core (21)	Rim (12)	Average Range		Core (15)	Rims (15)	Average Range		(7)	Average Range		(32)	
Rock type	Tourmalinite			Tourmalinite			Tourmalinite			Tourmalinite			Tourmalinite			Mica quartzite			Mica schist			Mica schist		
SiO ₂	36.43	35.51–36.51	35.94	31.37–36.24	33.09	30.47–35.79	36.37	35.00–37.48	36.48	35.76–37.15	36.48	35.93–37.04	35.82	35.08–36.45	36.43	35.98–36.72	36.36	36.20–36.56	34.78	34.37–35.40	33.60	31.70–35.44	31.70	
TiO ₂	0.19	0.12–0.34	0.64	0.46–0.75	0.64	0.48–0.92	0.59	0.31–0.78	0.63	0.45–0.74	0.18	0.09–0.35	0.71	0.33–0.97	0.56	0.44–0.77	0.48	0.44–0.52	0.98	0.66–1.07	0.83	0.61–1.13	0.61	
Al ₂ O ₃	31.63	21.23–31.84	30.07	28.87–30.48	29.83	28.50–30.91	30.20	29.48–31.48	30.07	29.33–30.75	32.03	31.32–32.76	30.91	30.44–31.48	32.45	31.16–34.18	32.17	31.89–32.32	30.53	30.09–31.13	31.14	29.94–32.48	31.14	
Cr ₂ O ₃	n.d.	n.d.	n.d.	0.00–0.17	0.00–0.17	0.00–0.13	0.00–0.13	0.00–0.25	n.d.	0.00–0.25	n.d.	n.d.	n.d.	0.00–0.06	0.00–0.06	0.00–0.12	0.00–0.12	0.00–0.12	0.00–0.06	0.00–0.06	0.00–0.06	0.00–0.28	0.00–0.28	
FeO	5.41	4.90–5.78	5.98	4.53–6.26	5.56	5.08–6.64	5.19	4.40–6.64	4.94	3.79–5.88	5.78	5.35–6.09	6.48	5.71–7.14	5.34	5.03–5.80	5.43	5.36–5.55	6.06	5.62–6.51	4.16	3.31–5.70	4.16	
MnO		0.00–0.02		0.00–0.02		0.00–0.21		0.00–0.31		0.00–0.13		0.00–0.22		0.00–0.02		0.00–0.12		0.00–0.06		0.00–0.04		0.00–0.23	0.00–0.23	
MgO	8.49	8.13–9.10	8.89	7.58–9.16	8.30	8.03–8.67	8.83	8.42–9.25	8.83	8.00–9.08	7.63	7.31–8.21	7.88	7.24–8.35	7.36	7.08–7.70	7.48	7.41–7.62	8.49	8.30–8.71	8.75	8.30–9.30	8.75	
CaO	0.89	0.85–1.08	1.60	1.43–1.95	1.60	1.29–2.27	1.60	0.81–2.17	1.59	1.31–1.73	0.66	0.54–1.06	1.52	1.02–2.08	1.22	1.07–1.35	1.49	1.35–1.69	2.27	2.11–2.75	1.59	1.26–2.16	1.59	
K ₂ O		0.00–0.31		0.00–0.12		0.00–0.08		0.00–0.06		0.00–0.03		0.00–0.20		0.01–0.03		0.00–0.06		0.00–0.08		0.00–0.03		0.00–0.06	0.00–0.06	
Na ₂ O	2.26	2.02–2.35	1.98	1.56–2.10	1.79	1.54–1.95	1.96	1.66–2.36	1.95	1.84–2.07	2.10	1.91–2.25	1.85	1.62–2.17	1.71	1.58–1.76	1.68	1.59–1.75	1.43	1.22–1.55	1.79	1.58–1.94	1.79	
		85.30		85.10		80.81		84.74		84.49		84.86		85.17		85.07		85.09		84.54		81.86		
<i>Number of ions on the basis of 49 positive charges</i>																								
Si	5.98	5.95	5.78	6.01	6.04	6.01	6.04	6.01	5.93	5.97	5.65	5.81	5.74											
Al	6.00	5.87	6.00	5.89	5.87	6.00	6.00	6.00	6.00	6.00	5.90	6.00	6.00											
Al	0.11		0.14			0.22			0.03	0.27		0.02	0.29											
Fe	0.74		0.81			0.80			0.88	0.73		0.85	0.59											
Cr		0.83		0.72		0.68					0.71													
Mn																								
Mg	2.07	2.19	3.38	3.49	3.25	3.22	3.03	3.21	3.08	3.07	3.51	3.51	3.51											
Ti	0.02	0.08	0.08	0.07	0.08	0.08	0.08	0.08	0.09	0.07	0.12	0.11	0.11											
Ca	0.16	0.28	0.30	0.28	0.28	0.28	0.28	0.28	0.27	0.21	0.41	0.41	0.41											
Na	0.72	0.64	0.61	0.63	0.62	0.67	0.67	0.67	0.59	0.54	0.51	0.46	0.59											

Tourmalines have been analysed with the Jeol super 733 microprobe, Geological Institute, University of Copenhagen, operated 10 microns apart.

drastic decrease in iron content and a smaller decrease in TiO₂ and CaO, whereas the contents of MgO, Na₂O, Al₂O₃ and SiO₂ increase. The chemical composition appears to be constant through the outer rim with the exception of SiO₂ and FeO. SiO₂ shows small apparent variations but a constant average, whereas FeO shows somewhat larger variation and a decreasing trend towards the periphery of the rim. On a 'large' scale through the particularly well zoned tourmalines from the core outwards, MgO, TiO₂ and CaO increase whereas Na₂O and SiO₂ decrease. The FeO and Al₂O₃ contents exhibit a more complex behaviour. FeO contents are generally highest, and Al₂O₃ contents lowest in the inner rim compared with the core and outer rim. Figure 18 furthermore shows a near perfect positive correlation between TiO₂ and CaO and a negative correlation between CaO and Na₂O. Similar results were ob-

tained by analysing a large number of tourmaline grains with less pronounced zoning (Table 2, fig. 17).

Two sets of microprobe analyses were carried out on the post-deformational (post-D₂) thin secondary tourmaline rims (Table 2, fig. 17). The secondary bluish tourmaline (329926A) is remarkable in containing virtually no titanium, whereas the very light green secondary tourmaline (329926, fig. 14) has normal titanium contents. However, the most remarkable feature of the secondary tourmalines is that their composition very closely resembles the composition of the bluish cores of the zoned tourmalines.

The tourmalines in amphibolites and in thin tourmalinites hosted in amphibolites contain detectable amounts of chromium, whereas no chromium was detected in the tourmalines of sediment hosted tourmalinites and in the metasediments (Table 2).

Scheelite occurrences

Prospecting for scheelite in ultra violet light has been carried out within a selected area at Store Malene as traverses and local detailed investigations (Plate 1). Scheelite has been found in a variety of Malene supracrustal rocks, such as banded amphibolites, calc-silicate bearing amphibolites, hornblendites, tourmalinites and mica

schists. Trace amounts of scheelite have been found in the gneisses enclosing the supracrustal rocks, but so far no scheelite has been found in any of the pegmatites.

The most frequent occurrence of scheelite is within banded amphibolites. The scheelite-bearing banded amphibolites are up to 4 m wide and have been traced

and tourmalinites from Malene supracrustal rocks on Store Malene

329815 (16)		329926 (4)		329926A (6)		329837				329919				329919A (4)		329866 (23)		329899 (33)		224781 (25)		
Average Range		Average Range		Average Range		Core (15) Average Range		Rim (12) Average Range		Core (23) Average Range		Rims (10) Average Range		Average Range		Average Range		Average Range		Average Range		
Mica schist		Tourmalinite		Tourmalinite		Tourmalinite				Tourmalinite				Amphibolite		Amphibolite		Amphibolite		Pegmatite		
34.75	33.80–36.30	36.06		34.92	36.42	36.04–36.97	35.65	35.40–36.10	35.23	34.13–36.28	34.78	34.16–35.37	35.73	35.53–35.86	36.61	36.06–37.01	35.46	34.77–36.15	35.83	34.70–37.12	SiO ₂	
0.44	0.35–0.54	0.58		0.05	0.44	0.08–0.71	0.83	0.68–1.09	0.76	0.69–1.01	0.99	0.25–1.18	0.78	0.59–0.93	0.77	0.63–0.97	0.88	0.73–1.18	0.23	0.06–0.28	TiO ₂	
31.96	31.29–33.18	31.59		31.98	30.58	29.44–31.93	29.71	29.54–30.07	30.48	29.50–31.16	29.49	29.21–31.33	30.04	29.48–30.77	28.55	28.06–29.21	29.53	28.53–30.71	32.86	32.57–33.24	Al ₂ O ₃	
	0.00–0.16				0.45	0.01–1.33	0.19	0.08–0.48	n.d.	n.d.	n.d.		0.22	0.20–0.23	0.44	0.19–0.23		0.00–0.06		0.59–0.99	Cr ₂ O ₃	
3.42	3.19–3.90	4.18		4.11	4.70	4.33–5.05	5.29	5.09–5.81	6.24	5.24–7.24	6.81	5.11–7.22	6.97	6.76–7.05	6.23	6.58–7.00	6.36	5.85–7.00	8.70	8.16–9.15	FeO	
	0.00–0.08					0.00–0.04		0.00–0.03		0.00–0.08		0.00–0.03		0.01–0.04		0.00–0.18		0.00–0.36		0.54–0.99	MnO	
8.80	8.55–9.02	8.90		8.46	9.01	8.52–9.29	9.46	9.00–9.62	8.14	7.56–8.30	8.15	8.05–8.44	8.10	7.77–8.34	9.20	8.95–9.31	8.31	7.94–8.59	4.74	4.57–5.06	MgO	
1.63	1.46–1.84	0.66		0.62	0.61	0.25–0.83	2.46	1.75–2.70	1.37	1.20–1.74	2.04	0.78–2.58	1.83	1.60–2.29	2.50	2.14–2.30	1.76	1.48–2.30	0.18	0.12–0.22	CaO	
	0.00–0.04				n.d.	n.d.		0.00–0.16		0.00–0.16		0.00–0.02		0.00–0.01		0.00–0.08		0.00–0.04		0.06–0.99	K ₂ O	
1.75	1.61–1.83	2.32		2.32	2.55	2.46–2.66	1.58	1.45–1.94	1.98	1.90–2.10	1.84	1.47–2.20	1.78	1.58–1.88	1.52	1.30–1.72	1.73	1.45–2.08	2.25	2.17–2.28	Na ₂ O	
82.75		84.29		82.46	84.76		85.17		84.20	84.10		85.45	85.82		84.03		84.79					
5.83	5.95	5.88		6.00	5.90	5.90	5.88	5.90	5.88	5.93	6.04	5.96	5.98	6.00	5.85	5.85	5.96	5.98	6.00	6.00	6.00	
0.32	0.14	0.35		0.65	0.73	0.02	0.87	0.02	0.96	0.97	0.86	0.89	0.46	0.03	0.06	0.06	0.89	1.21	0.46	0.46	0.46	
0.48	0.58	0.58		0.06	0.06	0.06	0.02	0.02	0.02	0.03	0.06	0.06	0.12	0.03	0.03	0.03	0.06	0.06	0.06	0.06	0.06	
2.20	2.19	2.12		2.21	2.33	2.21	2.03	2.03	2.05	2.00	2.26	2.08	1.18	0.07	0.10	0.10	0.11	0.11	0.03	0.03	0.03	
0.06	0.07	0.01		0.05	0.10	0.05	0.10	0.10	0.13	0.10	0.10	0.11	0.03	0.12	0.11	0.11	0.11	0.03	0.03	0.03	0.03	
0.29	0.12	0.11		0.11	0.43	0.11	0.43	0.25	0.37	0.33	0.44	0.32	0.03	0.57	0.49	0.49	0.56	0.73	0.73	0.73	0.73	

at 15 kV and 20 nA with wollastonite, olivine and hematite as standards. All microprobe analyses are averaged double analyses

with intervals for more than 1 km along strike. The scheelite occurs as millimetre-sized grains disseminated or concentrated in thin layers arranged parallel to the banding of the amphibolites. In addition, there are small scheelite-bearing quartz veins and veinlets which

are locally discordant on a small scale, but are evidently older than the main deformational events in the area. Scheelite is also locally found as centimetre-sized porphyroblasts and as joint coatings. Several of the scheelite-bearing banded amphibolites contain small

Table 3. Microprobe analyses through a zoned tourmaline

Analysis point	1	2	3	4	5	6	7	8	9	10	11	12
No. of analyses	2	2	2	2	2	2	2	2	2	2	2	6
Zone	OUTER RIM						INNER RIM					CORE
SiO ₂	35.63	35.49	35.72	35.60	35.81	35.56	35.54	35.72	35.70	35.75	35.64	36.08
TiO ₂	0.63	0.60	0.63	0.78	0.66	0.76	0.70	0.55	0.54	0.61	0.55	0.22
Al ₂ O ₃	29.99	29.85	29.82	29.88	29.84	29.65	29.43	29.72	29.86	29.63	29.75	31.29
FeO	4.68	5.05	4.96	5.55	5.00	6.08	6.14	5.49	5.67	5.35	5.57	5.18
MgO	8.84	8.82	8.72	8.55	8.63	8.42	8.29	8.57	8.46	8.56	8.56	8.06
CaO	1.73	1.68	1.65	1.53	1.53	1.82	1.67	1.66	1.53	1.63	1.67	0.86
Na ₂ O	1.82	1.86	1.86	1.96	1.87	1.75	1.90	1.98	1.92	1.88	1.89	2.14
	83.32	83.35	83.36	83.85	83.34	84.04	83.67	83.69	83.68	83.41	83.63	83.83
Number of ions on the basis of 49 positive charges												
Si	5.98	5.97	6.00	5.97	6.01	5.97	5.99	6.00	6.00	6.01	5.99	6.01
Al	5.94	5.92	5.91	5.91	5.91	5.87	5.85	5.88	5.91	5.88	5.90	6.00
Al												0.14
Fe	0.66	0.71	0.70	0.78	0.70	0.85	0.87	0.77	0.80	0.75	0.78	0.72
Mg	2.21	2.21	2.18	2.14	2.16	2.11	2.08	2.14	2.12	2.15	2.14	2.00
Ti	0.07	0.08	0.08	0.10	0.08	0.10	0.09	0.07	0.07	0.08	0.07	0.03
Ca	0.31	0.30	0.30	0.27	0.28	0.33	0.30	0.30	0.28	0.29	0.30	0.15
Na	0.59	0.61	0.61	0.64	0.61	0.57	0.62	0.64	0.63	0.61	0.62	0.69

Traverse marked A – B in fig. 18: GGU sample No 329926.

amounts of scattered sulphides, mainly pyrrhotite and chalcopyrite. Locally, however, there are up to 1 m wide zones with up to 25 per cent sulphides (pyrite, pyrrhotite, chalcopyrite and molybdenite), and often small amounts of scheelite. In the banded amphibolites millimetre-thick layers of tourmaline occur, and scheelite is frequently associated and locally intergrown with the tourmaline (Appel, 1985a). The scheelite in the banded amphibolites displays strong bluish fluorescence indicating very low contents of molybdenum.

Calc-silicate banded amphibolites generally only contain small amounts of scheelite. In these rocks the scheelite occurs as disseminated millimetre-sized grains, small porphyroblasts and joint coatings. Small epidote-scapolite rich boudins locally contain appreciable amounts of scheelite, mainly centimetre-sized grains with a white fluorescence indicating small contents of molybdenum.

Scheelite has furthermore been found in hornblende rocks as disseminated grains up to 5 cm across. These scheelite-bearing hornblende layers are locally rich in scheelite, but are mostly thin and impersistent.

In some of the tourmalinite horizons on Store Malene scheelite has been found in high concentrations, whereas other tourmalinites are barren. The scheelite in the tourmalinites, locally amounting to as much as 15 per cent, is found interstitial to the tourmaline together with plagioclase. The scheelite is massive to semimassive and displays a bluish to white fluorescence indica-

ting molybdenum contents of up to 0.3 per cent. The scheelite-bearing tourmalinites are up to 1 m wide and can be traced with intervals for more than 1 km along strike. Several of these tourmalinites are cut by quartz veins up to 10 cm wide (fig. 8), but the quartz veins do not contain scheelite. The tourmalinites are hosted in cordierite-rich metasediments, which are locally garnetiferous. These metasediments sometimes contain small amounts of scheelite as millimetre-sized disseminated grains, as small porphyroblasts and as joint coatings.

In the gneisses enclosing the Malene supracrustals rare scheelite occurrences have been found. This scheelite is mainly found as massive scheelite in veins and veinlets up to a few centimetres wide and a few tens of centimetres long. Scheelite-bearing veins and veinlets in gneisses have so far only been found in the immediate vicinity of supracrustal rocks. The scheelite in the gneisses displays a white to yellowish fluorescence indicating molybdenum contents of up to about 5 per cent. White fluorescent scheelite has also been found as joint coatings in the intra-Nûk dyke shown on Plate 1, where it cuts a Malene amphibolite sheet.

No systematic sampling, such as drilling or chip sampling across the scheelite-bearing horizons, has been carried out. Locally drilling and blasting has been carried out in sulphide-rich layers before sampling. However, it is not yet possible to present information of grades or tonnages of scheelite-bearing horizons.

Genesis of the tourmaline and the tourmalinites

The discussion of the genesis of tourmaline in the Malene supracrustal rocks can conveniently be subdivided into:

1. When and how was the tourmaline formed?
2. What is the likely source of the boron?
3. From which precursor mineral was tourmaline formed?

The tourmaline occurs as an accessory mineral in banded amphibolites and in a variety of Mg-rich metasediments. Tourmaline also occurs as a rock forming mineral in the tourmalinites where it locally constitutes more than 60 percent of the rock, the balance being made up of plagioclase, quartz, occasional scheelite and biotite, and minor pyrrhotite and chalcopyrite. The tourmalinites occur as lithostratigraphic units up to two metres wide and traceable for more than one kilometre along strike. Field and petrographic evidence shows that the tourmalinite horizons predate the prominent

pegmatites at Store Malene and were affected by the earliest phase of deformation (D_1), and that the tourmaline crystals were formed prior to at least the latest phase of deformation (D_2) of the supracrustals: the tourmalines (bluish cores and inner dark green rims) were in metamorphic equilibrium with the M_1 metamorphic garnet, hornblende and plagioclase. The replacement phenomena described above show that the tourmalines were formed prior to some quartz and biotite. It can thus be concluded that the tourmaline was formed at an early stage of metamorphism and deformation of the supracrustal rocks and prior to some of the rock forming minerals. The tourmaline is therefore without doubt stratabound, and the tourmalinites are generally stratiform. The rare occurrences of small and local discordant tourmalinites can be ascribed to metamorphic mobilisation.

The tourmalines in the amphibolites and metasediments are either homogeneous or display only a weak

zoning, and the chemical composition of these tourmalines closely resembles the chemistry of the inner rims of the zoned tourmalines in the tourmalinites (see below). This indicates that no gross change in chemical composition of the tourmalines took place during metamorphism or during post-metamorphic events. The latter is well documented by the large tourmaline crystals (329815 Table 3 & fig. 17) which occur in mica schists within a few metres from the Qôrqt granite (fig. 1). In spite of the proximity to the Qôrqt granite these tourmalines have no granitic affinities (fig. 17). On the contrary they have the highest proportion of dravite recorded in any of the Malene supracrustal tourmalines. The lack of pronounced zonation of the tourmalines in the amphibolites and mica schists is suggested to be a metamorphic phenomenon whereby the tourmalines were partly or completely homogenised probably contemporaneously with minor exchange of ions between the tourmalines and adjoining minerals such as amphibole and plagioclase. There are, however, differences in chemical composition between tourmalines in amphibolite and those in cordierite-quartz metasediment. The amphibolites are enriched in chromium and the tourmalines formed in amphibolites are chrome-bearing. The metasediments are often fairly rich in magnesium but with low chromium contents, and the tourmalines formed in the metasediments are more dravitic and contain less chromium than the amphibolite tourmalines. Whether the chemical characteristics are primary or metamorphic is an open question.

The tourmalines in the tourmalinites display a well preserved zonation with a homogeneous core and two sets of rims with delicate lamellae, showing that these tourmalines had a complex growth history which was not obliterated by metamorphism. It is presumably due to the peculiar chemical and mineralogical composition of tourmalinites that the complex textures in tourmalines survived in the tourmalinites and not in the metasediments and amphibolites. In these rocks there were very limited possibilities of metamorphic exchange of ions such as iron, magnesium and titanium between tourmaline and adjacent minerals (plagioclase and quartz), whereas there were ample opportunities of exchange of these ions in amphibolites and biotite schists. Ethier & Campbell (1977) and Taylor & Slack (1984) describe tourmalines with well preserved zoning in massive sulphides, and ascribe the lack of homogenisation to the peculiar matrix (in their cases massive sulphides), which 'isolated' the zoned tourmalines from metamorphic alteration.

The zoned tourmalines in the tourmalinites display a series of tourmaline forming events which took place under varying conditions. The first tourmaline forming

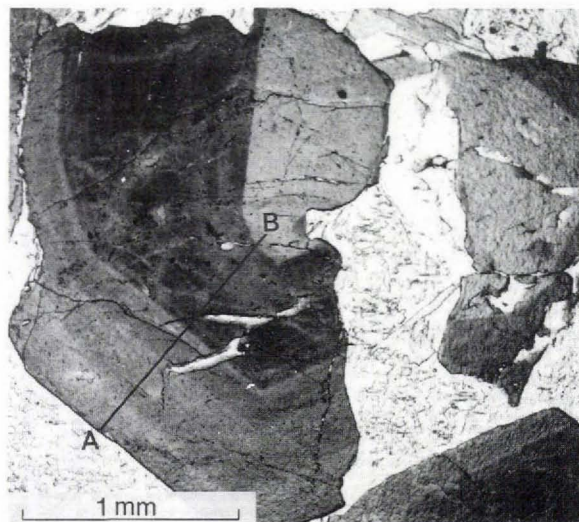
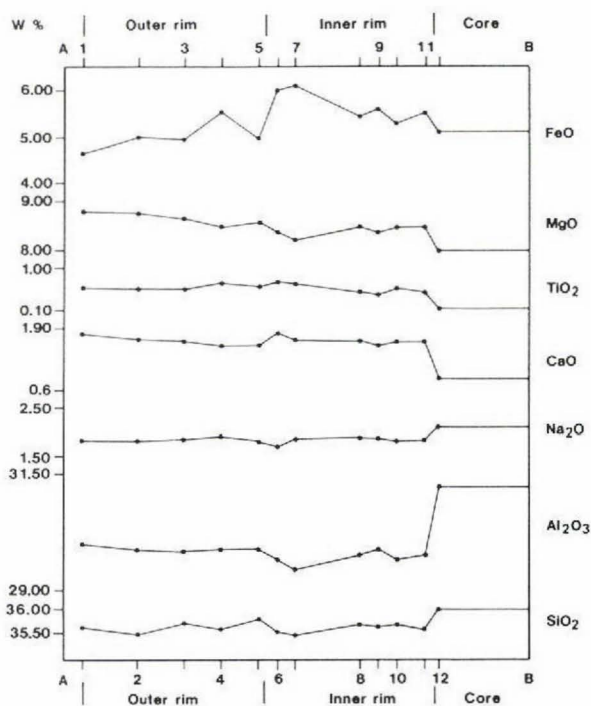


Fig. 18. Microprobe 'traverse' across a zoned tourmaline broken up by deformation and then partly replaced by plagioclase; it was subsequently overgrown by a thin dark rim of secondary tourmaline (GGU 329926). Analyses given in Table 3.

event, giving rise to the bluish tourmaline cores, formed homogeneous sodium-rich, calcium-poor tourmalines with high contents of aluminium and silicon and fairly low contents of titanium (fig. 18). These tourmalines often occur as sub- to euhedral grains. This growth stage may have preceded the D_1 - M_1 tectonometamorphic event.

The second tourmaline forming event, which created the inner dark greenish horizons mainly in cordierite-anthophyllite-bearing metasediments (figs 10, 11), took place under different chemical conditions, and the tourmalines (viz. inner rims) from this stage contain appreciably higher amounts of FeO, MgO, TiO₂ and CaO, and lower contents of Na₂O, Al₂O₃ and SiO₂ than the homogeneous core. The fluids supplying material for formation of the inner tourmaline rim must often have changed composition as shown by the delicate lamellae with varying compositions. This stage can be correlated with the high-grade M₁ metamorphism.

The third tourmaline forming event created the outer, only slightly lamellar, rims. This event took place under a decreasing supply of iron, coupled with a somewhat higher supply of magnesium and calcium. The conditions during which the outer tourmaline rims were formed appear to have been stable, as witnessed by the few and diffuse lamellae, as well as the regular decrease in FeO and a corresponding regular increase in MgO and CaO (fig. 18) through the outer rim. This event may be contemporaneous with D₂-M₂ deformation and metamorphism.

The fourth and last tourmaline forming event produced thin secondary rims on fragmented tourmalines (fig. 14), with a composition virtually identical to the first formed tourmaline (fig. 18). This final tourmaline forming event obviously took place after deformation and at a waning stage of metamorphism of the supracrustals, that is after M₂ and D₂. The chemical composition of this secondary tourmaline depicts the chemistry of a metamorphic tourmaline formed in equilibrium with plagioclase and quartz, thus having low contents of iron, magnesium and titanium. The Na₂O/CaO ratio of the secondary tourmaline was probably determined by partition coefficients of these elements in coexisting plagioclase and tourmaline. This late secondary tourmaline has no bearing on the genesis of the tourmalines and tourmalinites, and will not be considered further.

In summary, the tourmalines contain light blue cores which may well predate, and dark green inner rims which are contemporaneous with, the high-grade M₁ metamorphic event which produced the garnets, plagioclase and amphiboles in the amphibolites. The outer light greenish tourmaline rims are tentatively correlated with the D₂-M₂ events.

The next question concerns the origin of the tourmalines. The traditional interpretation of tourmaline-rich rocks is that they are epigenetic and of granitic pedigree. This explanation is clearly inadequate for the Malene tourmaline-rich rocks in spite of the presence of pegmatites. Arguably the chemical composition of tour-

malines in amphibolites could be partly altered by (pre-pegmatite M₁) metamorphic re-equilibration, but as shown above their field relations and petrography also indicate a non-granitic pedigree. Furthermore the chemical composition of the tourmalines in tourmalinites at Store Malene is markedly different from pegmatitic tourmalines elsewhere (Table 2 & fig. 17). The possible genetic models for the tourmalines are then: (a) detrital, (b) evaporitic-sabkha, (c) authigenic diagenetic, or (d) submarine exhalative.

Tourmaline is a common placer mineral and tourmalines of detrital origin in metamorphic rocks have been described by Schneider & Lehman (1977) and Henry & Guidotti (1985). A detrital origin, however, is not likely for the Malene tourmalines since they do not occur together with any of the other characteristic placer minerals. The close association between tourmaline and schelite also precludes a detrital origin for the tourmalines.

Tourmalines can be formed by metamorphism of rocks deposited in an evaporitic-sabkha environment. In metamorphosed evaporitic-sabkha type rocks minerals such as anhydrite and scapolite are common (Serdyuchenko, 1975; Kwak, 1977). The absence of anhydrite and the scarcity of scapolite in the Malene tourmaline-rich rocks show that an origin of these rocks from evaporite-sabkha sediments is not likely. The same interpretation can be argued from the high Al₂O₃ contents and the low CaO, Na₂O and K₂O contents of the Malene tourmaline-rich rocks, compared with presumed meta-evaporites from the Aldan shield (Serdyuchenko, 1975).

An authigenic-diagenetic origin would imply that the Malene tourmalines were formed by diagenesis and metamorphism of boron-rich clays. Clay minerals, especially illite, may contain up to 1000 ppm boron absorbed from sea water (Reynolds, 1959, 1965; Lerham, 1966; Harder, 1970). Some of the Malene metasediments contain up to five per cent tourmaline, and it would thus not require unrealistic amounts of boron-rich clays in the original pelites and pelitic sandstones to yield about five per cent tourmaline during diagenesis. An authigenic-diagenetic origin for the tourmaline in the Malene mica schists and sillimanite-cordierite-rich metasediments is thus considered possible. However, this would imply that boron was fixed in an insoluble form before or at the onset of diagenesis, as otherwise boron would have been removed by dewatering at the beginning of prograde metamorphism. The most likely insoluble phase in which boron could be trapped is tourmaline.

The tourmalinites and the tourmaline-rich layers in the amphibolites, however, are more enigmatic. The tourmalinites contain two to five percent boron (Table

1), and the tourmaline-rich layers in the amphibolites probably contain similar or higher amounts of boron. These boron contents are twenty to fifty times higher than the maximum of about 1000 ppm boron found in illites. It would thus require extensive and very thick layers of boron-rich clays in order to supply the amounts of boron necessary for formation of the tourmalinites and the tourmaline-rich layers in amphibolites. An authigenic-diagenetic origin for these tourmalines is thus unrealistic. An authigenic-diagenetic genetic model furthermore neither complies with the frequent occurrence of scheelite in the tourmaline-rich lithostratigraphic horizons, nor with the chemistry (low Al_2O_3 contents) of the tourmalinites.

No information is available on the boron contents of submarine exhalations. However, hot springs are known to contain appreciable amounts of boron in solution. Hot springs in Italy contain 35 ppm boron (Garbato, 1961) and more than 900 ppm boron has been recorded in hot springs in New Zealand (White, 1981). It must therefore be considered likely that brines of submarine exhalative origin can carry considerable amounts of boron in solution. The close association of tourmaline with scheelite in the Malene supracrustals indicates that they are cogenetic. The close spatial relationship and the geochemical similarities (see below)

between the Malene scheelite mineralisation and the iron-formation, which is of submarine exhalative origin, indicate that the scheelite and hence the tourmaline is of submarine exhalative origin.

It is thus concluded that the tourmaline in the tourmalinites and in the tourmaline-rich layers in amphibolites are of submarine-exhalative origin, and that the most likely tourmaline precursor was tourmaline, formed directly by precipitation on the sea-floor in restricted basins from boron-rich tungsten-bearing brines. Similar genetic models have been established for tourmalinites in the Broken Hill area (Plimer, 1983a) and for tourmalinites in the Appalachians and the Cordillera of Canada (Ethier & Campbell, 1977; Taylor & Slack, 1984; Slack *et al.*, 1984). Equivalent primary tourmalines have recently been found in stromatolites in the Archaean Swaziland system (Byerly *et al.*, 1986). It is possible that the boron enrichment in the submarine-exhalative brine was partly derived from leaching of authigenic boron in underlying clays in a volcanic-hydrothermal convection cell. The peculiar chemical composition of the Malene cordierite paragneisses (Beech & Chadwick, 1980) suggests extensive leaching of other elements including Ca, Na and K, in addition to Mg enrichment.

Genesis of the scheelite

The genetic model for the scheelite occurrences must encompass the following features:

1. Scheelite commonly occurs in banded amphibolites of presumed extrusive and tuffaceous origin.

2. Scheelite-bearing supracrustal units can be traced for tens of kilometres along strike.

3. Scheelite is common in folded quartz veins and veinlets within amphibolites.

4. Scheelite is often closely associated with thin tourmaline-rich layers in amphibolites and with stratiform tourmalinites.

5. Scheelite, locally associated with tourmaline, occurs sparsely disseminated in micaceous quartzites.

6. Bluish fluorescent scheelite is generally stratiform and found as disseminated grains and millimetre-thick 'layers' arranged parallel to the banding of the host rock. Molybdenum-bearing white to yellowish fluorescent scheelite occurs as centimetre-sized porphyroblasts, as joint coatings and in veinlets in a wide variety of rock types such as amphibolites, metasediments, ultrabasic rocks and gneisses.

7. Scheelite has not been found in any of the large deformed pegmatites in the Store Malene area.

8. Tungsten in the amphibolites is positively correlated with zinc, lead and gallium, whereas the correlation tungsten-molybdenum is weak and no correlation has been established between tungsten, copper and tin (Appel, 1986b).

9. The Malene iron-formation is highly enriched in tungsten, zinc, copper, molybdenum and tin (Appel, *in press*).

Field observations and microscopic evidence show that the scheelite is generally stratabound and locally stratiform within the Malene supracrustal rocks. The close association of scheelite and tourmaline indicate that they are probably cogenetic and coeval. The latter indicates that the scheelite was formed at an early stage of the history of the Malene supracrustals, possibly during early metamorphism and/or diagenesis. Folded scheelite-bearing quartz veinlets are often found in amphibolite horizons. It is suggested that the scheelite migrated into these quartz veins and veinlets during early

metamorphism. These features preclude any genetic relationship between the scheelite occurrences and the Qôrqut granite. The molybdenum-bearing scheelite veinlets are attributed to metamorphism, whereby scheelite was mobilised into the surrounding rocks. During migration molybdenum was incorporated in the scheelite.

The scheelite-bearing Malene amphibolites and the Malene iron-formation contain enhanced amounts of zinc, lead, gallium, copper, molybdenum and tin, and there is a strong positive correlation between tungsten-zinc, tungsten-lead and tungsten-gallium. These correlations indicate cogenetic relationships between tungsten and zinc, lead and gallium (Appel, 1986b). The close spatial association of tungsten with boron also suggests that these two elements are cogenetic. The tungsten and boron are of submarine exhalative origin and were carried in solution in the same brines which supplied the base metals and sulphur, and iron and silicon for the iron-formation. These brines also carried small amounts of tin in solution which was later precipitated in the iron-formation.

The precipitation of the material carried in solution in the hot brines was governed by local pH-Eh conditions as well as sea-floor topography. The iron-formation precursor was precipitated in restricted basins whereas the scheelite apparently was precipitated over very large areas, as indicated by the extensive, generally low-grade, scheelite-bearing banded amphibolites and meta-sediments found in the Godthåbsfjord area. Moreover, local conditions, possibly early diagenetic hydrothermal convection systems, favoured precipitation of higher amounts of scheelite usually accompanied by tourmaline, as depicted by the scheelite-bearing tourmaline-rich

layers in amphibolites and in the tourmalinites on Store Malene.

It is concluded that the scheelite in the Malene supracrustal rocks is syngenetic and that the scheelite precursor (probably scheelite) was chemically precipitated on the sea-floor contemporaneously with the precipitation of the tourmalinites and the iron-formation, and with the deposition of the amphibolites partly of tuffaceous origin. It can also be concluded that the tungsten is of submarine exhalative origin. The close association between tungsten and tourmaline indicates that boron complexes might have played a role in transporting the tungsten in the submarine exhalative brines, an explanation which has been put forward for similar occurrences in the Broken Hill area (Plimer, 1983a).

Acknowledgements

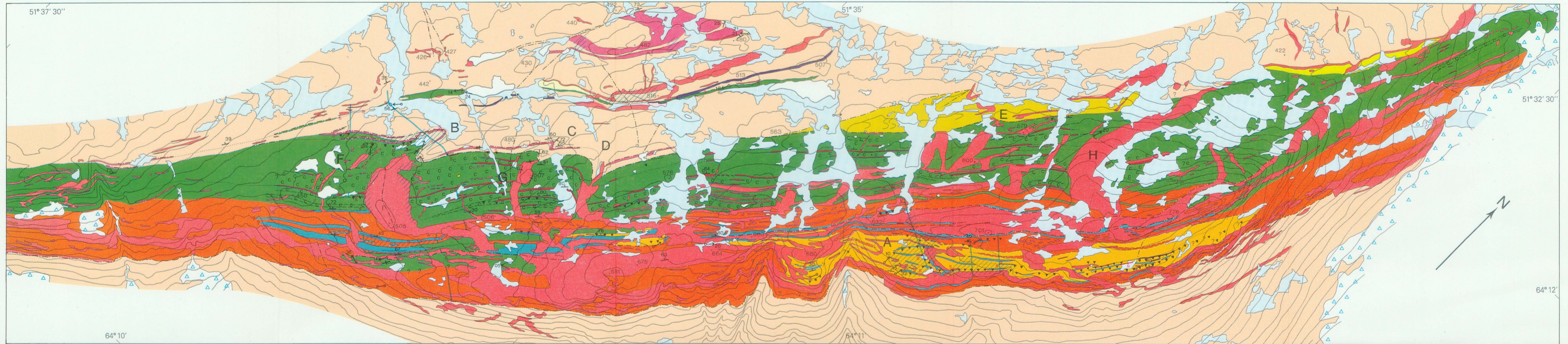
The authors are grateful to Charlotte Clausen and Jan Sangstad for their valuable assistance in the field; to Keld S. Dueholm, Technical University of Denmark, and Hans F. Jepsen, GGU, for assistance with geological photogrammetry; to John C. Bailey, Geological Institute, University of Copenhagen for XRF analysis; to Haldis Bollingberg, Geological Institute, University of Copenhagen for optical emission spectrographical analysis of tourmalinites; to Erik S. Leonardsen, Geological Institute, University of Copenhagen for X-ray determination of scheelite, and to Jørn G. Rønsbo, Geological Institute, University of Copenhagen for microprobe analysis of tourmalines. The Danish Natural Science Research Council funded the microprobe facilities. We thank Brian Chadwick, University of Exeter, and Ian R. Plimer, University of Newcastle, New South Wales, for critical reviews of the manuscript, and A. K. Higgins, GGU, for improving the English.

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Trykt ved Geodetisk Institut 1987.

QUATERNARY

- Snow fields (as per 31.7.1967)
- Moraine and talus

ARCHAEAN

- Pegmatite
- Intra-Nûk amphibolite dyke
- Nûk tonalitic gneiss
- Shattered Nûk gneiss with tectonic enclaves of supracrustal rocks

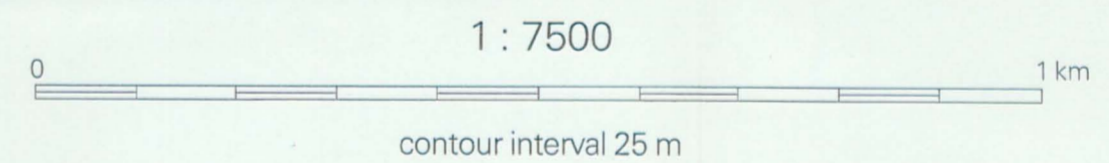
Malene igneous rocks:

- Amphibolite, undifferentiated, mainly fine grained hornblende-plagioclase banded; also homogeneous, calc-silicate banded and hornblenditic rocks
- Calc-silicate banded amphibolite
- Garnet amphibolite, iron-rich, often quartz banded, often with iron oxides and pyrrhotite
- Pale plagioclase-rich amphibolite
- Metavolcanic schist, acid to intermediate
- Ultrabasic rocks

Malene metasedimentary rocks:

- Biotite (-garnet) schist and undifferentiated metasediments
- Siliceous biotite schist/gneiss, often cordierite-rich, often with tourmaline, anthophyllite, sillimanite and/or garnet

- Tourmalinite and rock-forming tourmaline in supracrustals
- Scheelite mineralisation (only shown where checked by ultra violet light in small parts of the mapped area)
- Rust zone with iron sulphides
- Area investigated in ultra violet light
- Traverse investigated in detail in ultra violet light



Topography based on unpublished maps at 1:20 000 by the Geodetic Institute, Copenhagen (permission A.200/87), with corrections by GGU. Geology mapped at 1:7500 by A. A. Garde in 1985 and supplemented by geological photogrammetry at GGU and the Institute of Surveying and Photogrammetry, Copenhagen.