Skarn minerals and geological structures at Kalkheia, Kristiansand, southern Norway

Ina Vang

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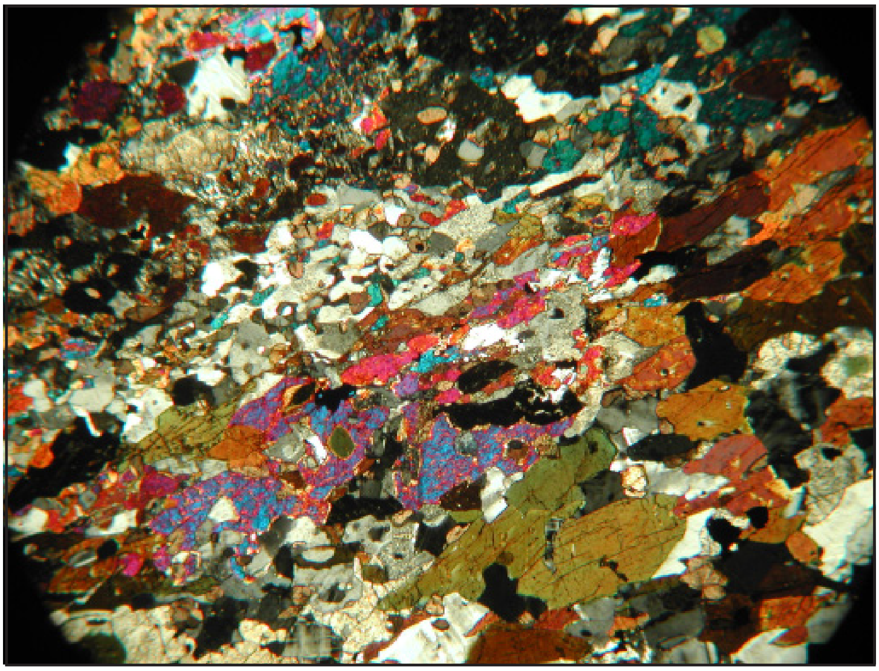

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Abstract: At Kalkheia, Kristiansand, southern Norway, a marble layer was mined from 1826 to 1915. The thickness of the marble varies from 0.5 to 5 metres and the layer can be followed for 700 metres. The area consists of amphibolitic gneiss, granitic gneiss, marble and pegmatites. The gneiss and the marble have originally been horizontal layers, later folded to a synclinal dipping 181,18. The synclinal is a parasite fold on a larger fold called Tveit antiform. Kalkheia is surrounded by faults running WNW - ESE and north – south. In the contact between marble and gneiss, and also inside the marble layer, large amounts of skarn minerals are found. The skarn minerals identified are clinopyroxene, garnet, scapolite, quartz, hornblende, titanite, apatite, chlorite and vesuvianite.

Keywords: skarn, marble, Kalkheia, southern Norway

Ina Vang, Department of Geology, GeoBiosphere Science Centre, Lund University, Sölvegatan 12, SE-223 62 Lund, Sweden. E-mail: inavang@hotmail.com

Skarnmineral och geologiska strukturer, Kalkheia, Kristiansand, södra Norge

INA VANG

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Sammanfattning: I Kalkheia, Kristiansand, södra Norge går ett marmorstråk där kalk har brutits från 1826 till 1915. Marmorns mäktighet varierar från 0.5 till 5 meter och stråket kan följas ungefär 700 meter. Området består av amfibolitisk gnejs, granitisk gnejs, marmor och pegmatit. Gnejsen och marmorn har varit horisontella lager som har veckats till en synklinal som lutar mot söder. Denna synklinal är ett parasitveck på Tveit antiform Kalkheia avgränsas av förkastningar som går VNV – ÖSÖ och nord – syd. I kontakten mellan marmor och gnejs och också i själva marmorn hittas stora mängder skarnmineral. Klinopyroxen, granat, skapolit, kvarts, hornblände, titanit, apatit, epidot, klorit och vesuvianit är skarnmineralen som har hittats. Vanligast är klinopyroxen och skapolit som bildar prismatiska kristaller i och omkring marmorn. Klinopyroxen är svart och skapolit är vit till ljusgul.

Nyckelord: skarn, marmor, Kalkheia, södra Norge

Ina Vang, Geologiska Institutionen, Centrum för GeoBiosfärsvetenskap, Lunds Universitet, Sölvegatan 12, 223 62 Lund, Sverige. E-post: inavang@hotmail.com

1 Introduction

The purpose of this paper is to investigate the marble lenses at Kalkheia, approximately 4 km northeast of the centre of Kristiansand, Norway. The aim of the study is

(1) to determine how the lenses occur in the surrounding gneiss, and

(2) to study the specific skarn minerals in one of the quarries.

Kalkheia is a hill approximately 900 x 400 metres rising 60 metres above the surroundings. The name means limy hill. Several small marble lenses occur interbedded in the country gneiss. The topography is steep, and the marble occurs from ≈40 up to ≈100 metres above sea level. Mining for marble took place between 1826 and 1915. It was used for mortar production (Frigstad, 1996). The rock is coarse grained and the marble layer can be followed more or less continuously for 700 metres. It varies in thickness from 0.5 to 5 metres. The skarn minerals are created during metamorphose, when marble and surrounding rock react, skarn is therefore found in the contact zone between marble and the country rock.

In this paper, most of the samples have been taken from quarries 11 and 12 (cf. Fig. 1). Quarry number 11 is called Pettersgruva, in this paper it will be referred to as Upper Pettersgruva and quarry number 12, Lower Pettersgruva.

1.1 Geological outline

1.1.1 Regional geology

The Southwest Scandinavian Province is the youngest part of the Fennoscandian Shield, consisting of southern Norway and south-western Sweden. It is Meso-Proterozoic in age. Regional shear zones and faults separate the province into several terranes (cf. Fig. 2). All the terranes are made up of metasediments, metavolcanic rocks and granitic plutons.

Fig. 1: Map over Kalkheia, the equidistance is 5 metres. The line from A to B shows where the profile is made. The quarries are numbered, no 2 is Kongegruva, no 3 is Langgruva, no 5 is Sommergruva, no 6 is Vintergruva, no 11 is upper Pettersgruva and no 12 is lower Pettersgruva. The lake where it says "øvre" lies 42 metres above sea level. The map is used with permission from Kristiansand Orienteringsklubb.

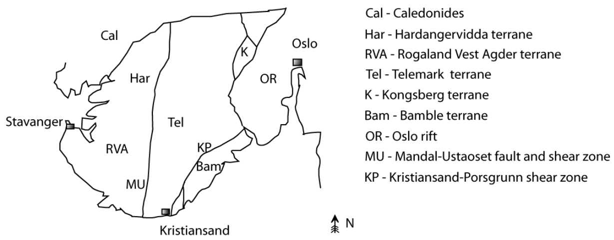

Fig. 2: Sketch map of the different terranes in southern Norway.

The oldest rocks are shelf-type sediments, approximately 1.7-1.5 Ga old (Bingen et al., 2001; Falkum, 1985). These sediments are now found in the Telemark, Bamble and Kongsberg terranes (Bingen et al., 2001). Originally the sediments comprised clay, sand and lime (Schnell, 1993). Their basement was probably gneiss or basalt (Falkum, 1985), and the source rock for the sediments were probably derived from the Fennoscandian Shield. A subduction of ocean crust under the Fennoscandian Shield led to the Gothian orogeny and volcanic activity from 1.7-1.5 Ga. An E-W compression led to N-S foliation, folding, and magma intrusions (Schnell, 1993).

After a calm period of several hundred million years, a continent-continent collision led to the Sveconorwegian orogeny, which lasted from 1.19 to 0.9 Ga (Bingen et al., 2003). The Sveconorwegian forms part of a world-wide orogenic system including a.o. the Grenville province in Greenland and parts of North America. This was the second regional deformation and metamorphic event in southern Norway. It was most intense in its southern and western parts. The Bamble area was pushed northwest above Telemark, along the Porsgrunn-Kristiansand shear zone (Henderson & Ihlen, 2004). Then the area was uplifted and eroded.

1.1.2 Local geology

Kristiansand is located immediately to the west of the Bamble terrane, in the southern part of the Telemark terrane. The gneisses in the Kristiansand area consist of supracrustal rocks, both sediments and volcanics. These rocks were later intruded by several generations of granite plutons (Falkum, 1969). According to Barth (1927), the marble in the Kristiansand area belongs to the Bamble terrane. Marble is found at various places around Kristiansand but also along other parts of the south coast of Norway. As seen in Fig. 3, Kalkheia is located in the western limb of the Tveit antiform. Falkum (1969) describes the rocks on Kalkheia as banded gneisses. In the description accompanying his map, Falkum says that the banded gneiss in Kristiansand normally has layers varying from 2 to 10 cm in thickness, but they may reach several metres, which is the case at Kalkheia. Normally the dark layers consist of biotite gneiss and the light ones of quartz-dioritic gneiss. A marble layer interbedded in the amphibolite in the antiform can be followed 15 km (Falkum, 1966).

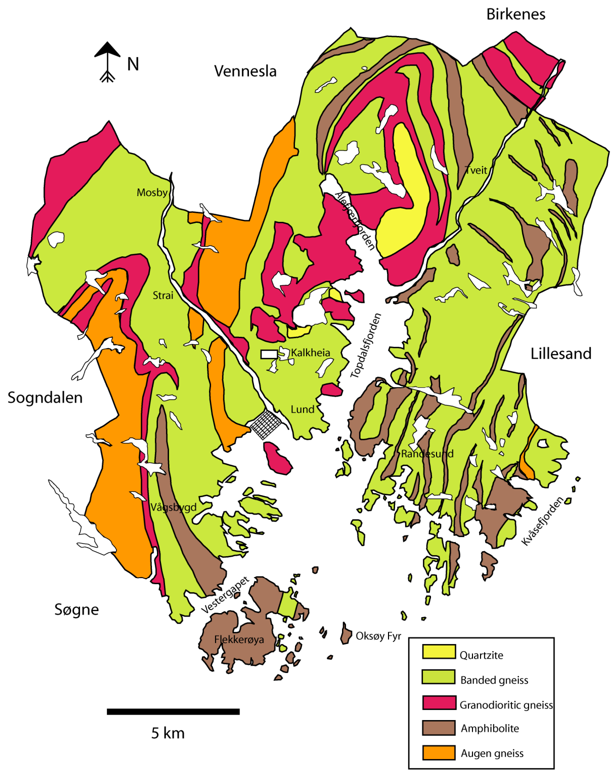

Fig. 3: Geological map of the Kristiansand area, modified after Falkum (1982) and Frigstad (1995).

2 Methods

The field work was carried out from 15 April to 2 May, 2008. Foliation directions were measured on the marble and the surrounding rocks. The program STEREO was used for plotting. A geological map was compiled, and a profile was made (cf. Fig. 6). Samples for mineralogical studies were taken mainly from Upper and Lower Pettersgruva (cf. Fig. 1). Eight thin sections were investigated under the polarizing microscope. A few minerals were studied in a scanning electron microscope (Hitachi S3400N fitted with an EDS analytical device (Link INCA)). The analyses are qualitative and made in low vacuum on unpolished and uncoated samples.

3 Results

Kalkheia consists of granitic gneiss, amphibolitic gneiss, pegmatite and marble. The granitic gneiss is fine to medium grained. The minerals that can be detected macroscopically are quartz, microcline and biotite; the biotite crystals seem to have a preferred orientation parallel to the layering. The colour of the granitic gneiss is light grey to pink. The amphibolitic gneiss is fine grained and black or dark grey in colour. Plagioclase and amphibole are the main minerals. The

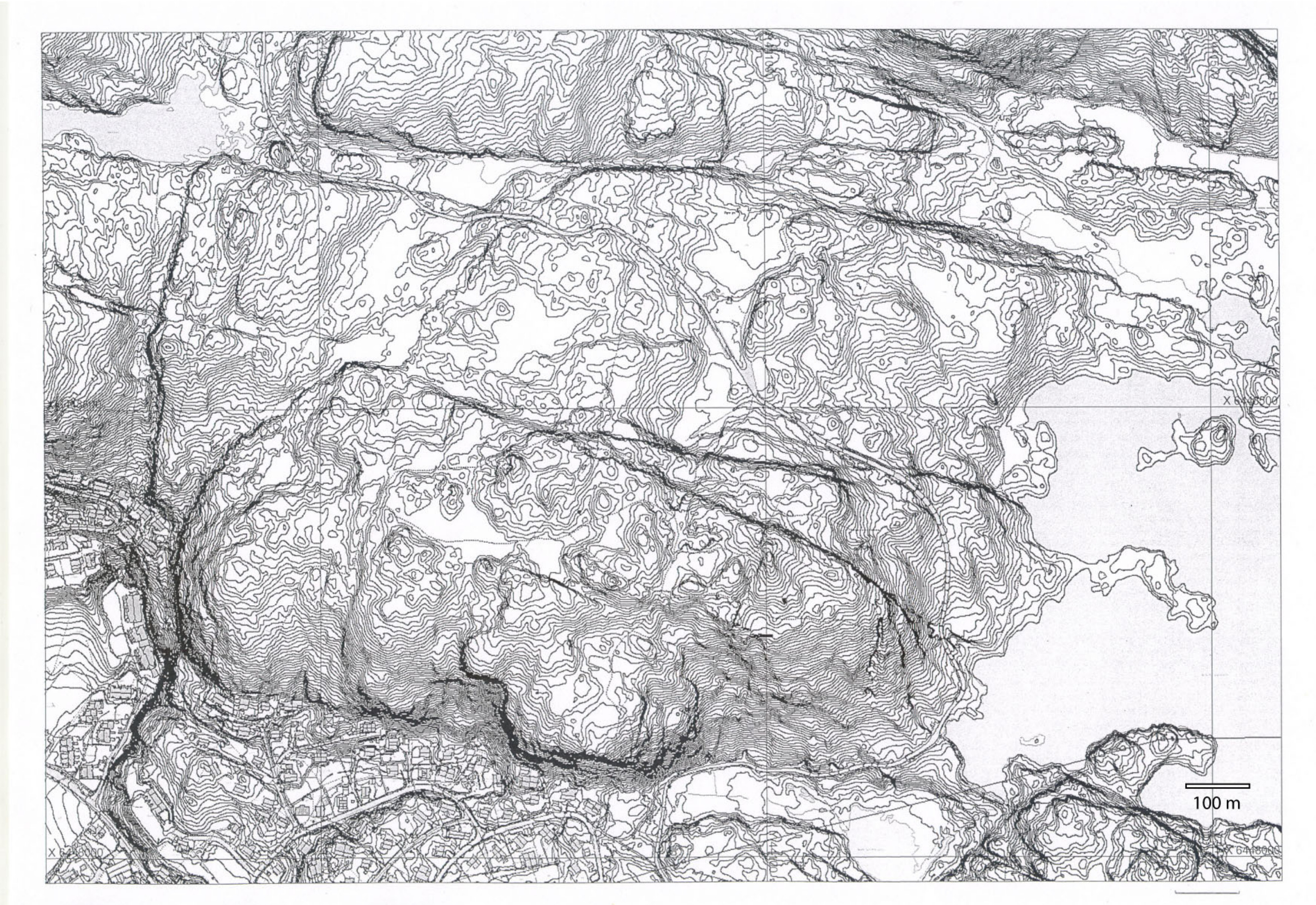

Fig. 4: Topographic map over Kalkheia showing the fault controlled hillsides going VNV-ESE and SSV-NNE.

preferred orientation is layer parallel similar to the relations in the granitic gneiss. Both country rocks have a varying amount of biotite present. Pegmatite seems to be more common in the granitic than in the amphibolitic gneiss and it cuts the foliation. The grain size of the pegmatite varies from megacrysts of microcline with 5 cm in diameter, to more medium grained pegmatite.

Around Kalkheia, steep hillsides run WNW-ESE and to a minor extent NNE-SSW (Fig. 4). They are probably faults. The topography gives an impression of more or less vertical fracture zones. Quartz layers, which might be slickenside structures, have crystallized on the vertical hillsides; this can for example be seen north of Vintergruva, Fig. 5.

The two faults, seen in Fig. 6, coalesce 200 metres to the west of the map margin. To the east they continue on the other side of the lake Jegersberg. 400 metres further north, another fault runs in the same direction. The southern side of Kalkheia is also very steep, with hillsides that can be followed across the dam, where this fault crosses the fault that marks the northern border of Kalkheia. West of Kalkheia, steep hillsides go NNE-SSW, which might also be fault-controlled.

Fig. 5: Photo taken north of Vintergruva where quartz has crystallized on the vertical walls in the fault. Probably slickenside structures indicating that Kalkheia has moved downwards and the northern side of the fault upwards.

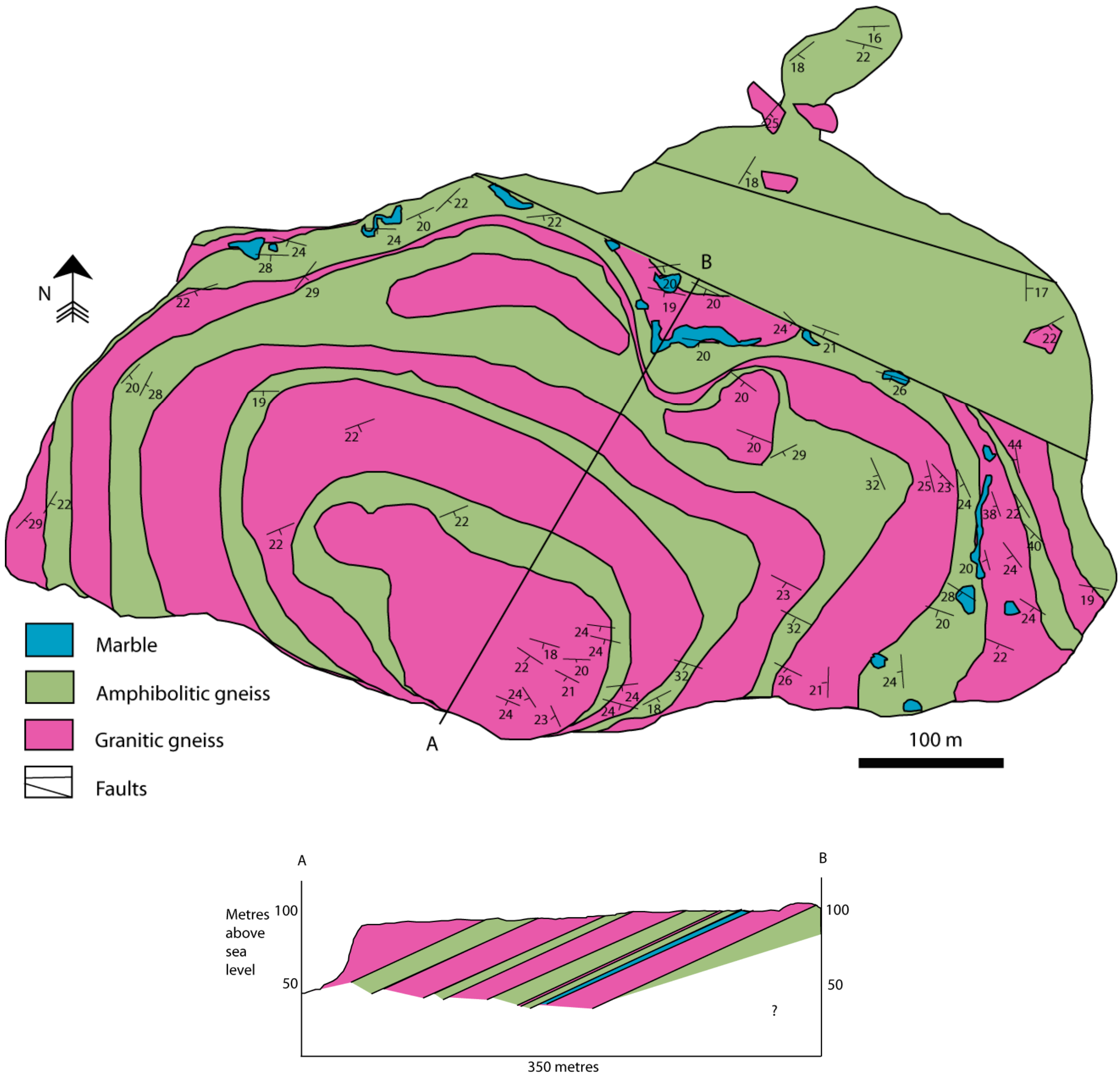

Fig. 6: An approximate bed rock map over Kalkheia, and a profile from A to B, roughly coinciding with the fold axis. The eastern side of the map follows the road. The profile is drawn with parallel layers, with even thicknesses. Especially the marble layer has a wavy shape and is probably not as continuous as drawn.

3.1 The map

When constructing the profile (Fig. 6) it is assumed that the granitic and amphibolitic gneisses form continuous layers over- and underlying the marble. As seen in the profile, granitic gneiss forms the uppermost layer on Kalkheia.

The amphibolitic and granitic gneisses are modelled as continuous layers of constant thickness (Fig. 6). This model is of course a simplification. The rounded granitic gneiss areas close to the marble form part of the third granitic gneiss-layer from the top and constitute the highest points in the area. The granitic gneiss layer occurring above the marble is drawn as a continuous layer; however, its presence could not be verified at the point, where it should be crossed by the profile. This layer might be absent from the hinge region. South of the quarries 1 to 3, seen in Fig. 1, the landscape is flat covered with water and much vegetation; consequently, the rock boundaries in Fig. 6 are uncertain for this part of the area.

Contacts between the granitic and the amphibolitic gneisses are sharp above the marble layer, and in the eastern part of the studied area, also below this layer. To the north of the fault, it is more difficult to identify the boundaries. The amphibolitic gneiss seems to dominate and it is strongly migmatitic. This is also seen on the southern side of the fault, below the marble in quarry 1 and between Kongegruva and Langgruva (cf. Fig. 7).

Fig. 7: Migmatitic amphibolitic gneiss, photo taken between Kongegruva and Langgruva.

Pegmatites are abundant at Kalkheia and range from 10 cm up to roughly 20 meters in width, as can be seen in the southern part under the cliff, just east of the profile. They are not displayed in the map. At some places pegmatite is intruded immediately above the marble, like in the northern part of the upper Pettersgruva. In the northern part of the studied area, north of the faults, pegmatites make up all high parts of the topography. In general, where the topography is steep, granitic gneiss and pegmatite are at the top and amphibolitic gneiss might be exposed at the bottom (cf. Fig. 8).

Fig. 8: Granitic gneiss above and amphibolitic gneiss below, photo taken along the path west of quarry no 17.

3.2 Geological structures

The foliation in Kalkheia describes a syncline, dipping towards the south. The poles closely fall on a great circle in the stereoplot (Fig. 9). The pole of this great circle is 181, 18. The syncline, defined in the major part of the study area, seems to be limited to the areas south of the faults. Some foliation measurements to the north of the faults seem to fit the same syncline but this is disproved by others, e.g. C (Fig. 1). The granitic gneiss is dipping SE, with the strike parallel to the path.

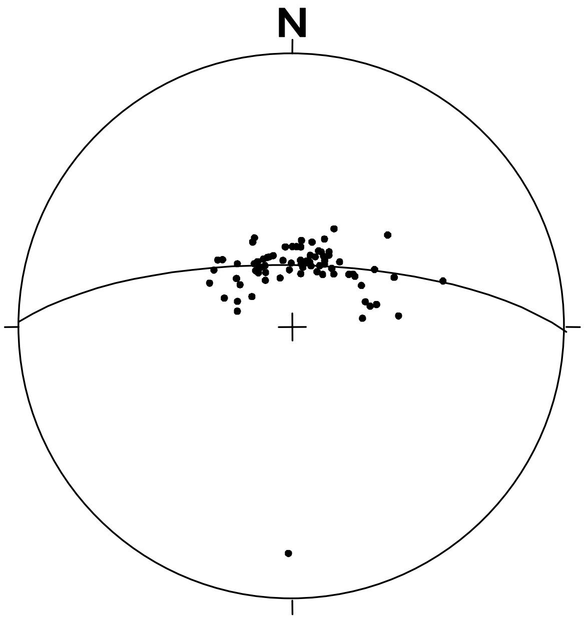

Fig. 9: Stereo plot of the foliation measures, cylindrical best fit of great circle and pole.

In Fig. 6, the layers in the profile are drawn with constant thickness, which is a simplification, especially for the marble. The quarries give the impression that the marble layer is formed as lenses in three dimensions (cf. Fig. 10).

Fig. 10: Quarry no 4, the marble has a lens shape parallel with the strike, amphibolitic gneiss above.

In the quarries, the marble thins in the sides of the quarries and also often in the dip direction. In Upper Pettersgruva, where the marble is exposed on both sides, the marble dips downwards on both the SW and NE side, although the layer dips towards SW. Small folds with wave lengths around 10 to 20 cm are found in the skarn zone (cf. Fig. 11).

Fig. 11: Fold in the skarn, photo taken in Kongegruva.

3.3 Petrographic descriptions of the various rocks

3.3.1 Marble

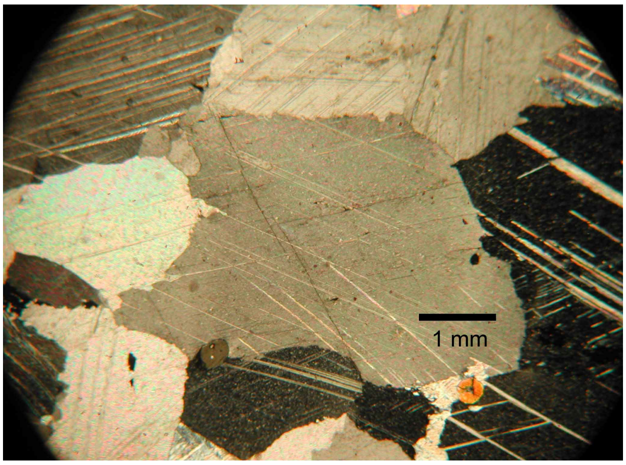

Fig. 12: Calcite crystals showing twinning in cross polarized light.

Coarse calcite crystals, approximately 1 to 4 mm, make up the marble. Under the polarizing microscope, the calcite shows twinning, high relief and very high birefringence. The calcite grains are colourless in plane polarized light and white, grey or black in cross polarized light. They seldom show crystal faces or fractures, see Fig. 12. It is difficult to distinguish between calcite and dolomite using optical microscopy. However, qualitative EDS analyses confirmed that the major mineral of the marble is calcite. Pyroxene, most likely diopside, is abundant in the marble, as well as scapolite. These crystals are well exposed where the marble is weathered. The diopside consists of black or green prismatic crystals, while scapolite forms milky, yellowish prismatic crystals. Under the polarizing microscope, pyroxene has a subhedral shape, light green colour and high interference colours. Scapolite was not detected in the thin sections from the marble; however the crystals are clearly visible macroscopically as seen in Fig. 13.

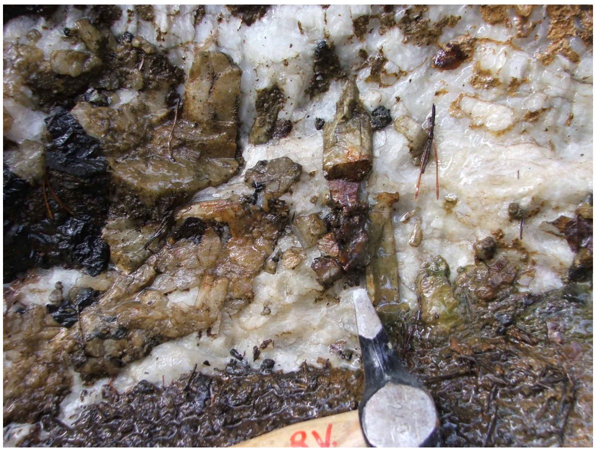

Fig. 13: Photo taken in lower Pettersgruva. The black crystals are clinopyroxene, the white are marble and the grey/beige are scapolite crystals.

Vesuvianite (idocrase) occurs in the marble in small quantities. As seen in Fig. 14, it is colourless with well developed prism faces showing the tetragonal symmetry and cleavage. Calcite fills the fractures. The sizes of the crystals are roughly 1 mm in diameter.

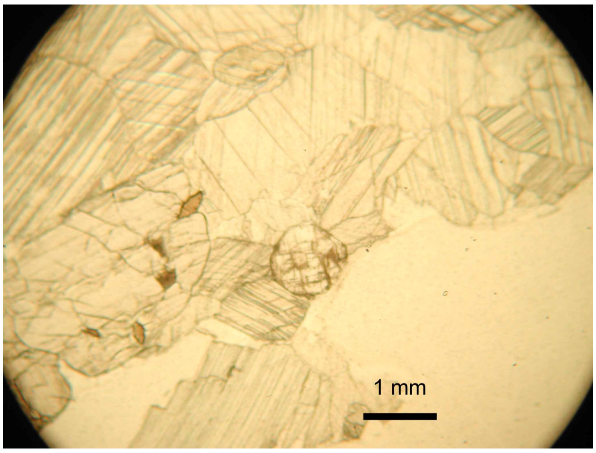

Fig. 14: Photo taken in plane polarized light, vesuvianite crystal in the centre of the photo, brown titanites and calcite.

3.3.2 Skarn

The marble that is visible in the quarries contains large amounts of impurities, skarn minerals. These occur in the contact zones between the marble and the upper and underlying rocks, but also as single crystals, continuous layers, which are several metres in length, and boudins of various sizes, in the marble. Figure 15 shows a large boudin from lower Pettersgruva.

Fig. 15: Lower part of lower Pettersgruva, amphibolitic gneiss above and marble below. The large boudin consists of amphibolitic gneiss and skarn in the border towards the marble.

The skarn zone has increased contents of skarn minerals towards the marble and might reach one metre in thickness. The contact between the skarn and the bedrock is often transitional, although sometimes amphibolitic gneiss is in direct contact with the marble without any skarn zone. The skarn has a varying mineral composition; Barth (1927) separates the skarn into garnet, scapolite, quartz, pyroxene and hornblende skarn.

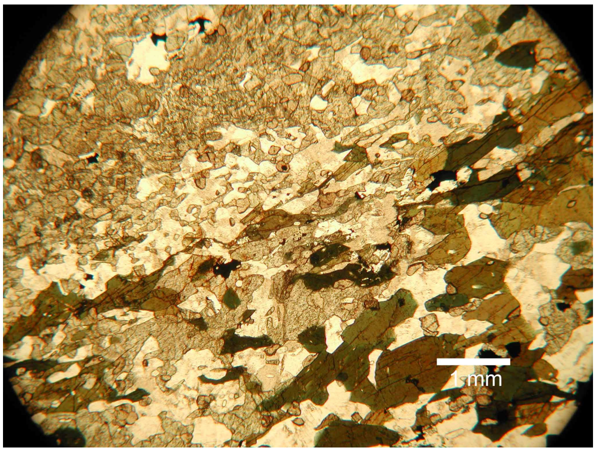

Fig. 16: Hornblende skarn below and pyroxene skarn above, photo taken in plane polarized light.

The contact between the country-rock amphibolitic gneiss and the skarn zone is made up of hornblende skarn. Hornblende skarn consists of plagioclase, quartz, opaque minerals, titanite and hornblende. The amphibole seems to be more pleochroic in the skarn than in the amphibolitic gneiss. Among the opaque minerals, pyrite can be identified macroscopically. Otherwise no studies have been made of the opaque phases; however, magnetite and ilmenite might occur. Titanite (sphene) occurs as small, rhombic crystals, about 0.2 to 0.5 mm in size, both in the skarn and the marble. The colour is brown in plane polarized light and bronze in cross polarized light. Sometimes opaque minerals occur inside the titanite. As seen in Fig. 16, the hornblende skarn has sharp contacts towards the pyroxene skarn, which has only minor amounts of titanite and opaque minerals and no plagioclase.

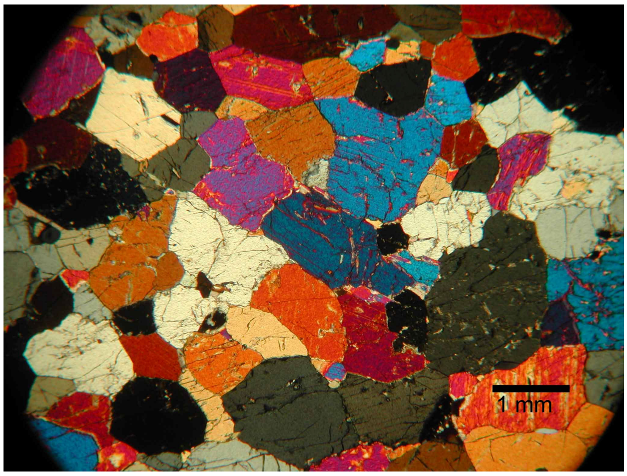

Fig. 17: Pyroxene skarn in cross polarized light.

Clinopyroxenes are abundant in nearly all the thin sections investigated (cf. Fig. 17). The pyroxene is assumed to be diopside; no augite was found, though Barth (1925, 1928) mentions that augite is abundant in the skarn. Diopside is mostly green in plane polarized light and exhibit a subhedral shape. At many places, the pyroxene crystals are altered to chlorite. Fine grained chlorite is therefore found along crystal faces and in fractures. The chlorite crystals are light green, pleochroic and show a low birefringence. Some small apatite crystals, ~0.3 mm in diameter, were also found in the pyroxene skarn above the marble and in the boudins. The apatite crystals are colourless, with straight extinction and occur as well developed, hexagonal crystals. Epidote is found in small quantities in the pyroxene skarn. It is colourless with a high relief. In the skarn zone a ~10 mm thick zone of coarser grained pyroxene, with approximate grain size of 3 mm, forms the contact with the marble.

During metamorphosis, calcite reacts with plagioclase to form scapolite. The scapolite skarn is therefore characterized by a symplectite of scapolite and plagioclase with irregular, wavy borders as seen in Fig. 18. Tiny, rounded quartz grains may occur inside the scapolite crystals. Scapolite is colourless, with a low relief and high interference colours.

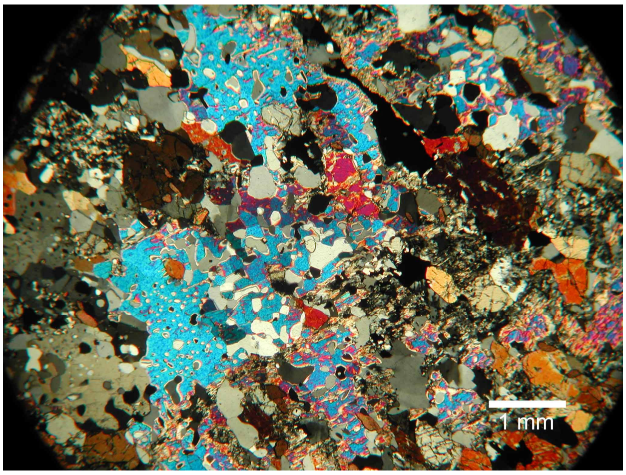

Fig. 18: Photo taken in cross polarized light. The blue crystals are scapolite, the grey ones are plagioclase and quartz, and the red and orange crystals are pyroxene.

Quartz veins occur in the marble, and quartz is present in most of the skarn, ranging from 1 to 30 %. The extinction is strongly undulating and the relief is low. Quartz occurs with microcline, pyroxene, altered pyroxene, titanite, plagioclase and opaque minerals. The grain size varies from 1 to 5 mm.

The garnet skarn is easier to find in loose blocks in the quarries than in the walls. Garnet skarn contains calcite and pyroxene in small amounts. In the skarn zones, especially in the lower part of the Lower Pettersgruva, garnet crystals are abundant, ranging up to 5 cm in diameter. Microscopic studies reveal that the garnet crystals generally are fractured in one direction with calcite filling the cracks as seen in Figs. 19 and 20.

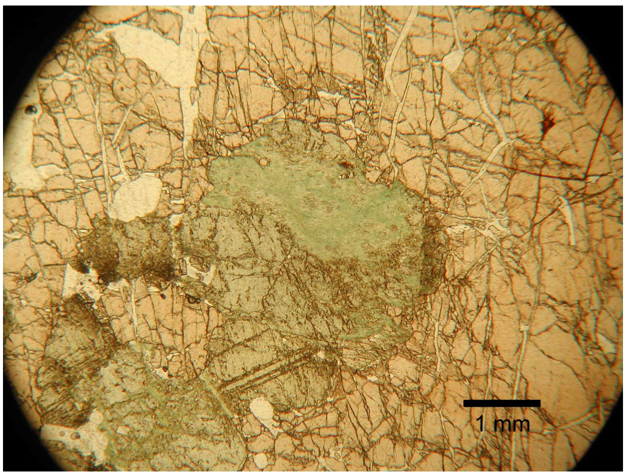

Fig. 19: Plane polarized light, the light pink is garnet, the green is pyroxene and the white is calcite.

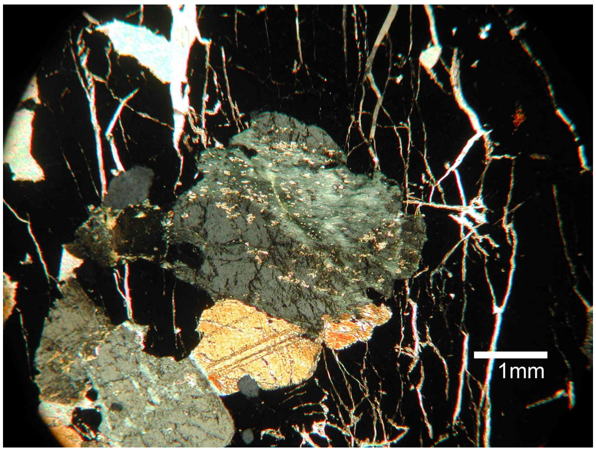

Fig. 20: Cross polarized light, the black is garnet, the grey and yellow is pyroxene and the white is calcite.

Small garnet crystals, around 0.2 mm, have well developed crystal faces. In plane polarized light its colour is pink. Qualitative EDS analyses preformed in low vacuum on uncoated samples suggests that garnet is mainly grossular with minor and varying amounts of the andradite component (cf. Fig. 21). Garnet occurs with calcite, pyroxene, chlorite and opaque minerals. Quartz was found in small amounts in samples consisting mainly of garnet.

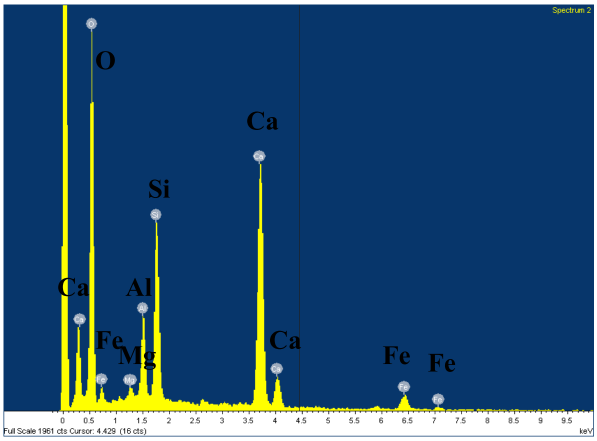

Fig. 21: Typical composition of garnet in the skarn.

Plagioclase altered to muscovite was found in the thin section from one boudin in the marble. The muscovite was colourless and with a high birefringence. Plagioclase is mainly found close to the amphibolitic gneiss in the skarn zone and is twinned according to the albite law.

3.3.3 Amphibolitic gneiss

The amphibolitic gneiss most often directly overlies the marble. It consists of amphibole (hornblende), plagioclase and biotite. The amphibole crystals are elongated, up to 3 mm in length, and with a preferred orientation parallel to the layering. Some crystals are fractured mainly along the long axis. In plane polarized light, the colour varies between dark green, light green and light brown. The plagioclase shows twinning.

3.3.4 Granitic gneiss

The granitic gneiss is fine to medium grained containing quartz, microcline, plagioclase and biotite. The biotite content is slightly varying. The colour in thin section is green or brown and in cross polarized light the interference colours vary from brown to light green. The microcline shows wavy extinction and cross-hatched twinning, the grains are roughly 1 to 2 mm in diameter (cf. Fig. 22).

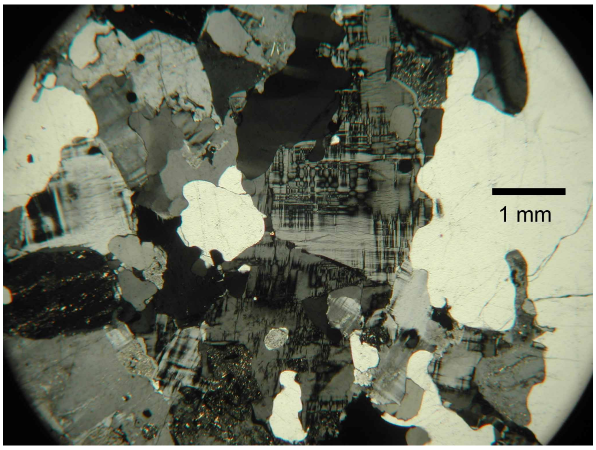

Fig. 22: The crystals with cross hatch twinning are microcline, the rest are quartz. Taken in plane polarized light.

3.4 Description of Pettersgruva

As seen in Fig. 23, the amphibolitic gneiss is directly overlying the marble. The marble layer is normally varying from 0.5 to 2 metres in thickness, but in the uppermost part of Upper Pettersgruva, the marble reaches 5 metres. In the upper part of Lower Pettersgruva, ≈ 1 to 2 metres of granite is overlying the marble. This is not included in the sketch. The shape is not known, but the amphibolitic gneiss is dominating, as drawn in the profile.

The largest boudins are found in lower part of lower Pettersgruva (cf. Fig 15). These seem to be amphibolitic gneiss. Pyrite crystals can be found in the skarn and the amphibolitic gneiss here. In the marble, scapolite and clinopyroxene crystals are large and easy to detect (cf. Fig 13). Especially clinopyroxene crystals follow the layering in the marble, and wherever a boudin is present, the layers curve around it. The skarn zone between the marble and the amphibolitic gneiss is fine grained, massive, and with a light grey colour. In Lower Pettersgruva, this zone is approximately 20 cm thick. The smaller boudins have the same mineral content. A marble layer occurs immediately above the skarn layer, and the upper border towards the amphibolitic gneiss shows flame structures. A thin marble layer occurs in the amphibolitic gneiss as well. At some places the amphibolitic gneiss appears rusty. In Upper Pettersgruva there is a 1 meter thick homogenous layer over the marble. It is the same massive, fine grained skarn as in lower Pettersgruva. Two vertical fissures go through the amphibolitic gneiss, skarn and marble. In the uppermost part of the quarry, the marble seems to increase threefold in thickness.

3.5 Metamorphic conditions

The minerals present in the marble is of special interest because the marble is more sensitive to pressure and temperature than the gneiss (Falkum, 1966). Garnet, pyroxene and scapolite are the most common skarn minerals, while epidote is found in small amounts. The garnet is mainly grossular, with a varying amount of andradite. This indicates that the area has been subjected to amphibolite facies metamorphism. According to Falkum (1966), the following reaction has taken place:

$$2Ca_2(Al, Fe)_3Si_3O_{12}OH + 5CaCO_3 + 3SiO_2 \rightarrow 3Ca_3(Al, Fe)_2Si_3O_{12} + 5CO_2 + H_2O$$

The oxidation of Fe is not taken into account.

Hornblende was not found close to the marble. Between the hornblende skarn and the marble, a layer of pyroxene skarn is present; according to Falkum (1966) a reaction between calcite and hornblende has taken place:

$$Ca_2Mg_5Si_8O_{22}(OH)_2 + 3CaCO_3 + 2SiO_2 \rightarrow 5CaMgSi_2O_6 + 3CO_2 + H_2O$$

4 Discussion

4.1 The marble layer

The marble layer can either be of carbonatitic or sedimentary origin. Carbonatites are associated with strongly alkaline volcanism, which is absent from the study area. The sedimentary origin is the likely one, because metasediments are abundant both in the Bamble and Telemark terrane. Marble is found around Kristiansand and along the southern coast, together with other metasediments such as quartzites and graphitic schist (Field & Råheim, 1980). At many places, the layers show stratigraphic endurances, like in the antiform of Tveit. Deformation and metamorphism due to two orogenies explain why the layers are discontinuous, and why no original structures are preserved. Marble is not a common rock in southern Norway, and the carbonate sediments cannot have formed thick sequences. However these sediments must have been deposited over

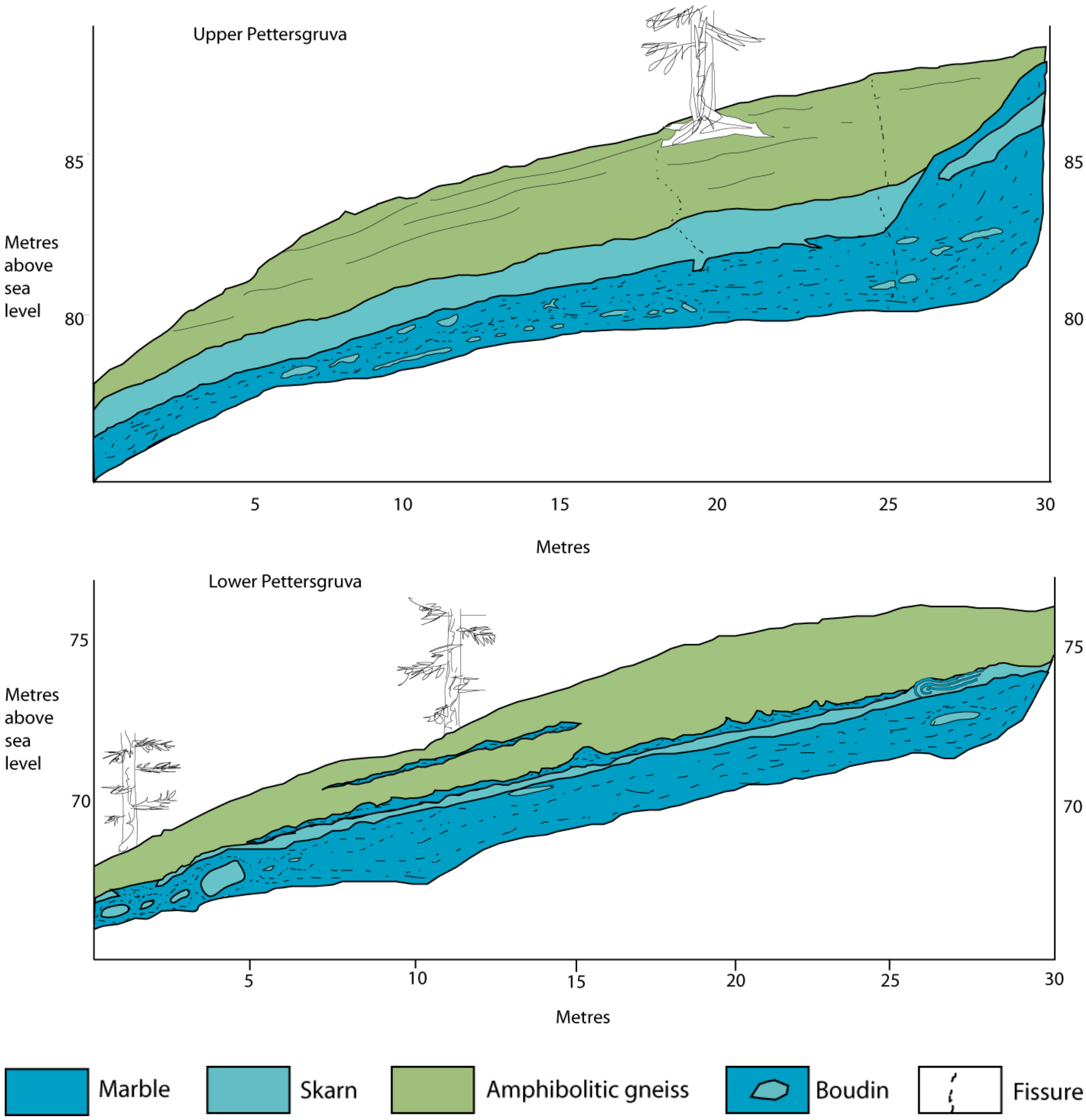

Fig. 23: Sketch of the exposed marble and overlying rock in upper and lower Pettersgruva. The white areas above and below are covered with quaternary material.

vast areas. In the small area of Kalkheia no facies changes should be expected; the layer must therefore have been continuous and with approximately the same thickness. There might however, have been more than one marble layer originally. Sommergruva and Vintergruva are located at different levels, with ~3 metres of gneiss/skarn between them. This might be two separate layers, or it might be a repetition due to deformation. These two occurrencies roughly coincide with the fold axis. If marble had imigrated to the fold hinge, one would expect the layer to increase in thickness, not to create two separate layers. Between Vintergruva and quarry 4, there is no marble and neither between Langgruva and Kongegruva (see Figs. 1 and 6). Either the marble thins and disappears completely in the areas where it has not been found, or the layer is totally hidden by quaternary drift. As seen in upper part of Pettersgruva, the layer varies in thickness.

The amphibolitic gneiss can have been basalt that has floated out on the ocean floor. In this case the layers would originally have been approximately horizontal, and the amphibolitic gneiss would, at least before the deformation, have formed a continuous layer above the marble. The ampibolitic gneiss might however, be an intrusive rock, gabbro or diabase. Limestone with high amounts of impurities might also, during metamorphism, alter to amphibolite. Granite always have an intrusive origin, however immature sandstone with quartz and feldspars, can after metamorphism give rock resembling granite, the same might be true for a rhyolitic lava. The layers in Kalkheia might have been volcanic material, shifting from rhyolitic to basic lava. This hypothesis would fit the map, assuming that the layers are roughly parallel to each other. Granitic intrusions that follow the layering of the amphibolite could be another possibility.

The plot of the foliation measurements (Fig. 9) at Kalkheia might form part of a great circle, which indicates a cylindrical fold. Another possibility is that the plotted points are part of a small circle and that the rocks have been folded several times. Falkum (1966) mentions a second deformation phase of the Tveit antiform, connected with granite and pegmatite intrusions. From the present data, Kalkheia seems to be a syncline, a parasite fold on the western limb of the larger fold at Tveit.

4.2 The faults

Whether there has been vertical movements or not along these fracture zones, is not known. The migmatite found under the marble in the western part of Kalkheia is similar to the migmatite on the northern side of the fault. Therefore it is more likely that the northern side has moved upwards. The quartz layer found north of Vintergruva indicates that the southern side, Kalkheia, has move downwards and the northern side upwards. This is however very speculative.

5 Conclusions

- In general, Kalkheia consists of granitic gneiss, amphibolitic gneiss, pegmatite and marble. The layers of amphibolitic and granitic gneiss vary from half a metre to several tens of metres in thickness.
- The marble lenses in Kalkheia represent a more or less continuous layer, folded to a synclinal around an axis 181, 18°.
- The marble is overlain by an amphibolitic layer.
- A WNW-ESE fault forms the northern boundary of Kalkheia.
- Below the marble and on the northern side of the thrust, the rock is more migmatitic with a higher amount of amphibolitic gneiss, than above.
- Pegmatite ranging in size from 10 cm to 20 metres is abundant; it is uncertain weather they follow the layering.

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