CONTRIBUTION TO THE GEOLOGY OF THE KVÆNANGEN WINDOW, BURFJORD, TROMS, NORWAY

By

A. G. MILNES and A. RITCHIE

CONTENTS

Abstract. The general geology of the area is described; three main geological units are recognized: 1. Amphibolite Complex, 2. Quartzite Group, 3. Psammitic Schist. The metamorphism of the amphibolite is discussed; it is low-grade, of Albite-Epidote-Amphibolite facies. An occurrence of an unusual scapolite-bearing limestone is described. An attempt is made to classify the minor structures of the area and to deduce the structural and geological history.

Introduction

The field work was carried out by two members of the Edinburgh University North Norway Expedition 1959, in the area surrounding Burfjord, East Troms, on the east coast of Kvænangenfjorden. This area includes part of the south-western "Raipas window", these windows being formed by updomings of the contact between the allochthonous thrust metamorphic Complex (mainly Eocambrian psammites) and the underlying autochthon. The latter is generally divided into two groups; the auto- or par-autochthonous Bossekop

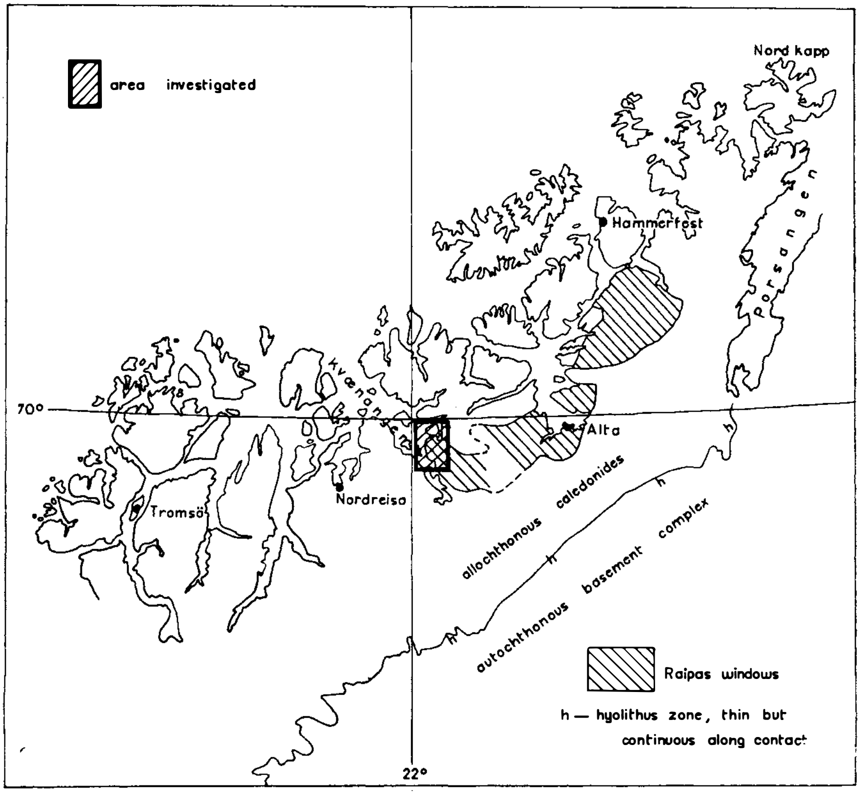


Diagram 1. Location of area investigated and generalized geology showing position of Raipas "windows".

quartzite (Eocambrian) and the underlying autochthonous Raipas supergroup of Precambrian age. The suggested relations between the windows and the basement to the south-east are shown on an excellent map by REITAN ("Geology of Norway", HOLTEDAHL, 1960) together with a summary of previous work in the area.

General Geology

The general succession in the Burfjord area can be summarized as follows:

3. *Psammitic Schist* ↑coarse rodded ↓fine schistose

∼∼∼∼∼∼∼∼∼∼∼∼∼∼ tectonic disconformity

2. *Quartzite Group*
   dark shales
   dolomite
   quartzites with black shale horizons

~~~~~~~~~~~~~~~ disconformity

1. *Amphibolite Complex*
   sediments with metamorphosed dolerite intrusions

No fossils were found in the area and lack of marker horizons makes the stratigraphy and detailed structure, particularly in the Amphibolite Complex, difficult to work out. From analysis of the minor structures however, a number of phases of movement can be distinguished. The major structure of the area is an anticline plunging at a small angle to the NW. This can be seen by the outcrop of the quartzites (see Map for location).

Amphibolite Complex

The group consists predominantly of amphibolites, massive, medium- to coarse-grain rocks containing ubiquitous amphibole (i.e. this name does not imply metamorphic grade), with intercalated irregular bands and lenses of pelitic and carbonate meta-sediments. Shearing and mylonitization of the amphibolites is widespread. A unique scapolite-bearing carbonate rock occurs in this series and some amphibolites show a high magnetic anomaly.

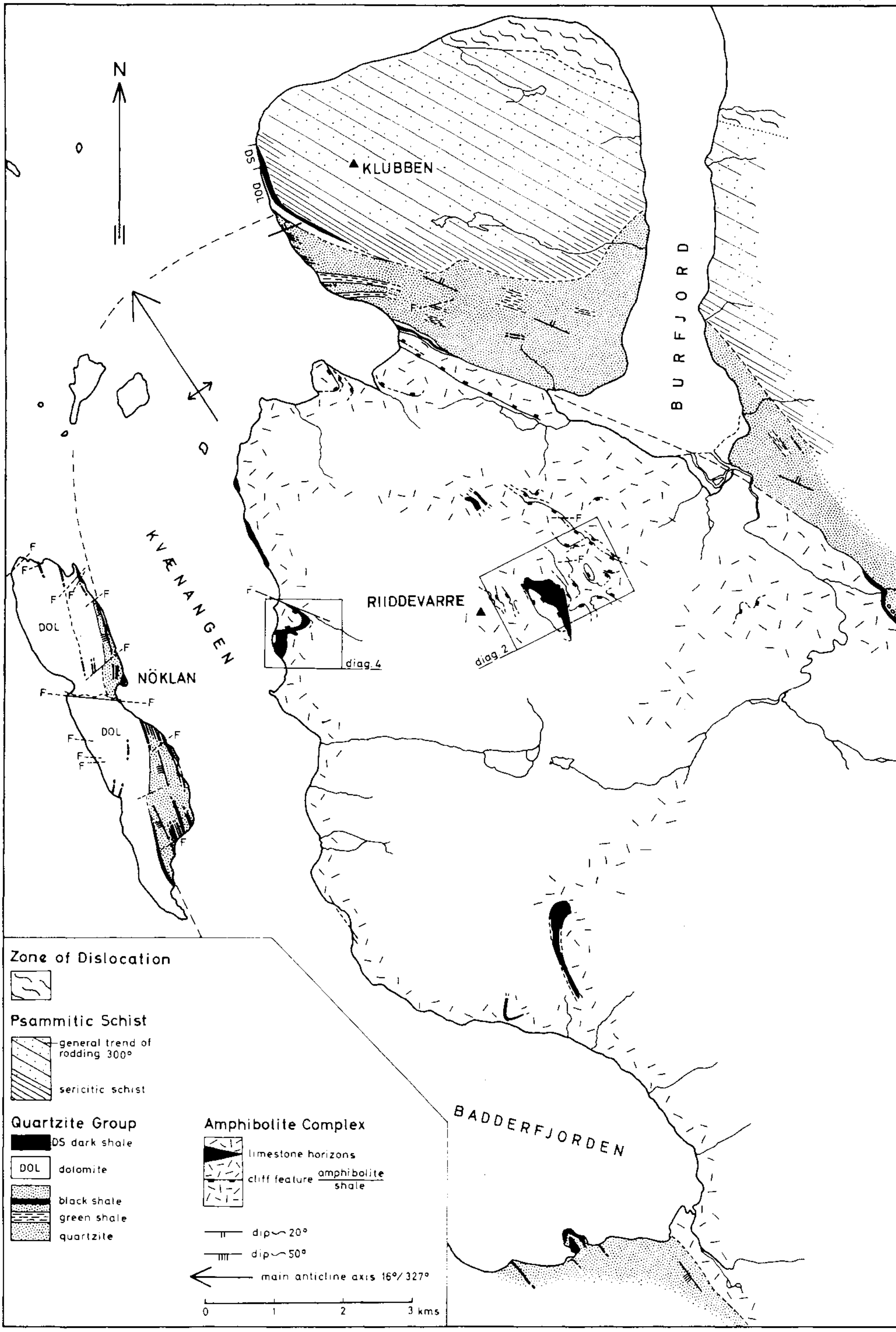
Amphibolites

In contrast to the uniform appearance of these rocks in hand-specimen, a wide range of mineral composition is found on examination of thin sections. However, certain minerals are of constant occurrence and can be said to be typical of these rocks.

Plagioclase. Where the plagioclase could be reliably determined, it was albite. It contains many inclusions and has complex twinning, low negative relief and an extinction angle of 15°—18°. Sometimes the plagioclase is completely saussuritized and indeterminate.

Amphibole. This mineral is biaxial negative, 2V 40°—60°. It varies greatly in pleochroic scheme and in crystal habit. It can be divided into three general types.
~~~~~~~~~~~~~~~

Geological map of the BURFJORD AREA, Kvænangen, Troms, Norway



Map for location

Type I: normal pleochroism, α yellow-green — β olive-green — γ blue-green, and compact prismatic habit.

Type II: faintly pleochroic, in shades of pale water-green, and usually fibrous, sometimes as acicular inclusions in albite or as large anhedral poikilitic crystals.

Type III: strongly pleochroic, α buff — β olive-green — γ deep blue-green, and compact prismatic or fibrous.

Several modes of crystallization may be represented together in the same rock.

Epidote. Although not always present, epidote occurs as small rounded crystals with zoning of interference colours. It is usually colourless in thin section although sometimes slightly pleochroic and greenish. Clinozoisite is also of wide occurrence, and is recognized by its anomalous blue and yellow interference colours.

Epidote also occurs in many places as irregular patches or veins of long prismatic crystals (EHLERS 1953, CARSTENS 1955).

Ore Minerals. Iron ore, probably magnetite in most cases, is widely distributed throughout the amphibolites. Large patches of turbid ore are common. Opaque minerals are often surrounded by turbid ore in a spherulitic texture suggesting ilmenite altering to leucoxene. Altered ilmenite lamellae occur inside some magnetites (see p. 89) Disseminations and small irregular veins of pyrites are common and widespread throughout the amphibolites. In veins it is seen, in reflected light, to be replaced by chalcopyrite. Magnetite appears to be associated with this later chalcopyrite.

Accessory minerals. A limited range of accessory minerals has been observed. Quartz is widespread; sphene, apatite, and biotite also occur. Secondary carbonate and penninite frequently occupy cracks throughout the rock. Small euhedral tourmaline crystals occur in the mylonitized amphibolite.

Textures. A great majority of the rocks show varying degrees of cataclasis so that in most cases the original textures are modified or destroyed by granulation, streaking out and mylonitization. Where the original texture is visible, it is invariably ophitic or sub-ophitic, often with rounded amphiboles, up to 1 cm in diameter, including euhedral plagioclase or plagioclase pseudomorphs (saussurite or epidote). This suggests that the rocks were originally dolerites or gabbros. The deduction that the rocks are intrusive is supported

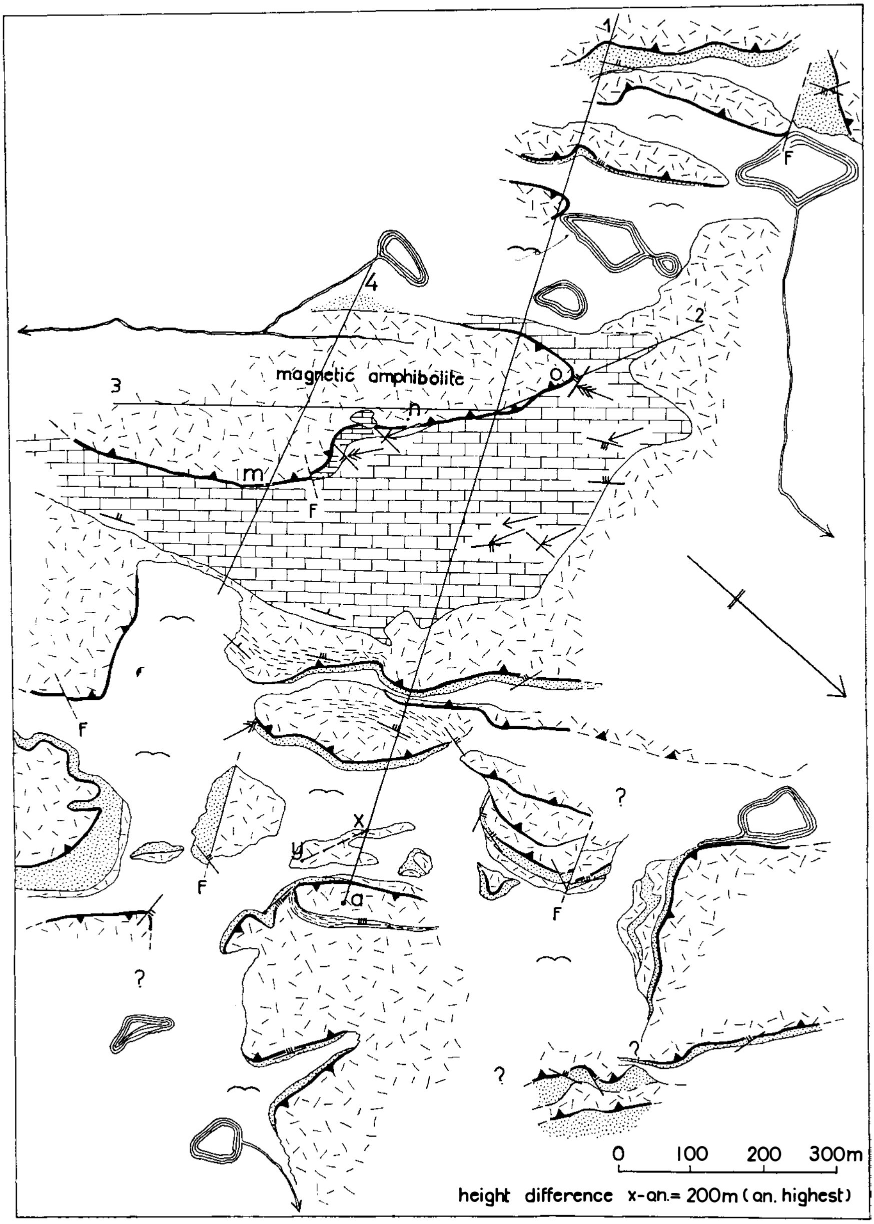


Diagram 2. Detail map of part of NE Riiddevarre (see Map for location), illustrating the complexity of the field relations.

further by the general coarsening of grain away from the contacts. This may, in some cases, be due to mylonitization near the contacts, but in an unsheared example from Svanefjell the rock shows typical ophitic texture 5 m from the contact whilst 1 m from the contact the texture is variolitic.

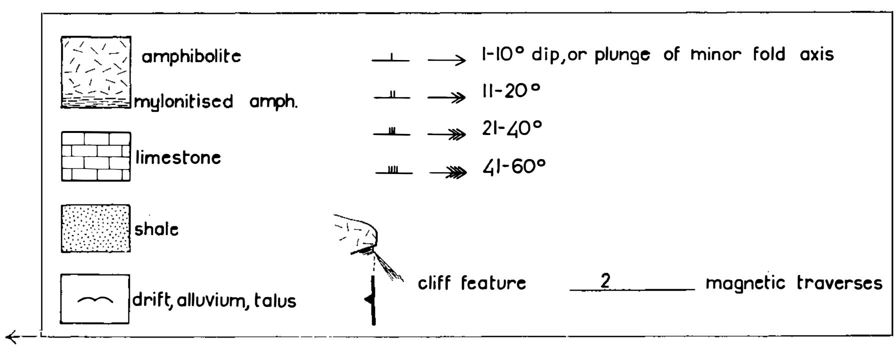
The view that the rocks were originally doleritic in composition is further confirmed by the presence, in a few slides of remnant pyroxene. In one particularly unaltered rock, augite is the dominant ferromagnesian mineral and is altered marginally to a fibrous hornblende.

Sediments

In general, the sedimentary intercalations in the amphibolites, except in the case of the limestones, are badly exposed because they normally occur at the base of the cliff features formed by the resistant amphibolites (Diagram 2.). The impression obtained is that the sediments form a very minor part of the Complex, but it may be that they tend to be hidden by talus and drift, since they are more easily eroded. The detailed field relations are extremely obscure. The sediments are of two main types; argillaceous and calcareous.

The argillaceous rocks are generally dark and sometimes very well foliated. They are indurated, and often difficulty was found in distinguishing them from mylonite in the field. One thin-section showed patches of glassy material and was carbonaceous. The contacts between amphibolite and argillite are often disconformable, which may be further evidence in favour of an intrusive origin of the amphibolites.

The carbonate rocks are very prominent in the field as yellowish outcrops on the hillside. They are often intensely folded on a minor



scale and show rapid changes in thickness. This, coupled with the wide variation in lithology, made correlation between the limestone outcrops impossible. It is not known whether the limestones represent one particular horizon or a number of different horizons. The main limestone of north-east Riiddevarre (Diagram 2.) may perhaps be correlated with the scapolite-bearing limestone, a unique rock-type outcropping on the west coast of Riiddevarre (see p. 89), since both are overlain by a magnetic amphibolite.

Quartzite Group

This series rests unconformably upon the Amphibolite Complex and can be divided as follows:

3. Dark shales (100 m).
2. Dolomite with shales horizons (200 m).
1. Quartzites with abundant black shale and occasional green shale horizons (600 m).

Thicknesses refer to the fullest succession which is seen in detail in the 300 m cliff of the west coast of Klubben (Diagram 3).

Quartzites

The contact with the underlying Amphibolite Complex is marked at a few localities by a thin conglomerate. The pebbles are mainly quartzite, usually extremely granulated and strained, and set in a matrix of shattered quartz and white mica. Although the contact plane was originally stratigraphic, there is evidence that some movement may have occurred along it. Just above the contact the quartzite is massive and veined with quartz. Where limestone occurs just below the contact, it is intensely boudinaged and shattered.

The quartzites are fine-grained and extremely well foliated in most places, the foliation being caused by very thin sericitic partings giving the rock a flaggy appearance (flags a few cms. thick). The foliation is sometimes boudinaged, the axis of the boudins being approximately parallel to the dip. A prominent black and white banding is seen in places which may or may not be parallel to the foliation and is sometimes isoclinally folded. KVALE (1947) in similar rocks, states that this type of banding is probably the original bedding.

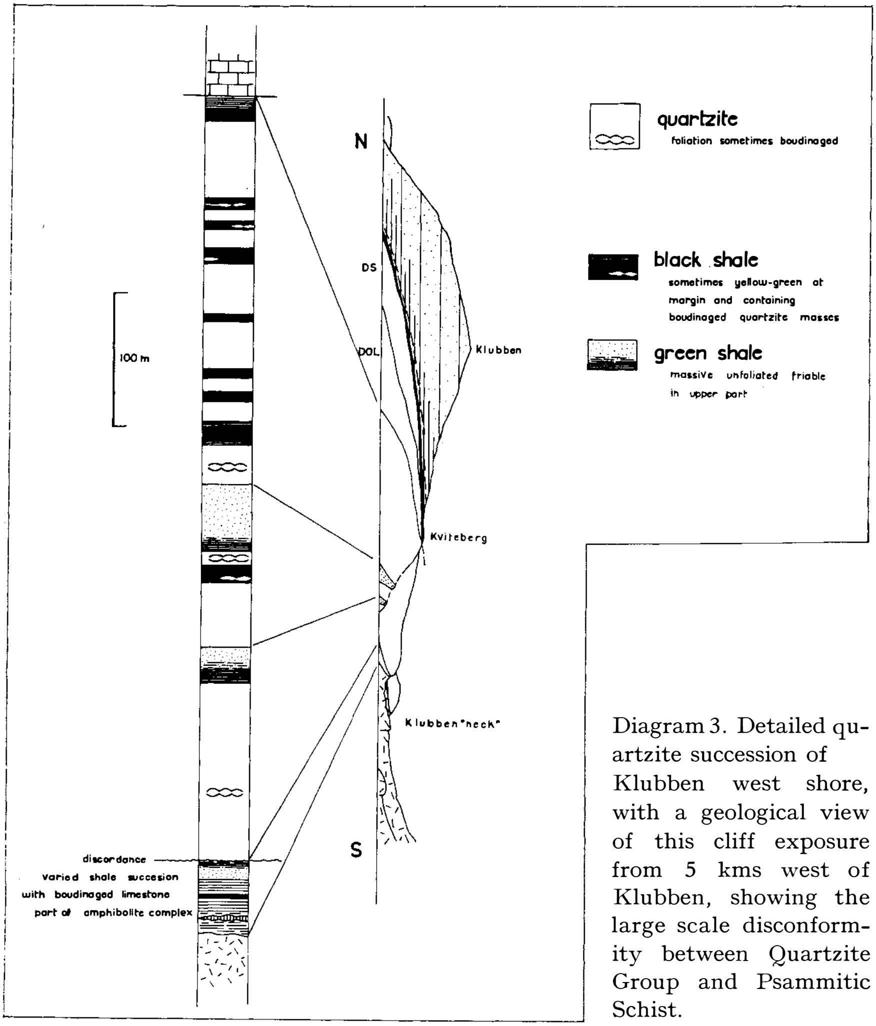


Diagram 3. Detailed quartzite succession of Klubben west shore, with a geological view of this cliff exposure from 5 kms west of Klubben, showing the large scale disconformity between Quartzite Group and Psammitic Schist.

In thin section, two types of quartz are seen; large irregular strained grains and small rounded grains apparently representing the granulated remnants of originally larger grains (i.e. every gradation of large grain can be observed from unstrained to crystals so intensely strained that in certain positions of the stage they appear to be made up of many small grains). A small amount of white mica is disseminated through the rock.

Throughout the quartzites a number of black shale horizons occur. These are often highly mineralized, mainly with quartz, felspar, calcite, and pyrites which are commonly in the form of irregular veinlets parallel to the foliation or irregular masses which disturb the foliation. The foliation is usually good but irregular (not slaty) and "flows round" the large masses of boudinaged quartzite which sometimes occur in these shales. Drag folding is often well developed. On the west shore of Klubben two thick green shale horizons occur. These have two components; a lower shaly horizon, highly mineralized and well foliated, and an upper massive horizon, friable with typical pock-marked weathering and not so highly mineralized (but with pyrite widely disseminated). At the top of the succession a shale with bright yellow-green colouring occurs and may pass gradationally in to the overlying dolomite (Diagram 3).

Dolomite

This rock was described by HOLTEDAHL and ANDERSEN (1922) when the following compositions were quoted:

	CaO	MgO	SiO_2
Nöklan: light dolomite	28.56	20.33	3.53
dark dolomite	29.07	20.62	3.25
Klubben west shore	31.60	19.60	1.13

The lithology is very uniform over the 200 m thickness seen in Klubben cliff, being mainly a grey fine-grained dolomite. Occasionally shale bands occur and these are often yellow-green at the margins. Also, throughout the rock, irregular quartzose bands occur (described as "flint-like" by Holtedahl) which, being resistant, stand up like walls from the wave-cut platforms. Especially on the shores, the dolomite is seen to be extremely blocky due to a very close rectangular jointing. Innumerable small faults can be seen (calcite-filled fracture zones) running parallel to this jointing, as well as one major fault, with a downthrow of 500 m to the south, dividing Nöklan. Mineralization occurs in the shales and one vein of pyrites was found in the dolomite in the extreme south of Nöklan.

Dark shale

These shales only appear from beneath the disconformity on the west shore of Klubben, and the top is not seen. The rocks are dark but variable in colour and often very well foliated (slate-like). Quartzo-felspathic injection is common along foliation planes.

Psammitic Schist

The contact between this and the underlying Quartzite Group was only seen in one place, on the shore at the north-west tip of Klubben. Here a green schist lies disconformably upon the slate (Dark shale), cutting across its foliation. On a large scale, the disconformity is seen in the cliff on Klubben west shore where the schist is seen to "transgress" the Dark shale and the Dolomite, coming to rest on the Quartzites (Diagram 3). In other places, the contact is approximately parallel to the strike and the disconformable relationship is obscured.

The schist is massive and featureless but with the following general relationship:

2. massive, coarse-grained, well-rodded
   (with a mullion structure in places)
   ↑
   gradational
   ↓
1. schistose, fine-grain, green

∼∼∼∼∼∼∼∼∼∼∼∼∼∼ disconformity

Quartzite Group

The schistose rock near the contact contains abundant sericite with a lesser amount of green biotite, together with interspersed granular quartz and large phacoids of strained and partly-granulated quartz. In the typical coarse-grained psammitic schist, the rods consist of granular quartz and alkali felspar in a groundmass of quartz, plagioclase and alkali felspar (some microcline) intergrowths and white mica (sericite).

In many places, the rock is cut by two sets of quartzose veins at a small angle to each other, which often show intense minor folding. Also, "zones of dislocation" are common and form topographic features. Characteristic of these zones is a dark-green, soft, shatteredlooking rock with definite margins and containing longitudinally striated pencils of quartz, orientated parallel to the regional rodding direction. In places, quartz veins can be seen to be intensely folded and sometimes broken up to form these "pencils".

Zone of Dislocation

This is a peculiar region across the north-east tip of Klubben and probably continued on the east side of Burfjord. It shows great resemblance to the minor zones above — characteristic dark-green shattered rock with intense rodding and crumpling of quartzose material. It has a steep general dip to the N. Its position only was mapped and no detailed work was carried out.

Metamorphism of Amphibolites

In a general way, the "amphibolites" are comparable with the epidiorites of the South-West Highlands of Scotland (WISEMAN 1934, READ 1923, PEACH et al 1911, TILLEY 1938) and perhaps the low-grade metamorphic series in the Sulitelma phacolite (VOGT 1927). The following features of similarity are found in the present rocks:

1. The albite is water-clear with abundant inclusions of fibrous hornblende and granular epidote;
2. Three types of hornblende occur, compact dark-coloured, normal and fibrous pale-coloured;
3. Clinozoisite-epidote is constantly present;
4. Steam cavities are absent, coarse ophitic textures are typical and occasional remnant augites occur.

But here a complicating factor arises; the rocks have been subjected to two metamorphic episodes (or the effects of different phases of the same episode).

1. *Low-grade regional metamorphism.*

This is probably not greater than Albite-Epidote-Amphibolite facies, equivalent to the metamorphism of some of the Highland epidiorites. In places the rocks appear to be only very slightly altered and the grade seems to vary considerably. This may reflect the local nature of the stresses promoting recrystallization or the time of intrusion of the different sheets. Some of the dolerites may have crystallized primary hornblende.

2. *Dislocation metamorphism.*

The main result of this phase was the mechanical breakdown of the minerals. It can be seen to be later than the regional metamorphism since the hornblende occurs as porphyroclasts in many of the sheared rocks. Cataclasis is present in varying degrees in most thin-sections. The following stages can be recognised:

1. Granulation of felspar, even when amphibole undisturbed,
2. Streaking out of amphibole; porphyroclasts of extremely strained quartz (often verging upon lamellar twinning),
3. Fine-grain, with good banding.

Some mineralogical changes may be associated with this metamorphism, for instance, chlorite and clinozoisite can both result from dynamic metamorphism, but in this case, they are difficult to distinguish from minerals formed in the first phase.

Magnetic Amphibolites

Large magnetic anomalies were found in two areas and a magnetic survey was carried out (Diagram 2). The anomalies were caused by certain amphibolites containing a very high concentration of magnetite (confirmed by study of polished sections in reflected light). The magnetite occurs in two distinct generations;

1. Large irregular masses of magnetite containing lamellae of ilmenite altered to leucoxene (or a very fine-grain sphene aggregate) in a triangular pattern. This type of intergrowth is characteristic of normal quartz-dolerites and is the result of direct igneous cooling. According to VINCENT and PHILLIPS (1954), exsolution only takes place below 500° C and certainly below 600° C. The lamellae are strained and destroyed in shearing and so are pre- dislocation metamorphism.
2. Widely disseminated euhedral crystals seen to be unaffected by the shearing and mylonitization and to cut across mylonite banding. This indicates a post-dislocation metamorphism mineralization probably associated with the main mineralization of the area.

Scapolite-bearing Limestone

A detailed map was made of the outcrop of this peculiar rock on the west coast of Riiddevarre (Diagram 4). The amphibolite above the limestone was found to be magnetic.

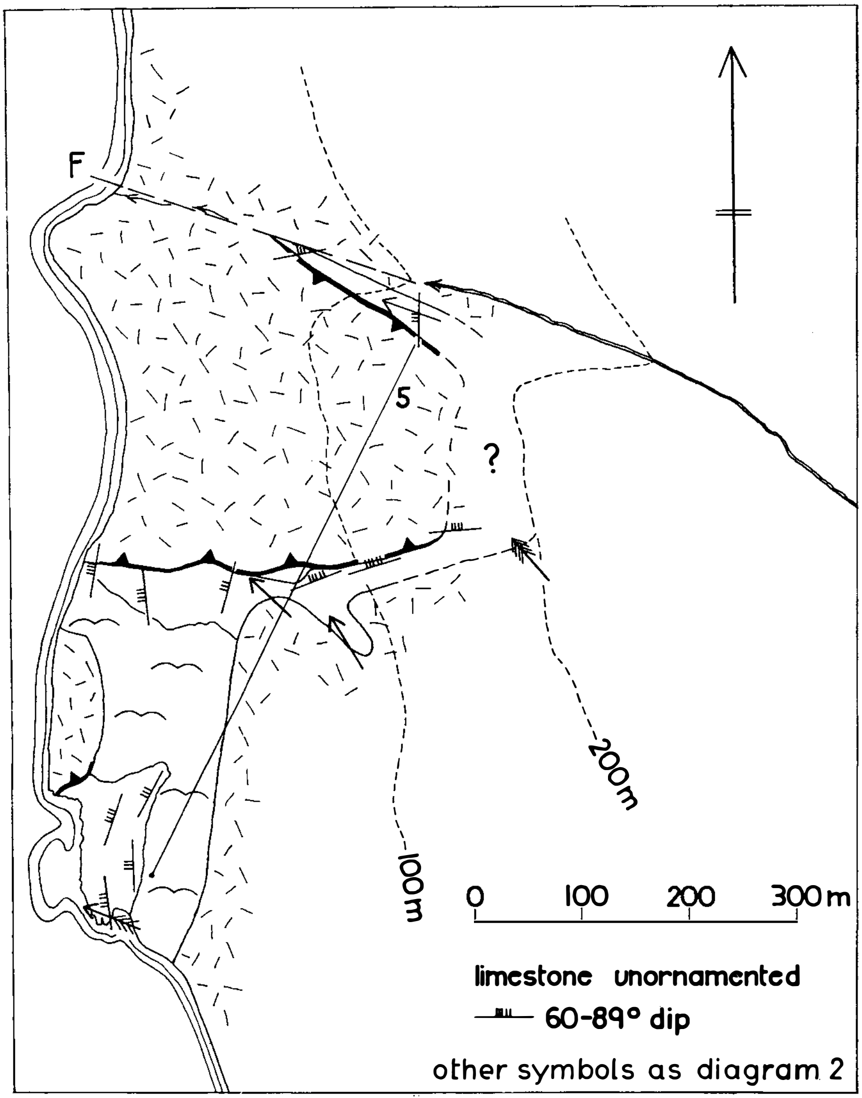


Diagram 4. Sketch map of the exposure of scapolite-bearing limestone, west coast of Riiddevarre (see Map for location). On the hillside the terrain is steep and difficult. The start of magnetic traverse 5 is an un-named house.

Fig. 1. Foliation surface of one kind of scapolite-bearing limestone showing the complete disorientation of the crystals and the absence in many cases of the axial part of the crystal which is filled with matrix. Approx × $\frac{1}{2}$.
(Photo: M. Murray).

The lithology of this small outcrop is extremely variable. The most spectacular rock-type is a clean, yellow-weathering limestone containing large (2—5 cm in length) prismatic tetragonal crystals (see Fig. 1). In thin-section, the groundmass is mainly carbonate with sparsely disseminated rounded quartz grains (often in aggregates) and minute phlogopite crystals. Apart from the scapolite, large green biotite crystals occur, disorientated and ragged in outline. The biotite shows intense straining (undulose extinction and strain lamellae) outside the scapolite, which includes it non-preferentially, but inside the scapolite crystals, the straining is only rarely seen and is less intense.

Scapolite. The mineral is uniaxial negative with birefringence $(n_\omega - n_\varepsilon)$ 0.026 — 0.029. The refractive indices are $n_\omega = 1.570 \pm 0.002$, $n_\varepsilon = 1.548 \pm 0.002$.

According to WINCHELL (1951) and TRÖGER (1952), the above data give a composition $Me_{50}Ma_{50}$ or just to the calcic side of this i.e. *mizzonite.* The crystals contain abundant inclusions, mainly of rounded quartz, the inclusions becoming less packed away from the axis of the crystal. Often the axial part of the crystal is missing and filled with matrix. The crystals show no preferred orientation, and where this rock-type is best developed it has irregular bands containing larger scapolite, smaller scapolite and no scapolite crystals.

In other parts, the rock is almost black, the aphanitic groundmass containing large oval crystals of scapolite and smaller rhomb-shaped crystals of calcite. These calcites are also characteristic of the white limestone in the north-eastern parts of the outcrop, where scapolite is absent. Intense minor folding occurs in some parts and where it does the rock is free of large crystals. The whole limestone varies rapidly in thickness from about 10 m in the north to 40 m in the south.

FYFE, TURNER and VEERHOOGEN (1958) discuss the conditions of formation of scapolite. They consider that the isochemical metamorphism of impure calcareous rocks will form calcic scapolite, but the formation of halogenbearing scapolite involves halides either in solution or in the gas phase. This is supported by SUNDIUS (1915) and EDWARDS and BAKER (1953). Due to the intermediate composition and lack of knowledge of the precise field relations, no conclusion regarding the origin and formation of the present occurence can yet be reached.

Structural Geology

The only major structure discernable is the late anticline of the Quartzite Group. The minor structures are very numerous and complex but three broad groups can be recognized:

- early isoclines,
- minor folds of many different types, difficult to relate to each other and to the major structure,
- linear structures with axis 12°/298°.

For analysis, the area was divided into a number of regions and the stereonets of foliation and minor structure axis plotted for each. (Diagram 5).

Foliation

1. The major structure of the area, indicated by the foliation in the Quartzite Group, is an anticline plunging to the NW (16°/327°) and with its SW limb steeper (55°/255°) than its N limb (20°/25°).

2. The irregularity within the Amphibolite Complex (stereonet 10) is obvious and could be due to the irregularity and disturbing effect of the intrusions or to a phase of folding before the quartzites were deposited.

3. The stereonet of foliation in the Psammitic Schist gives no true picture of the tectonics. For the most part, this represents measurements in the schistose rock near the lower contact with the Quartzite Group or near the minor dislocation planes, and as such reflects the attitude of the contact plane in this area. However, away from these planes, the rock is coarse and massive, very few foliation readings could be taken, and when this was possible, some were vertical and dipping to the SW. Hence, some large scale folding may be present within the Psammitic Schist, and this must have an axis parallel to the regional "rodding" direction since this remains absolutely constant throughout the region.

It should be noted here that the contour maximum of the "rodding" does not lie in the plane of the contour maximum of the foliation (foliation and "rodding" only occasionally being associated in the field).

4. The Quartzite Group — Psammitic Schist contact (net 1) is almost exactly parallel to the N limb of the anticline except in area 2. This area represents part of the turn-over of the major anticline, the

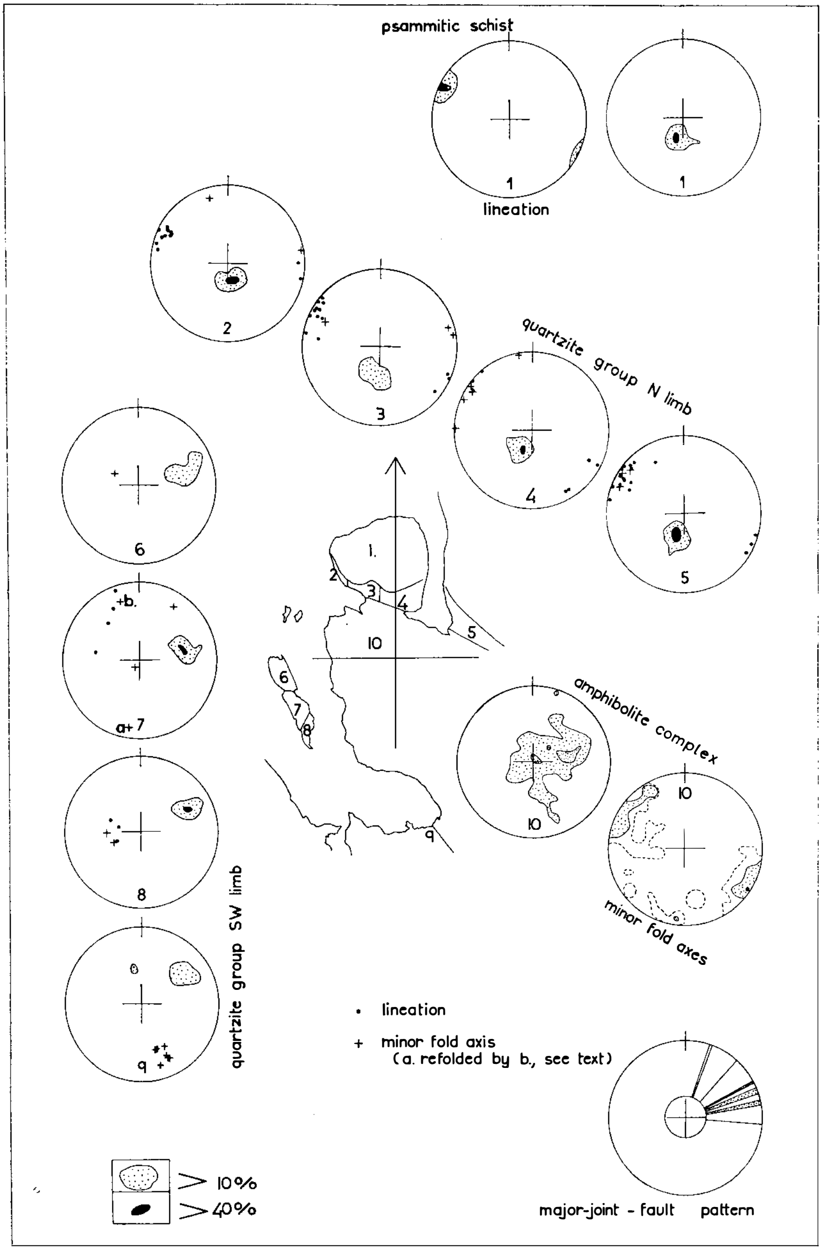


Diagram 5. Stereonets of foliation and minor structures.

disconformity being visible on a large scale in the cliff on the west coast of Klubben (Diagram 3). Because of this disconformity, and the fact that the limbs of the anticline are so regular, it might appear reasonable to deduce that the Psammitic Schist was completely later than the formation of the anticline. However, Zenzén's original field map shows the foliation in the Psammitic Schist on the other side of Kvænangenfjord dipping steeply to the SW (40°) and this, together with the very existence of the "window" would indicate that folding of the contact plane has subsequently taken place and the anticline is not as simple as might appear from the stereonets.

5. The fault/major joint pattern, taken from aerial photographs, shows a maximum at right-angles to the major anticline axis.

Minor Structures

The numerous minor structures can be described in terms of:

I. Minor folding, including the early isoclinal folding, drag folding associated with the formation of the major anticline and the minor folding which could not be related to any other structures;

II. Linear structures, restricted to the Psammitic Schist and Quartzite Group of Klubben (N limb of anticline).

I. Minor Folding

The minor folds can be classified into five general groups (Diagram 6).

1. *Isoclinal folds*

Three types of these folds were noted:

(a) Tightly-folded quartzo-felspathic veins in the shales of the Quartzite Group. No similar folding can be seen in the surrounding shale (Diagram 7).

(b) Folds in the black-and-white banding in the quartzites (page 84).

(c) Tight folds in quartzose veins in the Psammitic Schist.

The axes of these folds are not parallel to the major anticlinal axis (16°/327°) nor the main "rodding" direction (12°/298°). In each case, they can be seen to be early structures, i.e. they are affected by later folding (Diagram 7) or have lineation superimposed upon them (Diagram 6).

The axial planes of the isoclines (and the limbs) are parallel to the foliation. This suggests that the folding and the formation of the foliation are closely linked and may be the result of the same movements.

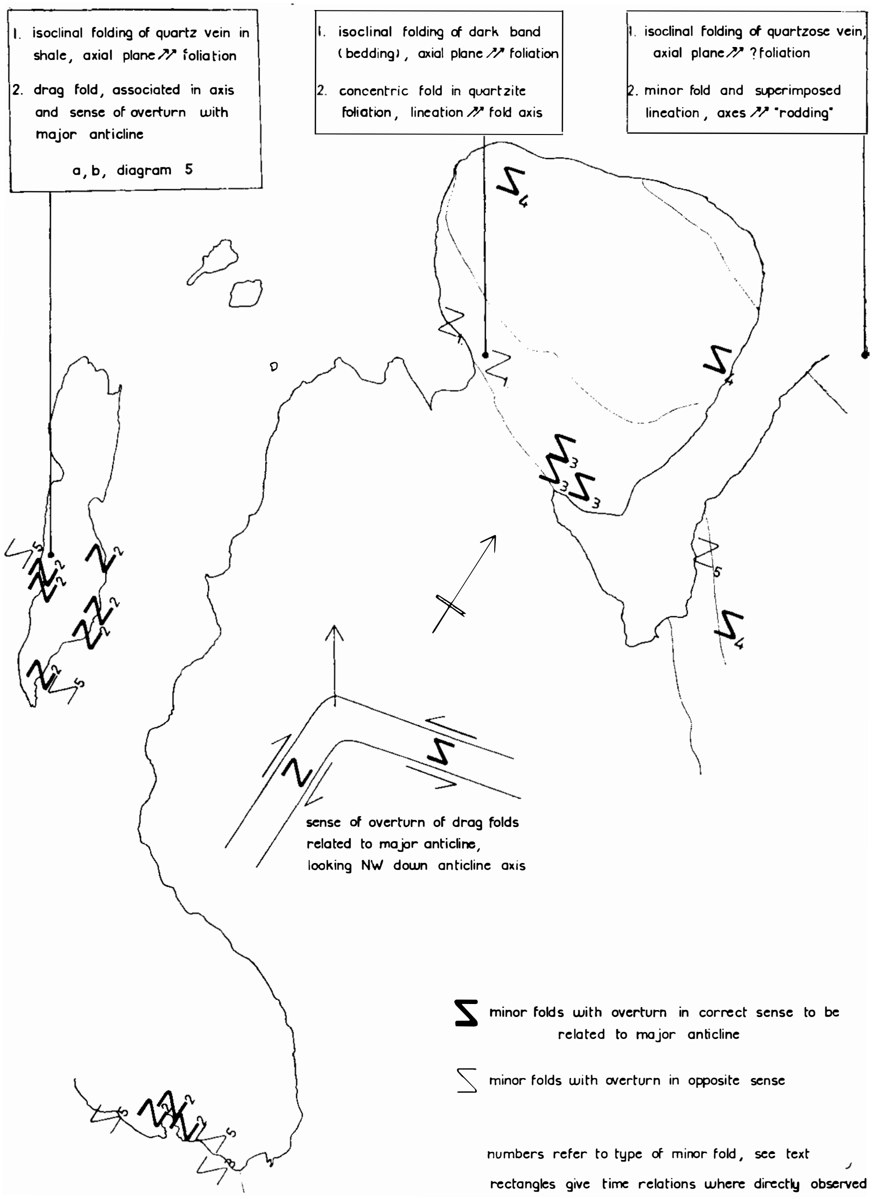


Diagram 6. Relationship between the sense of overturn of the minor folds and the major anticline, each fold looked at from the SE towards NW, down the plunge of the axis of the major anticline.

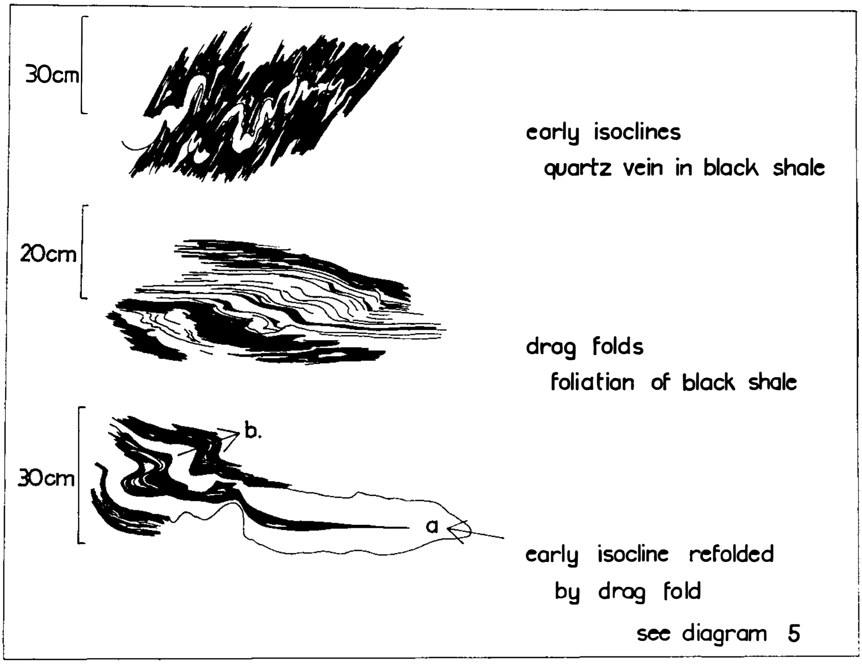


Diagram 7. Minor structures in the black shales from Nøklan, traced from photographs.

2. *Drag folds of the major anticline*

These are typically developed in the shale horizons of the Quartzite Series (Diagram 7). In both their sense of overturn and their axial direction, where this could be reliably determined, they are related to the formation of the major anticline (Diagram 6).

3. *Concentric folds in quartzites*

The axes of the concentric folds are parallel to the lineation in the quartzites of the N limb of the major anticline, but the relationship of these folds to the others is not known.

4. *Minor folds in quartz veins in Psammitic Schist*

The axis of these folds is parallel to the "rodding" direction in the schist. This folding is only irregularly developed in these veins, in many cases the veins show no folding at all.

5. *Other minor folds*

A number of minor folds do not correspond to any of the above types. In many cases, these would indicate inversion, by the relation of axial plane to bedding. But in an area with such a complicated history, this apparent inversion could be caused by refolding of earlier minor folds. No other evidence for widespread inversion was found.

II. Linear Structures

The following linear structures occur in the Psammitic Schist, and can be seen to be parallel in all exposures where they occur together.

1. "Rodding" of the coarse psammite, sometimes verging on mullion structure.

2. Lineation on surface of quartzose veins.

3. Minor folding of the quartzose veins in 2. type 4. of minor folds.

4. Intense minor folding and eventual formation of "pencils" (to distinguish from "rodding") of quartz within the dislocation zones.

All these structures have a regional axis 12°/298°.

In the Quartzite Group, a lineation is found on the foliation surfaces. On the N limb of the anticline, this lineation is very well developed and has the same general trend as the "rodding" (Diagram 5). The concentric folding of the quartzites is seen to have an axis parallel to this lineation. Hence this lineation and the concentric folds may be associated with the "rodding" in the psammites. However, on the SW limb the lineation, apparently the same in form, is very poorly developed and seems to have a very different orientation (stereonet 8).

The minor folding in the sediments of the Amphibolite Complex, extremely well developed in the limestones, shows an irregular pattern (stereonet 10). Nevertheless, there is a distinct general trend parallel to the regional "rodding" direction.

Relationship to previous work

When the field work was carried out in summer 1959, previous work on the region of the Raipas windows was extremely scanty. With regard to this particular area, the only information available was that, in the area of Klubben, there occurred a contact between the allochthonous «thrust metamorphics» and the autochthonous Raipas and Bossekop series, presumably a major thrust zone. The preceding description is an attempt at an objective account of our findings, and it will be noticed that since the position of a major thrust plane or zone is not obvious, no such major thrust has been mentioned.

Since then, however, three important works have come to our notice: the original field map of ZENZÉN (1915) of the Burfjord area; the "Geology of Norway" (HOLTEDAHL ed 1960) with a description of the present knowledge of the geology of Troms and Finnmark; and a description of an area, including the allochthon-autochthon contact zone, near Talvik, 25 kms. ENE of the present area, by GEUKENS and MOREAU (1960).

The following important facts emerge from the latter work. It is stated that the socalled Alta window is probably continuous with the Kvænangen window, i.e. the thrust zone in Talvik has its direct equivalent in the Klubben area. The division between autochthon and allochthon is placed above the Bossekop Quartzites ("Group de Storvandet") and is a plane of discordance. Directly above this plane lies a grey-white dolomitic limestone, itself overlain by a varied schistose succession characterized by veins of quartz and orthoclase parallel to the foliation (c.f. page 87). HOLTEDAHL (1918, 1922), also in the Alta region, has placed the autochthon-allochthon division between quartzite and dolomite.

In the present area, the succession quartzite-dolomite-dark shale is completely conformable and considered in isolation there is no reason to put a major tectonic plane between quartzite and dolomite. The only plane which can be said to represent a major division is the Quartzite Series- Psammitic Schist contact and this is incorporated tentatively as such in the following geological history. But this problem will only be solved when the whole region is known in detail.

Geological History

The following is the tentative history of the area studied, with an attempt to incorporate the structural geology just described.

1. Deposition of argillaceous and carbonate-bearing sediments (part of the Raipas supergroup).

2. Intrusion of thick sheets of basic magma, giving a series of dolerites, in places the rock being coarse-grained enough to be called gabbro (= "Epi-Raipas" of Zenzén, here called together with the sediments, the Amphibolite Complex). Contact metamorphism of in-

truded sediments giving glass patches in shale and possibly forming scapolite in an impure limestone.

3. Low-grade regional metamorphism with some folding. Certain non-metamorphosed dolerites may have been intruded towards the end of this phase.

4. Erosion, followed by deposition of the Quartzite Group (Bossekop quartzite of Eocambrian age); a quartzite succession with basal conglomerate and intercalated black and green shales, followed by a thick pure dolomite and an argillaceous series.

5. Movements causing isoclinal folding and foliation in the Quartzite Group. Possibly the dislocation metamorphism of the Amphibolite Complex is a response of more massive and irregular rocks to these same movements (isoclinal folding found in mylonite).

6. Initiation of major anticline.

7. Overthrusting of the Psammitic Schist (the thrust metamorphic Complex) which had already undergone the following history:

   a. Deposition of coarse felspathic sandstone (mainly Eocambrian).
   b. Metamorphism and movements resulting in isoclinal folding and a coarse foliation,
   c. Formation of two sets of quartzose veins at a small angle to each other,
   d. Movements causing intense "rodding" and minor folding and lineation of quartzose veins,
   e. ?Overthrusting (as (7) above), causing granulation and sericitization towards the thrust plane and the formation of many minor dislocation planes within the psammite. This may be a late stage results of the same movements (d) since lineation directions in the schistose rock and "pencils" in the dislocation zones are parallel to the "rodding".

8. Folding of the Quartzite Group- Psammitic Schist contact.

9. Erosion, including recent glaciation, to expose the core of this compound anticline.

Acknowledgements

The expedition was financially supported by the Carnegie Trust and the Cross Fund and it is through these that the work has been possible. Our thanks are due to all the staff of the Grant Institute of

Geology, Edinburgh, for their help and guidance, particularly to Dr. M. R. W. Johnson and Dr. E. K. Walton for critical reading of the script, and to Dr. M. J. O'Hara for refractive index determinations. Also, we received with gratitude many useful suggestions from Professor O. Holtedahl, Oslo, and Professor E. Wenk, Basel.

BIBLIOGRAPHY

CARSTENS, H. 1955: "Note on epidote in green schists". Norsk Geol. Tidsskr. bd. 35, p. 158—161.

EDWARDS, A. B. and BAKER, G. 1953: "Scapolitization in the Cloncurry District of NW Queensland". Jour. Geol. Soc. Aust. Vol. 1, p. 1—35.

EHLERS, E. G. 1953: "Stability relations of Al-Fe members of the epidote group". Jour. Geol. Vol. 61, No. 3, p. 231—251.

FYFE, TURNER and VERHOOGEN 1958: "Metamorphic reactions and facies". Mem. Geol. Soc. Am. No. 73.

HOLTEDAHL, O. 1918: Norges Geol. Unders. Nr. 84.

HOLTEDAHL, O. and ANDERSEN, O. 1922: "Om Norske Dolomiter ...". Norges Geol. Unders. Nr. 201, pp. 107.

KVALE, A. 1947: "Structural geology of Bergsdalen Quadrangle, W. Norway". Bergens Museums Årbok 1946—47, pt. II.

— 1953: "Linear structures and their relation to movement in the Caledonides of Scandinavia and Scotland". Q.J.G.S. Vol. 109, p. 51—.

LINDSTRÖM, M. 1958: "Toward a further hypothesis on the Scandinavian Caledonides". Geol. Fören. Stockholm Förhandl. Nr. 495.

PEACH, B. N. et al 1911: "Geology of Knapdale, etc." Mem. Geol. Surv. Scot. No. 28.

READ, H. H. 1923: "Geology of Banff, Huntly and Turriff". Mem. Geol. Surv. Scot. Nos. 86, 96.

REITAN, P. H. 1958: "Structure in the area of mineralization of Repparfjord, Finnmark". Norges Geol. Unders. Nr. 203.

— 1960: in "Geology of Norway" (Holtedahl ed.). Norges Geol. Unders. Nr. 208.

STRAND, T. 1952: "Raipas og kaledon i strøket omkring Repparfjord, Vest-Finnmark". Norges Geol. Unders. Nr. 183, p. 22—31.

SUNDIUS, N. 1915: "Beiträge zur Geologie des Südlichen Teils des Kirunagebiets". Vetens. Prakt. Unders. Lappland. Nr. 4.

TILLEY, C. E. 1938: "Status of hornblende in low grade metamorphic zones of green schists". Geol. Mag. No. 893.

TRÖGER, W. E. 1952: "Tabellen zur Optischen Bestimmung der gesteinsbildenden Minerale". Stuttgart.

VINCENT, E. A. and PHILLIPS, R. 1954: "Iron-titanium oxide minerals in layered gabbros of Skaergaard intrusion, E. Greenland". Geochim. Cosmo. Acta Vol. 6, No. 1.

VOGT, T. 1927: "Sulitelmafeltets Geologi og Mineralogi". Norges Geol. Unders. Nr. 121.

WINCHELL, 1951: "Elements of Optical Mineralogy". London, Chapman and Hall, pt. 2.

WISEMAN, J. D. H. 1934: "Central and SW Highlands epidiorites". Q.J.G.S. Vol. 90.

ZENZÉN, N. 1915: Unpublished field map of Kvænangen window kindly lent by Professor O. Holtedahl.

Manuscript received October 15, 1961.
Printed May 1962.