SVERIGES GEOLOGISKA UNDERSÖKNING

SER C NR 622 AVHANDLINGAR OCH UPPSATSER ÅRSBOK 61 NR 7

NILS EDELMAN

STRATIGRAPHY AND METAMORPHISM IN THE KRISTINEBERG AREA

NORTHERN SWEDEN

STOCKHOLM 1967

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Editor: Per H. Lundegårdh
C. DAVIDSONS BOKTRYCKERI AB, VÄXJÖ

CONTENTS

SUMMARY

The Kristineberg area forms the SW corner of the Skellefte schist belt in northern Sweden. Structurally it is composed of two anticlinoria with westerly plunging axes. The uppermost phyllite formation is compressed between the anticlinoria, but also occurs as undeformed, westerly dipping layers over the folds. Thus the area offers a good illustration of different tectonic styles at different levels of the earth's crust (Stockwerktektonik according to Wegmann).

The stratigraphical sequence in the present area is as follows, the youngest formation uppermost:

phyllites
amphibolites
graphite schists
acid volcanic formation
gneisses

This sequence fits well with the older stratigraphy of the Skellefte schist belt (Högbom 1937, Gavelin-Grip 1946) but in many respects it agrees well also with the stratigraphy proposed by Kautsky (1957). The gneisses in the core of the S anticlinorium were formerly called Jörn granite but are now interpreted as metamorphosed supracrustal, probably sedimentary, rocks.

A special problem is presented by sericitization and chloritization which occur in a zone underlain and overlain by rocks with parageneses of the amphibolite facies. The greenschist zone represents according to the facies principle a lower temperature of formation than that of the surrounding rocks. Two explanations are proposed. The first is that the border of the stability field of chlorite has been raised by an increasing partial pressure of water. The other is that the sericitizing, and chloritizing fluids expanded when reaching the strongly schistose rock and through the Juole-Thomson effect cooled the country rock. Probably both these factors have co-operated to change the metamorphic facies of the rocks.

The observed chronological order of the geological events in the area shows that the regional sericitization, and chloritization principally took place during the formation of the first generation of cleavage and had nearly ceased before the formation of the second generation of cleavage, which mainly appears as a bending of the first cleavage. An aplite, basic dikes, and quartz-tourmaline veins were intruded after the formation of cleavage II but before the emplacement of the complex sulphide ores. Hence the time interval between the regional sericitization and the emplacement of the ores is so great that a genetical connection between the two seems quite improbable. The two cleavages have, however, offered a multitude of joints as channelways for all kinds of fluids and this may explain the fact that the ores and the sericitization preferred the same rocks.

PREFACE

The Kristineberg area forms a southwesterly corner of the Skellefte schist belt in Northern Sweden. Several ores and ore prospects have been found in this area and at present two mines are in production. In connection with the discovery of the Kimheden ore Bolidens Gruvaktiebolag (Boliden Mining Co) decided to make a new survey of the area including geological mapping as well as magnetic, and electromagnetic mapping from the air. The here presented map and this paper give some results of this investigation. A preliminary report concerning the structural geology has already been published (Edelman 1963, 1965 b). The field work was carried out during the summers of 1962 and 1963. A limited area around the Kimheden ore was mapped in detail in the summer of 1960 by Mr C-A Larsson, Fil. kand. Messrs H Brännström, G Holmgren, A Stenlund, and F Widmark have assisted in the field work.

The work has been much facilitated by all older investigations in the present area. Especially Du Rietz's (1953), and Gavelin's (1955) papers have been of great importance. These scientists solved all the fundamental problems of the area and the present study has only brought about minute corrections to the map. The airborne geophysical mapping has given some new details and the petrographic study has resulted in a reinterpretation of some gneisses. The metamorphic history of the area presented below seems to be the only novelty which can justify the publishing of the present paper.

I will herewith express my thanks to all my coworkers. I will also express my gratitude to Mr Erland Grip, chief geologist of the Boliden Mining Co for his inspiring interest in this investigation and for allowing the results to be published. Mrs Leena Kiiskilä has drawn the figures and Mr Peter Padget, Ph. D., has corrected the language.

OUTLINE OF GEOLOGY

The Kristineberg area is an extension to the SW of Skellefte schist belt in northern Sweden. It is surrounded by potash granites on most sides and is connected with the main schist belt by only two zones in the N and NE. The granite in the E, S, and W belongs to the large Revsund granite massif of southern and central Norrland, whereas the small massif in the North has been assigned to the younger granite group of Sorsele and Adak.

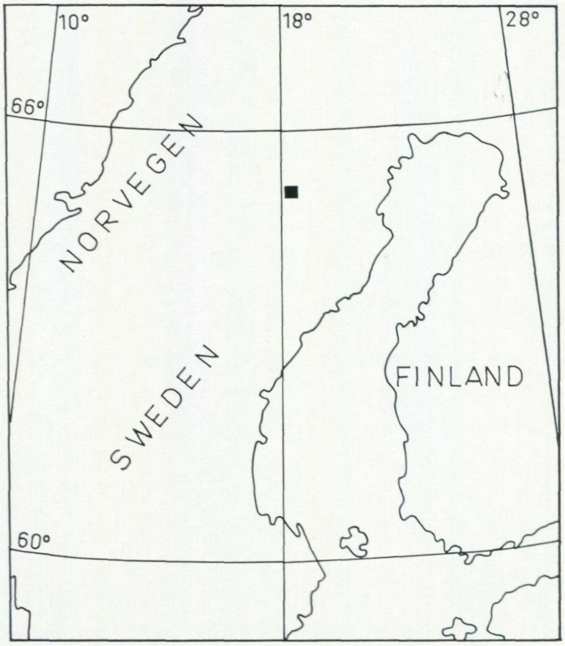

Fig. 1. Position of the Kristineberg area.

The supracrustal rocks, i. e. the rocks primarily formed upon the earth's surface, form two anticlinoria with moderately to flatly plunging westerly axes. The stratigraphical sequence in the anticlinoria is the following, the youngest formation uppermost

phyllites
amphibolites
graphite schists
acid volcanic formation
gneisses

The degree of metamorphism is, as a rule, high but primary sedimentary and volcanic structures are locally comparatively well preserved. The phyllites being the uppermost formation commonly show rather weak signs of metamorphism. The sericite-chlorite schists are the results of two, possibly three alterations. They were first affected by the regional metamorphism, thereafter by metasomatic sericitization, and chloritization, and in the S by the formation of andalusite, and cordierite. The gneisses of the core of S anticlinorium were formerly interpreted as gneissose granites belonging to the Jörn granite group but in this paper they are interpreted as metamorphic supracrustal rocks, probably of sedimentary origin.

Besides the above-mentioned potash granites infracrustal rocks are rare. Minute massifs of differentiated gabbro-diorites in the phyllites could possibly be subvolcanic intrusives. Two poorly exposed zones of ultrabasites can easily be followed on the magnetic maps. In the core of the S anticlinorium there is an elongated aplite massif which is cut by amphibolitic dikes and brecciated by quartz-tourmaline veins. Younger than all these are the sulphide ores. The problems of the age relations of the infracrustal rocks cannot all be solved because the necessary contact relationships are not all present in the area.

PETROGRAPHY

GNEISSES

The gneisses of the cores of the two anticlinoria are different in some respects and will therefore be treated separately. Those of the S anticlinorium occupy a part of the area formerly marked on the maps as Jörn granite, a synorogenic granite. In this granite were, however, included sericite, and chlorite schists as the contact was drawn along the border of a weak magnetic anomaly. It has, however, been possible to draw some sections of the contact rather accurately using petrographic differences between adjacent exposures. This petrographic contact cuts the magnetic anomaly which makes sharp anticlines to the W.

The N anticlinorium also has a core of gneisses as well as a magnetic high. The core is here, however, so poorly exposed that it has been impossible to determine the borderline between the gneisses of the core and the overlying volcanic formation. Therefore there has been no other choice than to draw the border along the outer limit of the magnetic anomaly. The borders of the gneiss cores of the two anticlinoria are hence drawn according to quite contradictory principles but the lack of exposures might justify this inconsistency for the present.

Core of the N anticlinorium

The gneisses of the core of the N anticlinorium are as a rule banded. There is a considerable variation in the mineralogical composition ranging from that of a mica schist over different types of gneiss to that of amphibolite. The lack of exposures makes it difficult to get a correct picture of this varying formation. Here can only be described some types without stating which is the dominating one.

The gneisses are medium- to fine-grained and granoblastic or porphyroblastic. The principal minerals are quartz, plagioclase, and biotite. Quartz is absent in the amphibolites and plagioclase in the mica schists. Microcline has only been found in two slides in small amounts. Garnet is common in some types generally as porphyroblasts. A special type consists almost entirely of cordierite porphyroblasts with numerous inclusions of biotite, quartz and other minor constituents. In this type feldspar is absent. A layer of skarn consisting of epidote and quartz has been found. Common alteration products are chlorite and sericite. Ore minerals and apatite are accessories.

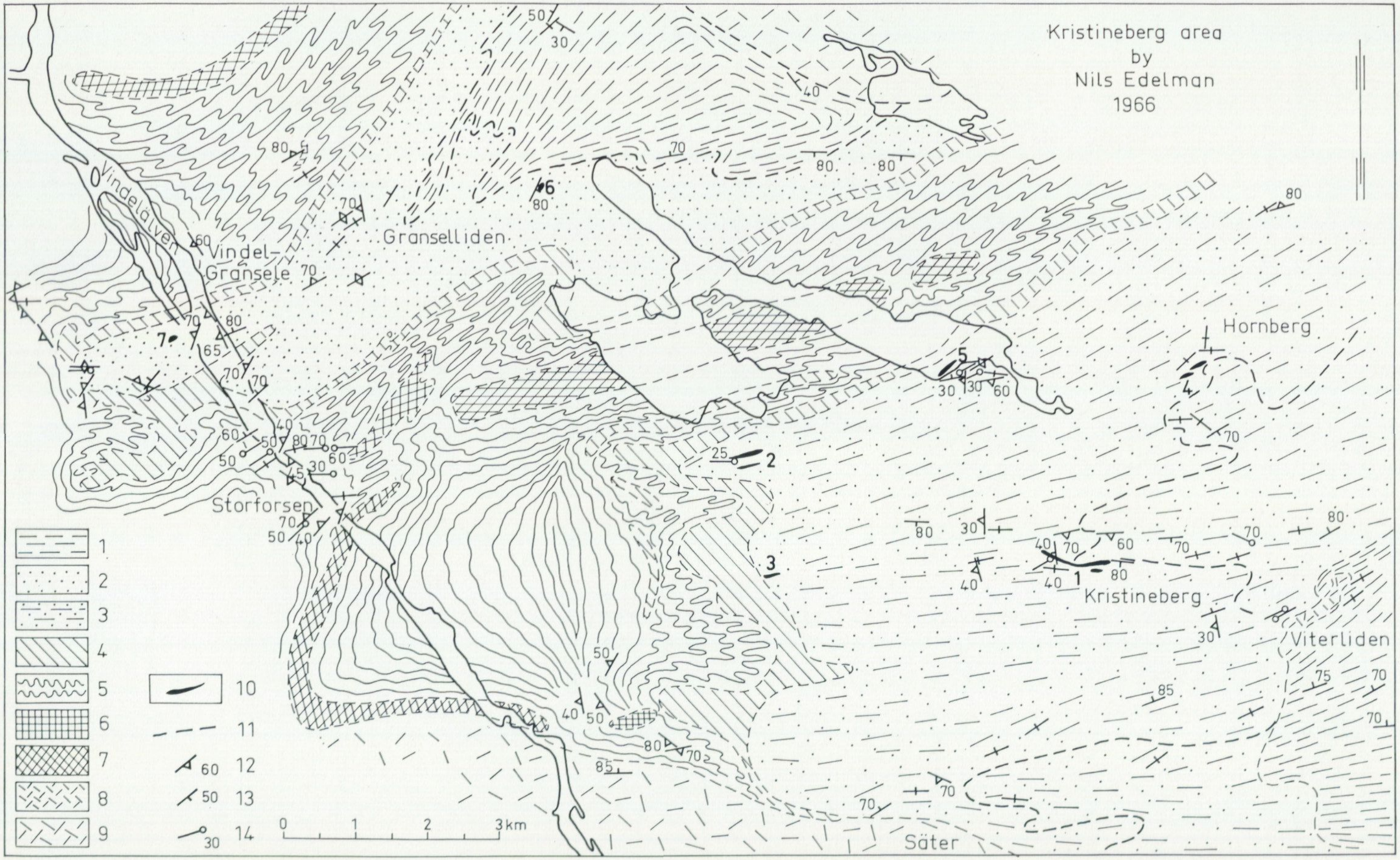

Fig. 2. Geology of the Kristineberg area. 1 gneisses, 2 acid volcanic formation, 3 acid volcanic formation strongly sericitized and chloritized, 4 amphibolites, and graphite schists, 5 phyllites, 6 gabbros, 7 ultrabasites, 8 aplite, 9 granite, 10 sulphide ores, 11 border of magnetic anomaly, 12 bedding, 13 schistosity or cleavage, and 14 fold axis. The ores or ore prospects are 1 Kristineberg, 2 Rävlidenfältet, 3 Rävliden, 4 Kimheden, 5 Hornträskviken, 6 Granlunda, and 7 Vindelgransele.

The composition as well as the banded structure indicate a supracrustal origin for both gneisses and mica schists. Most of them have seemmingly been graywackes, or clays. The amphibolites again have, in all probability, been basic volcanic layers.

Core of the S anticlinorium

The gneisses of the core of the S anticlinorium differ in some respects from the gneisses of the N anticlinorium. They are well exposed in the hill of Viterliden and one gets therefore a more representative idea than is the case for the gneisses described above.

The gneiss of the S anticlinorium appears to be rather homogeneous. Thin zones of chlorite schist, broken bands of bedded gneisses, and rows of folded skarn fragments occur as inhomogeneties. The gneiss is grey, and schistose and looks megascopically like a gneissose granite. Formerly it was interpreted as a deformed granodiorite belonging to the so-called Jörn granite group. In the present paper it is, however, interpreted as a metamorphosed supracrustal rock.

The principal minerals of the gneiss are plagioclase, quartz, biotite, and often also hornblende. Epidote, which is abundant in the skarn inclusions, occurs in the gneiss only as an alteration product like chlorite and sericite. Opaque minerals are the most common accessory minerals whereas apatite and titanite are met with in only a few slides.

The gneiss is as a rule porphyroblastic with porphyroblasts or aggregates of plagioclase, hornblende, and biotite in a fine-grained matrix of plagioclase, and quartz (Fig. 3). In only a few slides is the texture to some extent blastohypidiomorphic. Plagioclase commonly forms porphyroblasts full of inclusions. Straight rows of small quartz grains can, in one slide, be followed through several plagioclase porphyroblasts. Hornblende, which occurs principally in the inner or E part of the gneiss core, forms also regular porphyroblasts or aggregates. Biotite forms lens-shaped aggregates but occurs also as small grains in the matrix. Quartz occurs in the matrix and sometimes also as big granulated grains.

On the basis of the megascopic features and the field relations it is difficult to decide whether the gneiss has been a granite or a sediment with graywacke composition. The bulk composition may resemble that of a granodiorite but the lack of typical accessory minerals does not favour a magmatic interpretation. The microscopic texture of the gneiss gives a rather clear indication of a supracrustal origin. The fine-grained matrix points to a still more fine-grained primary rock because grains as a rule grow coarser during the metamorphism. A granodiorite in a massif more than 10 kilometres across can scarcely have been very fine-grained from the beginning and it can hardly have been entirely mylonitized. Therefore the gneiss has, in all probability, been a fine-grained supracrustal rock, seemingly a clay or a siltstone belonging to the graywacke suite. This gneiss has the same stratigraphical position as the gneiss core of the N anticlinorium and as the Maurliden schists

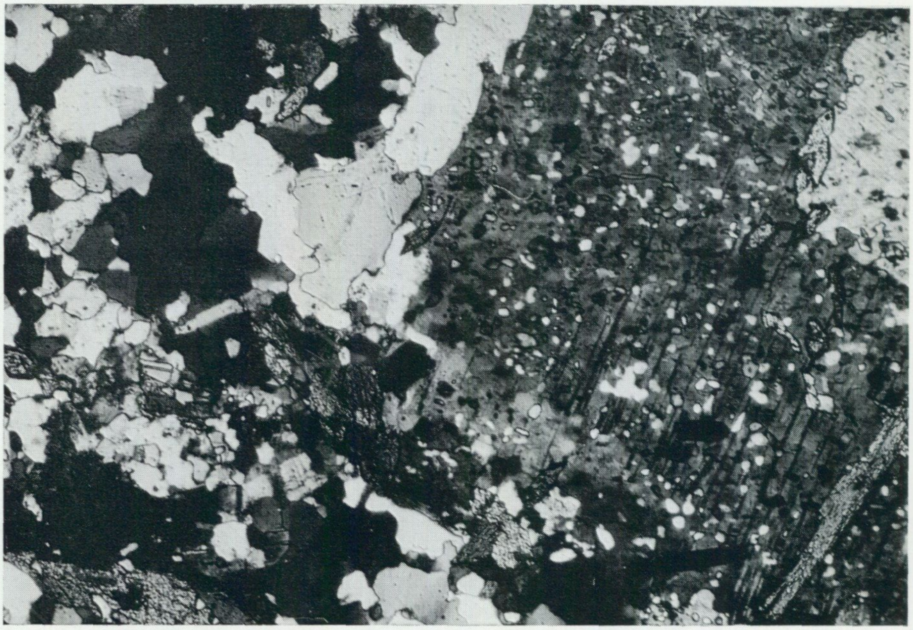

Fig. 3. Gneiss with plagioclase porphyroblasts in a fine-grained matrix. Exposure outside the map area, E of Viterliden. Crossed nicols. 35x.

(Maurlidenschiefer) in Kautsky's (1957) stratigraphical scheme for the Skellefte district. Many different observations and considerations, therefore, favour a supracrustal origin the gneiss and even if none is conclusive proof in itself together they make this interpretation very probable.

ACID VOLCANIC FORMATION

Over the gneisses follows a series of acid metamorphic rocks, the so-called volcanic series of the Skellefte district (Gavelin & Grip 1946) or Maurliden volcanics (Maurlidenvulkanite, Kautsky 1957). The degree of metamorphism is very different in the two anticlinoria; in the N one the rocks are, as a rule, fine-grained gneisses whereas in the S one they have been transformed into sericite or chlorite schists. Relict textures indicating a volcanic origin are, in the present area, comparatively rare. Some observations point to a sedimentary origin for some schists.

The N anticlinorium

The rocks belonging to this formation in the N anticlinorium are as a rule, fine-grained light grey gneisses. They consist commonly of plagioclase, quartz and biotite. Sericite is a common alteration product whereas chlorite is rare. Microcline and hornblende occur in some types, though not together. Epidote, hornblende, biotite and plagioclase are the main minerals of some intercalated skarn layers or inclusions. Opaque minerals and apatite have been found as accessories.

These gneisses are commonly granoblastic, and more or less schistose. Plagioclase sometimes forms bigger grains giving an impression of old phenocrysts but they may perhaps be porphyroblasts. Angular grains of quartz occur in some gneisses. The schistosity often curves around the big grains and this fact indicates that these grains are older than the schistosity or at least older than the last movements. Some kind of banding, probably a relict bedding, can often be observed in the gneisses.

The gneisses belonging to this formation seem to have a different origin. Those with blastoidiomorphic plagioclase grains seem, with great probability, to be metamorphic volcanics with a keratophyric composition whereas those with angular quartz are more likely to be metamorphic arkosic silts. It is difficult to decide the ratio of sedimentary rocks to volcanics in this formation owing to the fact that most of the rocks in question have lost their primary textures through metamorphism.

The S anticlinorium

The rocks belonging to this formation show, in the S anticlinorium, very divergent degrees of metamorphism. The best preserved rocks are the porphyritic keratophyres which in the Kristineberg mine, for example, form rather thick sequences. They are fine-grained with plagioclase phenocrysts often surrounded by granophyric rims. Also spherulitic types have been found among the keratophyres (Fig. 4). The

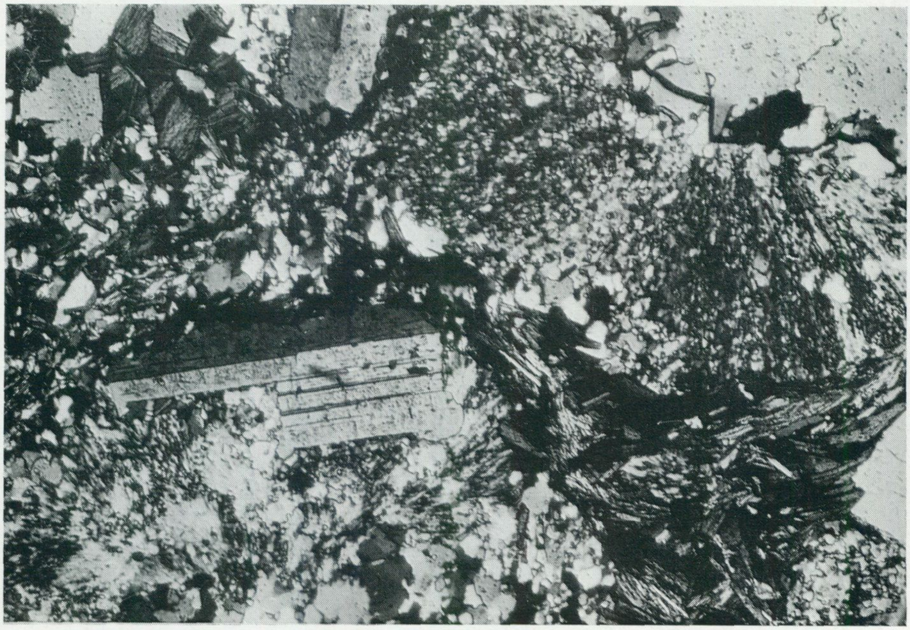

Fig. 4. Keratophyre with spherulites. In the vicinity of Kimheden ore. Crossed nicols. 35x.

matrix consists of plagioclase, quartz and biotite. As alteration products occur chlorite, sericite and sometimes epidote. Opaque minerals and apatite are accessories.

Well preserved volcanics are, however, exceptions and the dominating rocks are sericite and chlorite schists. They are strongly schistose and as a rule medium-grained. The mineral composition is rather monotonous with quartz, sericite and/or chlorite. Plagioclase, and biotite occur in some slides as relicts. Tourmaline has been found in a number of slides. In a sericite-chlorite schist from the 490 metre level in the Kristineberg mine anhydrite occurs as porphyroblasts dispersed in the rock (Fig. 5). An X-ray powder diagram (made by prof. K. J. Neuvonen) gives somewhat displaced reflections indicating that Ca to some extent might be replaced by other ions. Anhydrite is the youngest mineral in this rock and it has seemingly originated in connection with the formation of the sulphide ore in the vicinity.

It is possible to distinguish between sericite-rich and sericite-poor schists and of course also chlorite-rich schists although there are intermediate types of all kinds. The sericite-poor schists consist principally of quartz and they are at least in some cases intercalated with and folded together with sericite-rich types. This fact indicates that the differences in mineralogical and bulk composition are probably primary differences and that the sericite-poor types could be metamorphic quartzose rocks probably of sedimentary origin. The chlorite-rich schists represent rocks with a more basic primary composition. One is inclined to interpret them as metamorphic derivatives of andesitic or basaltic volcanics intercalated in the sequence of acid volcanics and sediments (Fig. 7).

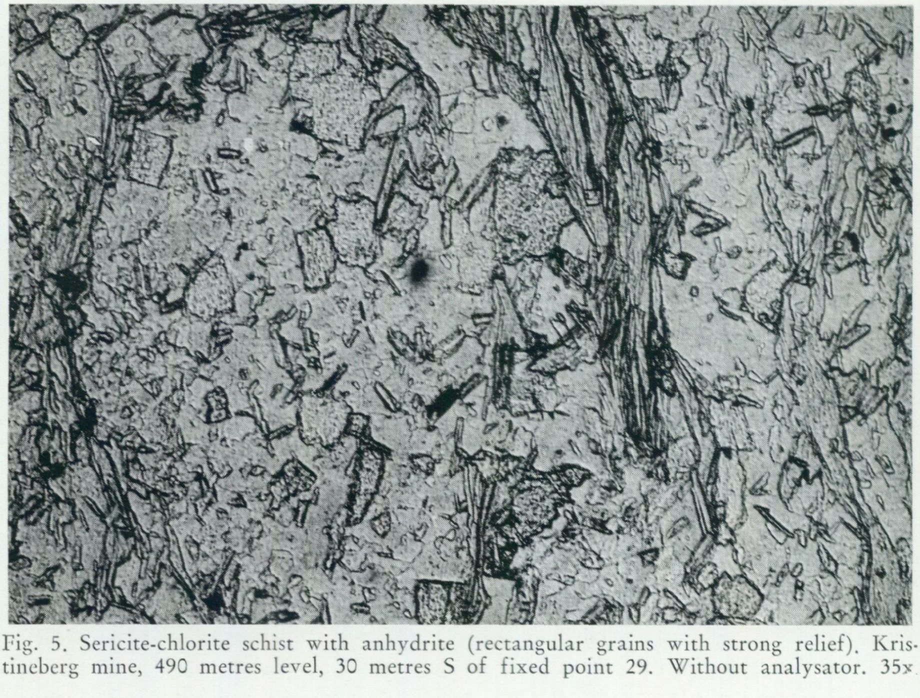

Fig. 5. Sericite-chlorite schist with anhydrite (rectangular grains with strong relief). Kristineberg mine, 490 metres level, 30 metres S of fixed point 29. Without analysator. 35x.

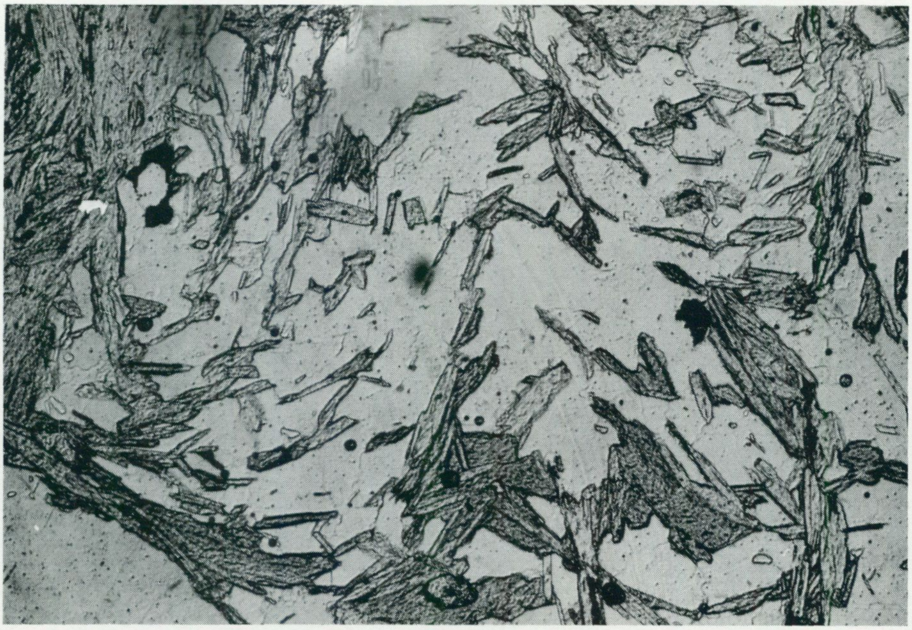

Fig. 6. Chlorite-sericite schist. The older curved schistosity cut by a younger cleavage. N slope of Viterliden hill. Without analysator. 35x.

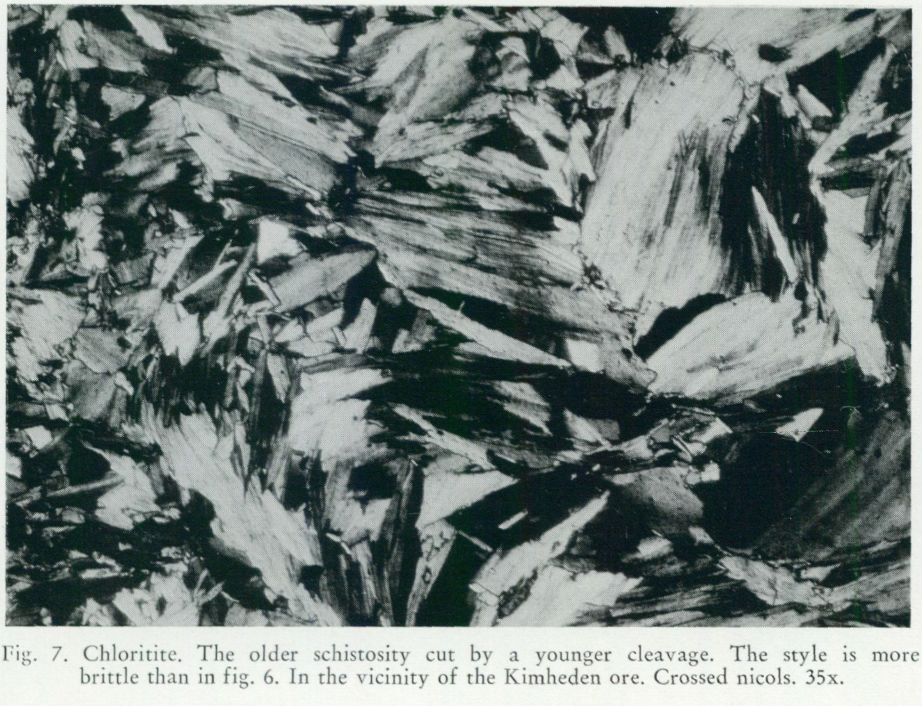

Fig. 7. Chloritite. The older schistosity cut by a younger cleavage. The style is more brittle than in fig. 6. In the vicinity of the Kimheden ore. Crossed nicols. 35x.

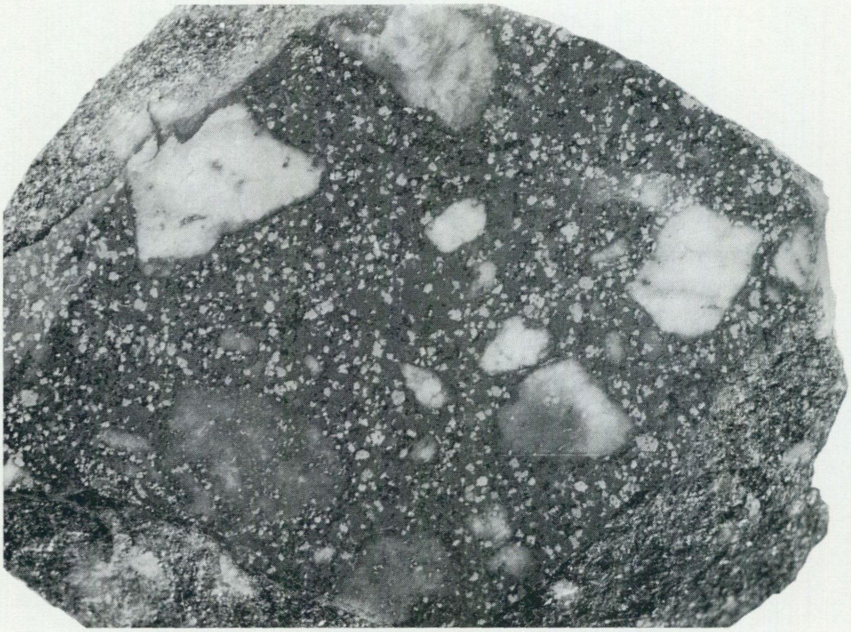

Fig. 8. Breccia with angular fragments of limestone in a compact sphalerite ore. The Sture ore, Rävlidenfältet mine. About natural size.

Limestone layers in the volcanic series have been found in the Rävlidenfältet mine. The Sture ore in this mine has partly replaced, partly intruded and brecciated (Fig. 8) a strongly folded limestone layer. Although limestone can originate through volcanic activity, most limestones of the world are sedimentary and therefore one is more inclined to interpret the present limestone as sedimentary rather than volcanic.

In the area between Kristineberg and Säter the sericite schists commonly contain such minerals as andalusite, and corderite as already pointed out by Du Rietz (1953). These minerals form, as a rule, porphyroblasts. The andalusite grains show folds conformable with the surrounding folded sericite in the schist but they do not show any signs of deformation the extinction being simultaneous in all parts of the grains (Fig. 9). Andalusite is traditionally an antistress mineral and also for this reason such a strong folding is very improbable. The andalusite must therefore have crystallized as pseudomorphs after folded sericite and hence after the folding of the schist, probably in connection with the emplacement of the Revsund granite as pointed out by Du Rietz (1953). Owing to the very uneven distribution of the exposures it has not been possible to trace the zone of andalusite- and cordierite-bearing schists along the contact of the granite. Andalusite occurs in the schists about 1 kilometre from the contact, cordierite about 2—3 kilometres from it. Hence, andalusite seems in this area to represent a higher temperature than cordierite if these minerals formed as a result of the thermal metamorphism caused by the granite. But differences in the primary composition may explain the distribution of these minerals equally well. In some rocks of the same zone plagioclase and microcline have grown prophyroblastically instead of andalusite. The plagioclase porphyroblasts sometimes form laths with an excellent crystal shape although they are full of inclusions (Fig. 10). The formation of feldspars may depend on differences in the primary bulk composition of the rocks and on a possible metasomatic supply of alkalies.

GRAPHITE SCHIST — AMPHIBOLITE ZONE

Over the volcanic formation in both the anticlinoria follows a narrow zone consisting of graphite schists and amphibolites. This zone is rarely exposed but can be followed on the geophysical maps because the graphite schists cause strong electromagnetic anomalies and the amphibolites magnetic ones. The magnetic anomalies are continuous whereas the electromagnetic anomalies which lay stratigraphically below the magnetic ones are interrupted in many places. This shows that the incompetent graphite schists have been compressed to lenses. In the crests of the anticlines the anomalies are abnormally broad depending partly on the gently plunging

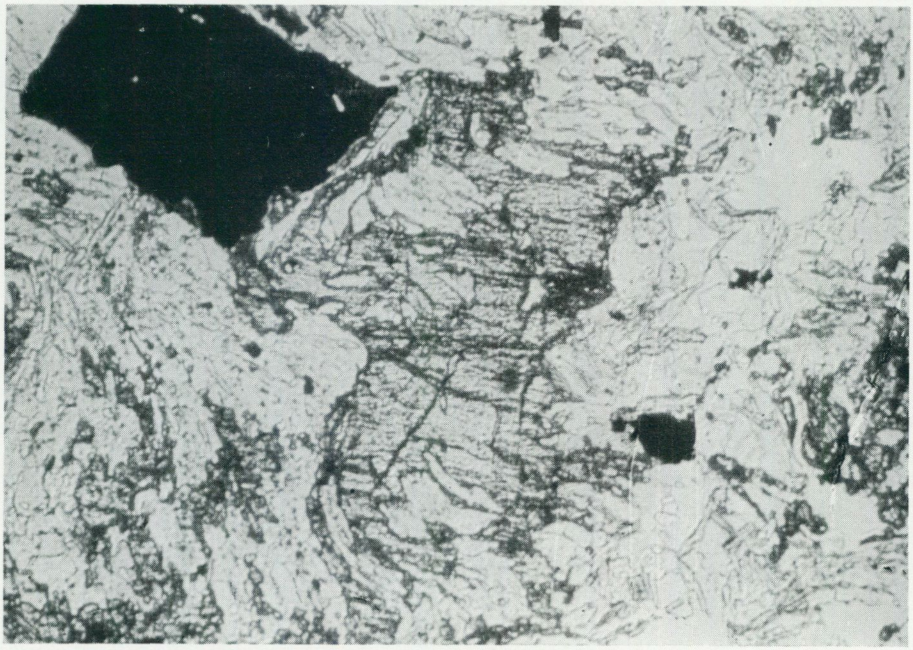

Fig. 9. Sericite schist with andalusite porphyroblasts showing curved shapes conformable with the folded sericite. Simultaneous extinction in the whole grain indicates crystallization after deformation. Exposure 2,8 kilometres N of Säter near to the road to Rävliden. Without analysator. 35x.

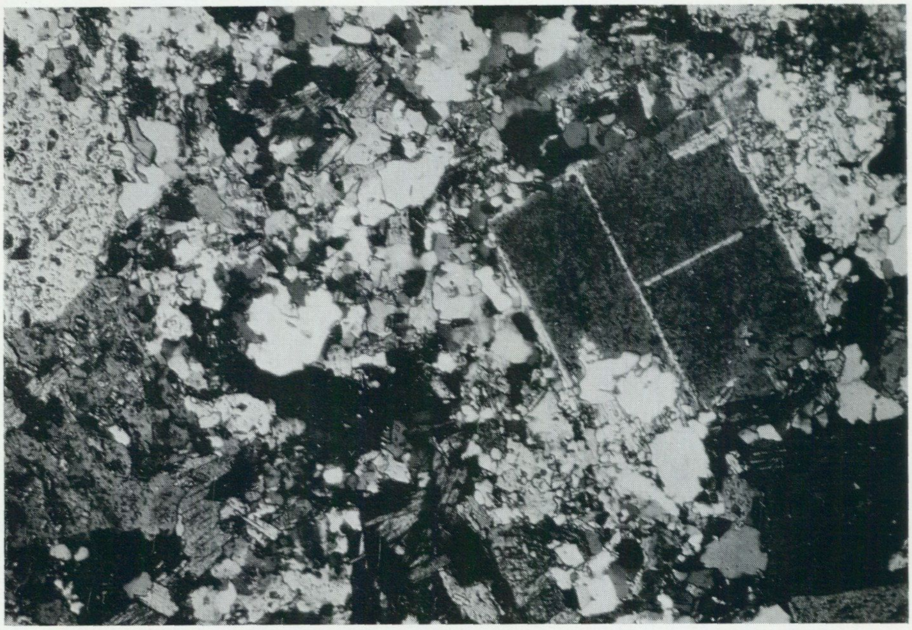

Fig. 10. Plagioclase porphyroblasts in a gneiss in the sericite schist area. About 2 kilometres N of Säter. Crossed nicols. 35x.

axis and partly on the incompetency of the graphitic schists. Stratigraphically the graphite schists correspond to the "Petikträskschiefer" and the amphibolites to the "Skogshedenvulkanite" in Kautsky's scheme.

The graphite schists are exposed only in the Rävlidenfältet mine and in drill holes and they have not been examined microscopically. The amphibolites are best exposed in the area W of the river of Vindelälven. They are commonly fine-grained with a granoblastic or porphyroblastic texture. In some slides a blasto-porphyritic or blasto-ophitic texture is visible. The mineral composition of the amphibolites is monotonous with hornblende and plagioclase as the main constituents. As minor constituents, or as alteration products occur biotite, chlorite and rarely calcite. Opaque minerals, apatite and titanite are accessories.

PHYLLITE FORMATION

Over the amphibolite formation follows a thick formation of well preserved schists of phyllites. The bedding is as a rule recognizable, often well preserved, and only in the part which lies between the two anticlinoria obscured or destroyed by the schistosity. The phyllites are almost without exception thin-bedded. In some cases the bedding is not easily visible because the differences in colour and grain-size between adjacent beds are small but in exposures along the Storforsen rapid the bedding is often well marked by thin layers or lenses of fine-grained quartz. These thin quartz layers make it easy to follow the single beds even when they are folded, or dislocated along the cleavage surfaces. Also the alternation of homogeneous and schistose type layers shows, in many cases, distinctly the bedding, especially on the shore exposures.

The phyllites can be divided into two groups on the basis of the composition viz. phyllites *sensu stricto* consisting of quartz and mica and graywacke phyllites consisting of quartz, feldspars, micas and chlorite (Figs. 11—13). The phyllites proper are generally even-grained, and very fine-grained, granoblastic and often schistose. The graywacke phyllites again are somewhat coarser, with irregular grain-size often containing bigger angular grains of quartz, feldspar and rock fragments. The recrystallization is not so complete as in the true phyllites, the bigger grains retaining their primary, often angular shape. The texture of the graywacke phyllites is in general blastoclastic. It is often difficult to distinguish between the true phyllites and the graywacke phyllites in the field and therefore it has not been possible to decide whether these two rocks form separate formations or occur as more or less alternating layers throughout the whole formation. The uneven distribution of the exposures makes it impossible to solve this question with certainty but the fact that the true phyllites as well as the graywacke phyllites have been observed in different parts of the present area which, however, covers only the lowermost part of the phyllite formation, indicates that these two types of sediment have been deposited alternatingly.

Fig. 11. Folded phyllite. The folding of the bedding fissility is the incipient stage of the formation of a younger cleavage. Shore of the Storforsen rapid. Without analysator. 175x.

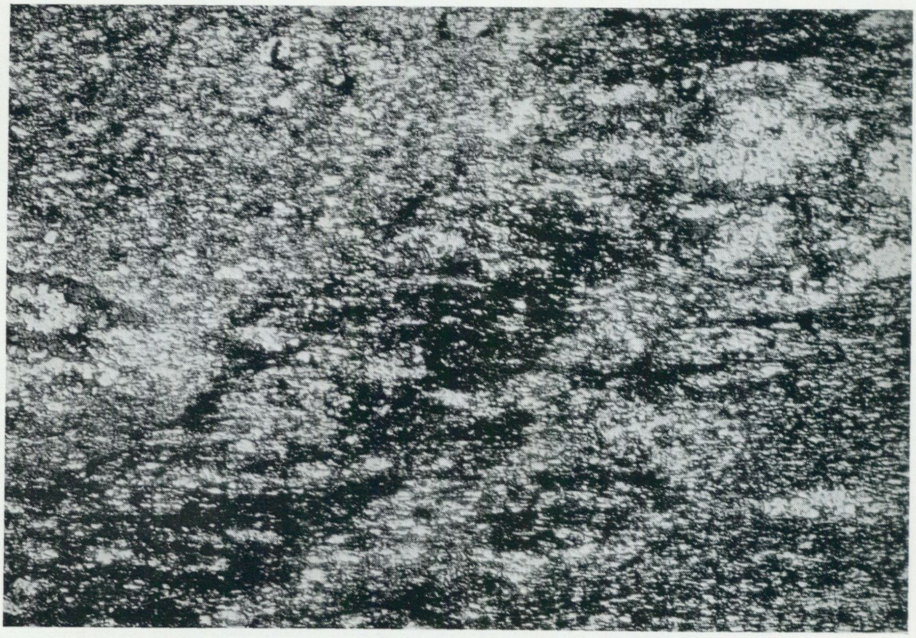

Fig. 12. Phyllite. The bedding which cuts the photo diagonally is transected by an axial plane schistosity. Storforsen rapid. Without analysator. 175x.

Fig. 13. Graywacke phyllite. Storforsen rapid. Crossed nicols. 35x.

The phyllites consist of quartz and biotite or sericite some of them being rather poor in mica. The biotite is commonly to some extent chloritized. It is generally so fine-grained that it is very difficult to distinguish it from stilpnomelane but the bigger flakes do show the caracteristics of biotite e. g. mottled extinction, bent flakes, and 2V distinctly greater than 0°. Furthermore they show no cleavage normal to the base and this cleavage is a characteristic of stilpnomelane. Feldspars occur in some types. Opaque minerals are common accessories and they may be found in considerable amounts.

The graywacke phyllites contain plagioclase sometimes also microcline and chlorite besides the minerals of the true phyllites. Feldspar and quartz commonly form bigger angular grains in the fine-grained matrix (Fig. 13). Calcite, clinozoisite and tourmaline have been found as minor constituents. Apatite and opaque minerals are accessories.

The phyllites are metamorphosed pelites with a varying content of clay minerals. The graywacke phyllites have been poorly sorted sediments or fine-grained graywackes. The thin quartz layers are probably metamorphosed chert bands of either sedimentary or diagenetic origin. The thick phyllite formation with, on the whole, a monotonous composition resembles the flysch or graywacke sediments typical for geosynclines and indicates rapid transport and sedimentation for a long period.

The phyllite formation is stratigraphically and lithologically equivalent to the "Elvabergsschiefer" in Kautsky's scheme (1957). The Elvabergsschists are, according to Kautsky, separated from the basic volcanics by a great hiatus and thick conglomerates. In the present area the lower contact of the phyllite formation is not with certainty exposed but no signs of conglomerate or boulders of conglomerate have been found. Whether there is a disconformity or not between the amphibolites and the phyllites in the present area is an open question.

GABBROS

Small massifs of gabbro and related more acid rocks have been found in the phyllites in the vicinity of the basal contact with the amphibolites. The gabbro above the S anticlinorium seems to be a rather homogeneous hornblende gabbro with the hint of a blasto-ophitic texture, whereas the massif in Granselliden is more heterogeneous with a composition ranging from gabbro to granite. The basic types of the latter massif occur in the S part whereas the granite has been found only in the N part of the northernmost exposure. This distribution agrees well with a gravitative differentiation because the beds and formations face NW in this part of the area.

These gabbros could of course be considered as intrusions related to the Jörn granite but their limited size, the lack of areal connection with Jörn granites, and their position in the phyllites just above the amphibolite formation suggest they could be subvolcanic intrusions during the geosynclinal phase and hence related to the underlying formation of basic volcanics. Also higher up in the phyllite formation on the W shore of the Storforsen rapid a basic lava flow has been found. This shows that the basic volcanic activity has not been restricted exclusively to the phase of amphibolite formation. The blasto-ophitic texture of the S gabbro as well as the eventual crystallization differentiation in the N massif indicate cooling under tectonically quiet conditions and this is a further indication of intrusion during the geosynclinal phase and not under the orogenic phases. The fact that the two massifs lie in weak phyllites explains why the textures have been so well preserved; all tectonic movements have taken place in the phyllites leaving the gabbros more or less intact.

The rocks of these massifs are medium-grained. The texture is granoblastic but shows often signs of an older ophitic, or hypidiomorphic texture. The mineral composition of these gabbros is rather simple: hornblende, plagioclase and biotite. Chlorite, sericite and epidote have been found as alteration products and opaque minerals are the observed accessories. The granite has the best preserved hypidiomorphic texture and it consists of microcline, quartz, biotite and hornblende with minute amounts of epidote and apatite. The high content of microcline is remarkable because microcline is very rarely found in all the rocks of the present area with the exception of the microcline granite.

ULTRABASITES

Only three exposures of ultrabasic rocks have been found but it is easy to follow these rocks on the magnetic maps where they appear as strong anomalies. The S zone is about 15 kilometres long and forms a large anticline. The N limb of this is, according to the magnetic map, broken in three places and one of the fragments between these seems to have been pressed into the schist causing disturbances. The N zone is somewhat shorter and unbroken.

There seems to be a difference in mineral composition between the two zones. The rocks of the S zone are almost entirely serpentinized and chloritized peridotites with remnants of olivine besides secondary amphibole and biotite. Ore minerals occur accessorily. The structure is massive. A slide from the only exposure of the N zone shows a foliated ultrabasite consisting of chlorite, amphibole and opaque minerals.

The ultrabasites appear as sills or sheets probably intruded more or less conformably in the schists. They are hence younger than the schists but older than or contemporaneous with the folding. Especially the breaking up of the S zone shows that the orogenic movements have continued after the hardening of the ultrabasites. The fact that the ultrabasic zones curve is another indication of folding although there is a very small possibility that the ultrabasites could have been intruded along curved and folded bedding surfaces.

APLITE

In the hill of Viterliden there occurs an aplite about 500 metres long and up to 150 metres broad. It seems to lie on the whole in the contact between the gneiss of the core and the sericite schists belonging to the acid volcanics. In the contact against the gneiss the aplite cuts the schistosity of the latter and intrudes it with dikes. Gneiss fragments also occur as inclusions in the aplite. In the N part the aplite seems to have an interfingering contact with the gneiss. Along the SE contact the aplite has reacted with the gneiss to give a 10—20 metres broad zone of hybrid rock with a weak parallel structure. The well exposed NE part of the pale reddish aplite is strongly brecciated by quartz-tourmaline veins which are partly thin and straight, partly broader and folded.

The fine-grained aplite has commonly a texture with rather idiomorphic grains. The albitic plagioclase grains are comparatively well formed laths whereas the quartz fills the interstices. Besides the main minerals plagioclase and quartz the aplite contains often small amounts of biotite, sometimes chloritized, sericite and opaque minerals. Microcline has been found only in one slide and it seems to be the youngest mineral showing a tendency to form porphyroblasts. The hybridic aplite of the SE contact is intersected by obliquely cutting chlorite zones. This hybrid is the only type of aplite in which apatite has been found as an accessory mineral.

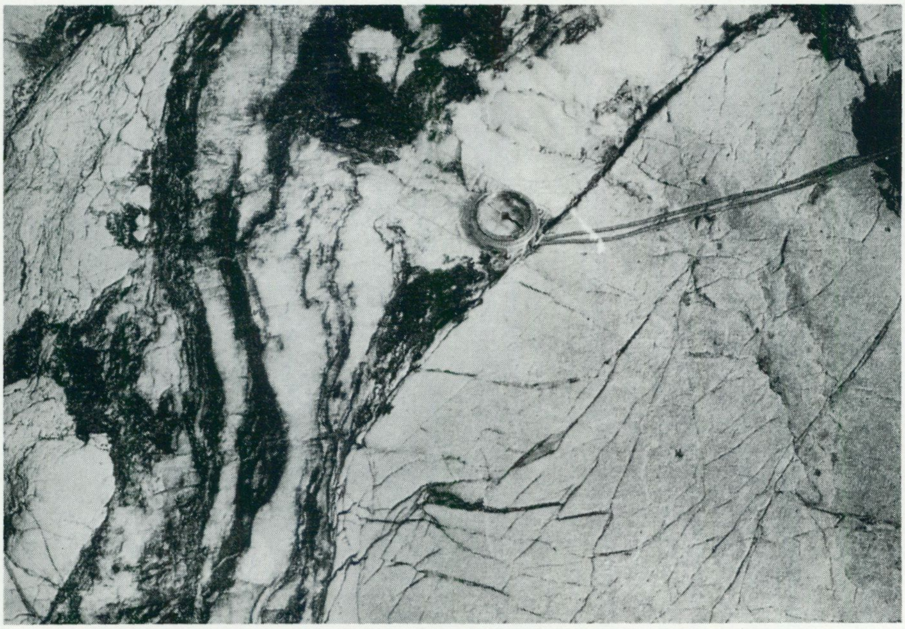

Fig. 14. Aplite with quartz-tourmaline veins. The broad veins are folded whereas the thin veins are rectilinear. Viterliden hill.

The cutting contacts and the dikes as well as the hybridization along the SE contact indicate a more or less magmatic origin for this aplite. The composition with albite as the only feldspar points to a genetic connection with the primorogenic granites which in the Skellefte district have been called Jörn granites. The serorogenic granites e. g. the Revsund granite are, as a rule, rich in microcline. For the present this aplite could preferably be connected with the primorogenic or Jörn granites.

BASIC DIKES

Basic dikes, generally with an amphibolitic composition, are numerous in the well exposed parts of the Viterliden hill. In other parts of the area they are seemingly much rarer or quite lacking. In the Kristineberg mine some basic dikes have been described by Du Rietz (1953).

The dikes strike about SE, exceptionally E and are vertical or steep. They are mostly less than one metre broad. They cut the gneiss, the aplite and the country rocks of the Kristineberg ore but are themselves cut by quartz-tourmaline veins (one observation) and occur as fragments in the Kristineberg ore (Du Rietz 1953).

Several dikes show structures which indicate movements along them. One has a strongly folded contact in biotite and chlorite and containing crystals of tourmaline and irregular aggregations of quartz. Another dike has a parallell structure almost perpendicular to the dike which has been bent and dragged along the NE contact to the NW. A similar drag is seen in the schistosity of the gneiss close to the contact of another dike. In both these cases the SW block has moved to the SE (Fig. 15). Grip (1951) has described movements in the same direaction along joints striking SE in the Kristineberg mine. In the N contact of a dike striking E the curved schistosity of the dike shows a drag indicating that the S block is the upthrown side.

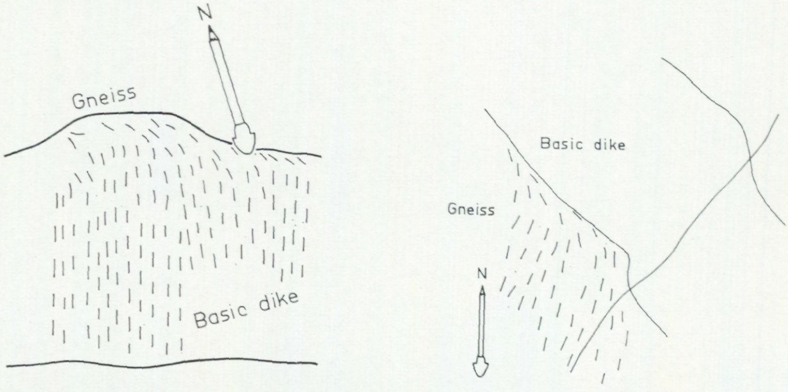

Fig. 15. Sketches of basic dikes. a) A weak parallel structure almost perpendicular to the dike is deflected close to the contact indicating a movement of the SW block to the SE. b) The schistosity of the gneiss is deflected close to the basic dike showing a movement in the same direction as in case a. Viterliden hill.

The basic dikes are granoblastic and fine-grained. They have commonly a more or less pronounced parallel structure. The mineral composition is simple hornblende, and plagioclase being the main constituents. Biotite, epidote and sericite occur in some cases and opaque minerals are the only accessories. One dike has an almost ultrabasic composition with hornblende, chlorite and epidote.

The basic dikes are entirely metamorphosed and therefore it is difficult to decide whether they were primarily diabases or lamprobhyres. The general lack of biotite points to a diabasic composition whereas their close connection to the aplite and the occurence of ultrabasic dikes among them favours lamprophyric associations.

QUARTZ-TOURMALINE VEINS

Quartz-tourmaline veins occur principally as a network brecciating the aplite. They have also been found in the Kristineberg ore (Du Rietz 1953) and in the vicinity of the Kimheden ore. In one case such a vein has been observed cutting a basic dike. As a rule the quartz-tourmaline veins do not penetrate the basic dikes although they cut the surrounding aplite. This fact indicates that the aplite must have been exceedingly more brittle than the basic dikes during the formation of the veins. As mentioned above (p. 21) the quartz-tourmaline veins in the aplite are partly straight, thin joint fillings, partly broader, curved, or folded and banded zones (Fig. 14). The straight veins are thin, at most a few millimetres wide whereas the banded zones are much thicker, up to a several tens of centimetres. This folded banding of the broad zones points either to deformation of a plastic rock or to intrusion of a plastic mass. A crystallization *in situ* from a dilute hydrothermal or pneumatolytic fluid does not agree with the folded and banded structure. There seem to be no reasons for assuming that the veins have been plastic after the crystallization and therefore the most probable explanation is that they crystallized during the movement of an intruded crystal mush with a pneumatolytic or hydrothermal fluid as lubricant. Movements along the broad zones have, of course, broken the other parts of the aplite into angular fragments and the fluid part of the quartz-tourmaline mush could fill the openings between the fragments while the already crystillized matter remained in the broad zones. This means that the quartz-tourmaline mass was mostly crystalline during the emplacement.

In the Viterliden hill a tourmaline vein cuts the aplite as well as a quartz vein in the aplite. In the aplite the tourmaline vein is thin and even but in the quartz vein it is considerably broader and has rugged outlines. This gives the impression that the tourmaline has grown in the quartz outwards from the joint. This fact indicates that there are quartz veins somewhat older than the tourmaline veins. Seemingly the difference in age has been small as the quartz has been so extensively replaced by tourmaline. In the Hornberget hill some quarts-tourmaline veins have been dislocated along the older cleavages. This shows either that there has been late movement along the old planes of weakness or that there are quartz-tourmaline veins of different ages. In the quartz-tourmaline veins in the Kristineberg mine sulphides have brecciated the tourmaline according to Du Rietz's observations (1953). This fact shows that at least a part of the ore is younger than the veins.

The mineral composition of the veins is very simple. Quartz and tourmaline are the only minerals and they are commonly concentrated to pure quartz and pure tourmaline bands. The grain size is often uneven with bigger crystals in a fine-grained matrix. Tourmaline occurs also as scattered grains in the aplite close to the veins and this indicates a metasomatic supply of matter to the aplite.

ORES

It is not the purpose of the present paper to describe the ores of the Kristineberg area closer. Some of them have earlier been described (Du Rietz 1953, Gavelin 1942, 1955, Grip 1951). They are, as a rule complex sulphide bodies with compact disseminated parts. Most of the compact ores are pyritic with more or less chalcopyrite and/or sphalerite. The contents of precious metals are commonly subordinate. Galena occurs in considerable amounts in some minor ore bodies in the Rävlidenfältet mine. These ores have the shape of compact joint fillings or dikes which cut through the folded country rocks.

All the known ores in the present area lie in the acid volcanic formation and their positions seem to have been controlled by fold structures (Gavelin 1942). The ores of Rävliden, Rävlidenfältet and Vindelgransele lie in the upper parts of anticlines. The Sture ore in Rävlidenfältet mine forms a complicated fold but this depends principally on the fact that it follows a strongly folded limestone. The limestone layer has evidently been a zone of weakness in the schists and hence offered the best channelways for the intruding ore. The ore fluids have further reacted with the limestone and the other country rocks, principally sericite and chlorite schists, and replaced them to a considerable extent. There is, however, in the Sture ore a breccia with angular fragments of limestone in a compact sulphide ore rich in zinc (Fig. 8). This breccia can scarcely be explained as a result of replacement for in this case one would expect the fragments to be corroded and have irregular lobate contacts. If the ore was intruded as a dilute hydrothermal solution, the fragments of limestone could hardly have remained freely floating until this solution finally crystallized. The simplest explanation is that the ore was intruded as a crystal mush lubricated by a saturated hydrothermal ore solution (Gavelin 1939, Ödman 1941, Edelman 1963).

The older opinion about the Kristineberg ore is that it lies close to a granite anticline but the present studies make this granite very dubious. There are, however, anticlinal folds between the open pits in the NW end of the Kristineberg ore. The Hornträskviken ore lies also close to a small S-shaped fold in the overlying amphibolite horizon clearly seen in the magnetic anomaly. There are, furthermore, folds with flat westerly pitching axes in the schist close to this ore. The Kimheden ore seems to cut through a fold easily seen on the magnetic map but also observable in the strongly schistode rocks in the outcrops. Around the Granlunda ore the bedrock is not exposed with the exception of the edges of the open pit. The ore lies to some extent in graphite schists and this indicates that the graphite schists formation is downfolded in the volcanic formation in this place. The structural control of the ore deposition is obvious in some cases but in others it is more obscure or dubious. The fact that there are folds in the vicinity of almost all the ores in the present area does not prove that the folds have in all cases been the principal ore controlling factor. The rocks in this area are so strongly folded that it would be more surprising if folds were absent from the vicinity of the other ore bodies.

The mineral parageneses of the ores indicate that the temperature of formation has been in the hydrothermal range. Especially such minerals as galena and sphalerite point to a rather low temperature. In the same direction points also the breccia with sharp angular limestone fragments. At higher temperatures one would expect strong chemical reactions between the ore fluids or gases and the limestone resulting in the formation of skarn minerals and in corrosion of the fragments.

As mentioned above (p. 22) fragments of the basic dikes have been found in the Kristineberg ore (Du Rietz 1953). Ore minerals have also been observed to brecciate tourmaline of the quartz-tourmaline veins in the same ore (Du Rietz 1953). These facts show that the ore with certainty is younger than the basic dikes and with great probability also younger than the quartz-tourmaline veins. The brecciation of the tourmaline is not quite conclusive regarding the age relations because sulphide minerals can be easily mobilized and then intrude the minute cracks of the tourmaline. In the absence of contradictory observations one is for the present, justified in considering the ore to be younger than the veins.

When comparing the ores in the present area with the Boliden ore (Ödman 1941) one gets the following age scheme, the youngest uppermost

Boliden (Ödman)	Kristineberg area
pyrite ore (Cu, Zn)	complex ore (FeS_2, Cu, Zn)
quartz-tourmaline veins (Pb, Bi, Ag, Au)	quartz-tourmaline veins (barren)
lamprophyres	basic dikes (possible lamprophyres)
arsenopyrite ore	arsenopyritic quartz veins of uncertain age (Gavelin—Grip 1946, Gavelin 1955)

There is a marked similarity between the areas but also evident differences. The arsenopyritic stage is absent in the ores of the Kristineberg area. Quartz veins with arsenopyrite have been found W of Vindelgransele (Gavelin-Grip 1946, Gavelin 1955) but their age relations to other geological events in the area have not been determined. Large arsenopyritic ore bodies like that of Boliden are quite unknown from the present area. Another difference is the fact that the quartz-tourmaline veins in the Kristineberg area are quite barren whereas those at Boliden are rich in precious metals, lead and bismuth. In spite of these differences the similarities in the evolution of the Kristineberg area and the Boliden area are remarkable.

GRANITE

During the present mapping the bordering granites have been reached in only a few places and the contacts are generally poorly exposed. There are some differences between the granites on different sides of the area and the peculiar contact zone along the brook from Rågoträsk lake NW of the area is worthy of closer examination and description than is possible here.

The granites are red or grey and medium- to coarsegrained. They contain rarely nebulitic remnants of country rocks or fragments of veined gneisses. The texture is often porphyroblastic with big microclines. The matrix is commonly granoblastic but the plagioclase has, in many cases, a rather well developed crystal shape. The quartz grains again are often granulated. The granite consists of microcline, plagioclase, quartz and biotite. Sericite, chlorite, epidote and calcite are rather common alteration products and opaque minerals are the only observed accessories.

Just outside the NW corner of the map area the granite has intensely granitized the schists in the vicinity of the contact along the brook from Rågoträsk lake. The schists contain basic volcanic layers and these have been strongly brecciated and the matrix of the breccia has been granitized whereas the fragments are commonly well preserved. Plagioclase, microcline and quartz have grown porphyroblastically in the matrix. The plagioclase shows sometimes zonal structure and a tendency to idiomorphic shape. It is often surrounded by myrmekite and a great part of one slide consists exclusively of myrmekite grains without visible cores of pure feldspar. The big blue quartz grains occur in the granitized matrix as well as in such frag-

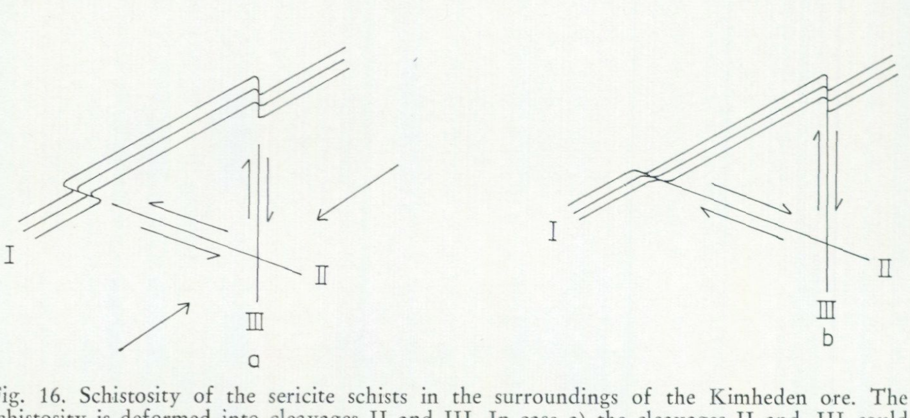

Fig. 16. Schistosity of the sericite schists in the surroundings of the Kimheden ore. The schistosity is deformed into cleavages II and III. In case a) the cleavages II and III could be interpreted as conjugate shear planes caused by the same stress, but in case b) this explanation is not possible.

ments as contain feldspar porphyroblasts. They seem, therefore, to be a result of the granitization although they often show a tendency to idiomorphic shapes with six-sided cross-sections.

The granite massif N of Långträsk lake N of the map area has been reckoned to a younger group, the Adak granites, whereas the large granite massif surrounding the Kristineberg area to the E, S, and W belongs to the Revsund granite. Whether these are of different ages or not will not be discussed here because neither of them has been studied in detail.

STRUCTURAL HISTORY

The structures of the present area have been described earlier (Du Rietz 1953, Gavelin 1943, 1955, 1942, Grip 1951, Edelman 1963) and the new observations made during the summer of 1963 fit well in the picture and the evolution outlined in the preliminary report (Edelman 1963). Therefore a short recapitulation of the structural history of the area with some supplementary observations may be sufficient for the present purpose.

The gneisses and the acid volcanic formation with the thin cover of graphite schist and the amphibolite formations form two sharp anticlinoria with westerly pitching axes (Fig. 17). The graphite schists have seemingly been squeezed into separate lenses and hence form discontinuous layer as shown by the electromagnetic

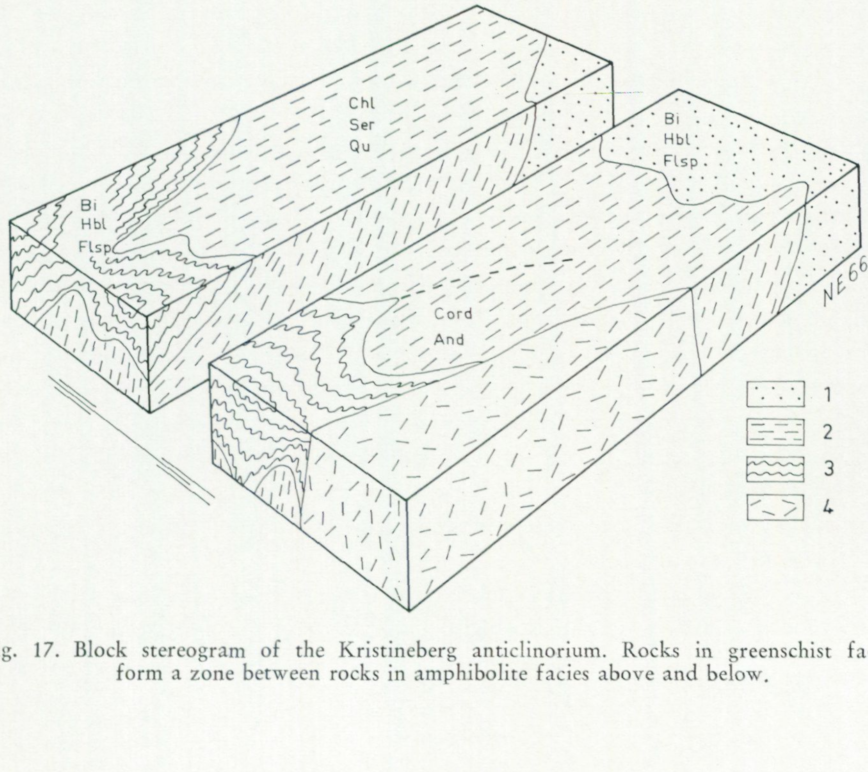

Fig. 17. Block stereogram of the Kristineberg anticlinorium. Rocks in greenschist facies form a zone between rocks in amphibolite facies above and below.

indications. The phyllite formation covers the anticlinoria. In the phyllite synclinorium which like a septum separates the two anticlinoria from each other the phyllites have well developed axial plane cleavage at least in the W part where they are well exposed. In the area over the crests of the anticlinoria with westerly plunging axes or in other words W of the anticlinoria the cleavage disappears rapidly in a westerly direction, probably because this part has not been compressed between the anticlinoria. The deformation style of the phyllites shows that these weak rocks have yielded passively to the stresses. They have been comparatively gently shear-folded and glided or "floated" more or less undisturbed on top of the strongly folded lower formations. The strong influence of tectonic stress and movement with the formation of axial plane schistosity was only felt in the phyllites which lay between the anticlinoria.

The ultrabasic zones have taken part in the folding but the folds in the S zone has a much greater wave-length than the folds in the acid volcanics. This might depend on the fact that the ultrabasic zone is entirely embedded in the incompetent phyllites and the difference in competency determines the wave-length of the folds (Ramberg 1964). Another explanation is that the phyllite formation was already to some extent folded when the emplacement of the ultrabasite took place. Against the latter explanation is, however, the fact that the incompetent phyllites cannot form folds with so great a radius as that of the ultrabasite fold. The S ultrabasite zone hardened so much during the phase of orogenic movement that it broke into fragments which turned and moved separately in the phyllites.

Connected with the folding is the axial plane cleavage which in the phyllites around the Storforsen rapid is of strain-slip cleavage type. In the sericite schists the cleavage has commonly destroyed the primary bedding and appears as closely spaced sericite surfaces between thin quartz-rich bands or lenses. The sericite surfaces are only a few millimetres apart. This cleavage or schistosity appears, therefore, as a microbanding caused by tectonic stresses and movements combined with a metamorphic differentiation and metasomatic reactions. Intermediate types of cleavage are common. In many places one can observe that the first cleavage has been subject to a deformation which has produced a second slip cleavage with an angle of 30—40° with the first one. This second generation of cleavage is common in the sericite schists. In the phyllites on the other hand cleavages with these two directions have been found along the Storforsen rapid but as a rule not together in the same exposures. It seems as if the second generation of cleavage had developed in such parts of the phyllites as had not been hardened by the formation of the first generation of cleavage (Edelman 1963). In the sericite schists there were no weak undeformed parts and therefore the second generation of cleavage has generally deformed the first one.

These two generations of cleavages show that the stresses which caused the deformation and cleavages turned clockwise about 30° from 150—160° to 180—190° (or from N 20—30° W to N 0—10° E). A further clockwise turning of the stress to the direction 80—90°, or almost E, is indicated by weaker signs of a third generation of cleavage striking about 0°, or N (Edelman 1963). The continued investigations during the summer of 1963 disclosed that this northerly cleavage is more common in the Hornberget hill than was formerly thought. This third cleavage is, however, only a weak impression upon the older ones but in some cases it may be much more distinct than the second cleavage. The origin of this cleavage could be connected with the formation of the lobe of microcline granite about 5 kilometres E of the present area (Edelman 1963). Gavelin (1955) mentioned signs of a westerly thrusting in the schists W of this granite lobe. In some cases the slip along the third cleavage or along surfaces striking N could be interpreted as conjugate shear to the second cleavage but often such an interpretation is impossible (Fig. 16).

The movements along the basic dikes which strike SE or ESE are sinistral the NE part having moved to the NW (Fig. 15). This shear movements fits well with the easterly stress. This fact points to the possibility that the emplacement of the granite lobe was at the most contemporaneous with the intrusion of the basic dikes, probably later. Conclusive proof of this fact is, however, unobtainable because there may have been stresses with the same direction in the crust at different times. Movements in the same direction have been observed in the Kristineberg mine by Grip (1951). Furthermore the S side of one dike has been upthrown.

Signs of still later movements and stresses are shown by the quartz-tourmaline veins. During the formation of these veins the aplite was brittle whereas the basic dikes have been strong and though. Therefore the veins occur almost exclusively in the aplite. Along the broad veins the aplite has, however, softened so much that the fragments of it have rounded outlines due to movements along the veins (Fig. 14).

The structure of the ores have not been studied so thoroghly and no new observations can be presented here. The most interesting fact is the breccia with angular fragments of limestone in a part of the Sture ore in the Rävlidenfältet mine (Fig. 8). This shows that the limeston was brittle and the ore probably comparatively viscous during emplacement. In the compact sphalerite ore in Kristineberg there are also folded and deformed fragments of the country rocks freely floating in the ore.

STRATIGRAPHY

SUPRACRUSTAL ROCKS

The regional structures of the Kristineberg area is rather simple with moderately westerly pitching anticlinoria (Du Rietz 1953, Gavelin 1955, Edelman 1963). Although determinations of top and bottom are impossible in the greater part of the area owing to strong deformation and metamorphism, there seems to be no reason for the strata to be overturned on a large scale. There is, for example, a similar sequence of formations in both anticlinoria and this sequence agrees well with the sequences of other parts of the Skellefte district (Kautsky 1957) as well as of other parts of the Svecofennides (Edelman 1960). This does not of course mean that there could not locally occur overturned strata in the present area. When comparing the sequence of the Kristineberg area with Kautsky's stratigraphical scheme of the Skellefte district one observes, however, some differences.

Skellefte district		Kristineberg area
Högbom 1937, Gavelin—Grip 1946	Kautsky 1957	
Conglomerates		
Revsund granite		
Jörn granite	Folding, deformation	Aplite (?)
Skellefte sedimentary series	Elvaberg schists	Phyllite formation
	Conglomerates Disconformity and hiatus Weak folding, Jörn granite	
Skellefte volcanic series	Skogsheden volcanics	Amphibolites, volcanic
	Petikträsk schists	Graphite schists
	Maurliden volcanics	Acid volcanic formation
	Maurliden schists	Gneisses

As the table shows the stratigraphy of the Kristineberg area agrees well in its lower parts, up to amphibolites, with the stratigraphical scheme proposed by Kautsky (1957) whereas the upper part fits better with the older opinions of Högbom (1937) and Gavelin-Grip (1946). Neither in exposures nor as erratics have conglomerates been found in the present area. This suggests that they are absent but there is no definite proof of this. Nor have any signs of a great hiatus been observed or of a disconformity between the amphibolites and the overlying phyllites. The fact that basic lava flows occur in the phyllite formation favours an insignificant age difference between these two formations.

The graphite schists are metamorphic, sapropelic slates indicating anaerobic conditions in poorly ventilated basins. The separation of these basins points to vertical movements producing shallow sills with the open sea. The overlying ampibolite formation consisting of basic volcanics, lava flows or tuffs, shows that the movements have caused deep-reaching fractures which have acted as feeding channels for the basic magma. The intense basic volcanic activity has been of a comparatively short duration owing to the small thickness of the basic volcanic formation but the gabbros and the basic lava flows in the phyllites indicate sporadic volcanic activity later.

A special problem is presented by the magnetic anomalies of the anticlinoria. They coincide partly with the gneiss cores but in the comparatively well exposed S anticlinorium the magnetic anomaly has protrusions which extend far W of the petrographic contact. These protrusions simulate sharp anticlines and fit well in the folds or the other formations. Therefore they have earlier been interpreted as folds of the gneiss or the "Jörn granite" as it was formerly called. This gneiss is in its present habit, no granite. It has probably been a pelitic rock of the graywacke suite stratigraphically equivalent to the Maurliden schists. The contact of this gneiss with the sericite schists of the acid volcanic formation seems to be rather sharp because these two different rocks occur in adjacent exposures only some tens of metres apart from each other. Only on the N slope of the Viterliden hill have intermediate types been found which in some cases microscopically resemble deformed granites. The rocks of the magnetic protrusions are sericite or chlorite schists which in the lobe N of Säter contain corderite and some plagioclase. They are, in other words, almost identical with the schists which surround the protrusions as already noted by Du Rietz (1953).

The magnetic anomaly depends, in all probability, on a low content of magnetite. This must either be a primary constituent of the rocks or a product of the metamorphism. In the latter case it may either reflect a difference in the primary composition or a difference in the conditions during the metamorphism if the primary composition has been identical. The fact that the protrusions fit well in the tectonic structure of the area favours a primary difference between the magnetic area and their surroundings. It is furthermore difficult to conceive that special magnetiteforming conditions could have occupied such fold-shaped spaces in the crust. It seems therefore more probably that the magnetic anomalies reflect a primary difference in composition and that they show the former extension of the lowermost formation, the main part of which has been transformed to the gneiss of the core. If this is true, we have in the Kristineberg area a stratigraphic sequence which is similar to the general sequence of the Svecofennides (Edelman 1960).

INFRACRUSTAL ROCKS

The infracrustal eruptive rocks occur commonly as separate intrusions. The large granite massifs are also separated from other eruptive rocks. Contacts between the intrusive rocks are therefore rarely exposed and many of these are not likely to be in contact with one another in the present area at all. Therefore some of the age relations are obscure and can only be tentatively outlined.

The small gabbro massifs lie in the phyllites close to the underlying formation of basic volcanics. It has been supposed above that they are related to these volcanics but have erupted so late that a part of the phyllite formation had already been deposited and that they hence formed subvolcanic massifs in it. The hypidiomorphic texture of the gabbros has been comparatively well preserved. This does not prove that the gabbros are younger than the regional metamorphism for they lie in an environment with a low degree of metamorphism. The soft phyllites have sheltered the embedded gabbros from stresses and differential movements.

The ultrabasic rocks lie as long curved zones in the phyllites and must therefore be younger than a great part of this formation. They have, however, been folded and are hence older that at least some phases of the folding. Their emplacement seems therefore to have taken place at the transition from the geosynclinal phase to the folding phase.

The aplite is younger than the two phases of folding which have caused cleavages because the aplite cuts the cleavage of the gneiss and of the sericite schist. It is therefore also younger than the sericitization. The aplite is, on the other hand, cut by the basic dikes and the quartz-tourmaline veins. The age relations between the basic dikes and the quartz-tourmaline veins has been difficult to establish but finally one case was found where a quartz-tourmaline vein undisputably cuts a basic dike. In another case there was tourmaline in the biotitized and deformed contact of a basic dike.

The sulphide ore of Kristineberg contains fragments of basic dikes as inclusions and the sulphides also cut the quartz-tourmaline veins according to Du Rietz (1953). The age relation of at least one type of the Kristineberg ore to the dikes and the veins is hence undisputably established but this does not conclusively prove that all the different types of ores in this area younger than the dikes and the veins. It is worth mentioning that in the Boliden ore about 90 kilometres E of Kristineberg the basic dikes and the quartz-tourmaline veins originated between the arsenopyrite ore and the pyrite ore according to Ödman (1941). He points out, however, that some basic dikes are broken into fragments in the arsenopyrite ore and that fissures in them are filled with sulphides, in some cases even with arsenopyrite. These observations make the age relations also there somewhat doubtful. The mineralization in the Kristineberg area was of course a process of long duration and it can be divided into several phases but there are for the present no observations which indicate an ore-forming phase older than the basic dikes and the quartz-tourmaline veins.

The age relations of the other ores in the present area to these dikes and veins are obscure partly owing to limited investigations, partly owing to the absence of dikes and veins in the ore. In the absence of information to the contrary the ores are considered younger than the basic dikes and the quartz-tourmaline veins. This hypothesis is proved correct for at least a part of the Kristineberg ores and no contradictory observations are yet known.

The position of the microcline granite or Revsund granite in the scheme outlined here is uncertain because of the lack of observed contacts of the granite and infracrustal rocks. It is quite certain that the granite is younger than the supracrustal rocks. The formation of andalusite and cordierite in the sericite schists in the vicinity of the contact is probably a result of the influence of the heat of the granite showing the latter to be younger than the sericitization and folding. The observations along the contact near the brook from Rågoträsk lake corroborate this conclusion. The relation between the granite and the aplite is open. Chemically these two rocks are very different; the aplite is a sodium-rich rock with albite as nearly the only feldspar whereas microcline dominates in the granite.

If we consider the granite as a granitization product of older plagioclase-bearing rocks then there seems to be a slight theoretical possibility that the introduced potassium has expelled sodium which together with alumina and silica formed the albitic aplite. It would be the same process as has been proposed for explaining the myrmekite rims around microcline porphyroblasts (Edelman 1949). There is nevertheless the question whether this process can work on such a large scale that it produces an aplite with an area of about 50 000 square metres. The other possibility is that the aplite is not related to the microcline granite but belongs to the older plagioclase granite group or to the so-called Jörn granite. This explanation is in accordance with the general stratigraphical scheme of the Svecofennides (Edelman 1960) with basic dikes intrusive between the older plagioclase granites and the younger microcline granites. With this somewhat hypothetical age for the granite one gets the following stratigraphical scheme for the Kristineberg area.

Revsusnd granite (perhaps contemporaneous with the ores and the quartz-tourmaline veins)

Sulphide ores
Quartz-tourmaline veins
Basic dikes
Aplite

Folding and cleavage II
Folding and cleavage I

Ultrabasites
Phyllites with some basic volcanics and subvolcanic gabbros
Amphibolites (basic volcanics)
Graphite schists
Acid volcanics (sericite and chlorite schists)
Gneisses

METAMORPHISM

In the Kristineberg area one can distinguish several more or less separate metamorphic events partly superimposed upon one another. The first of these is the regional metamorphism which transformed the supracrustal rocks into crystalline schists of different kinds. The second is the metasomatic formation of the sericite and chlorite schists zone between the biotite-bearing phyllites above and the gneisses below. The third event is the growth of andalusite and corderite porphyroblasts in the sericite and chlorite schists in the neighbourhood of the microcline granite. Still more local than the last mentioned event are such cases of contact metamorphism as the formation of feldspar porphyroblasts in the contact breccia along the brook from Rågoträsk lake or the formation of a hybrid between the aplite and the gneiss.

A closer treatment of the regional metamorphism seems unnecessary because the different rocks have been described in the petrographic chapter. Only some general features are worth mentioning. The degree of recrystallization increases downwards in the stratigraphic column. Although the phyllite anticlinorium pitches westwards below the Revsund granite, the influence of this granite is limited to a narrow contact zone the breadth of which in the section of the present earth's surface is less than two kilometres. Measured perpendicular to the contact the breadth of this zone may be much less. This fact proves that the regional metamorphism in the schists and the phyllites is not connected with the formation and emplacement of the Revsund granite.

The phyllites are fine-grained and especially the big grains of quartz and feldspar in the graywackes have preserved their primary angular shape and they commonly show no signs of recrystallization. Biotite sometimes shows a weak tendency for porphyroblastic growth. In the acid volcanics one can observe very great differences in recrystallization. The main rocks are medium-grained and entirely recrystallized sericite and chlorite schists but better preserved parts show beautiful porphyritic and granophyric textures. The sericitization and chloritization are, however, not results of a regular regional metamorphism and they have affected the rocks in very different degrees seemingly owing to local circumstances. In the gneisses of the core the matrix is entirely recrystallized and markedly coarser than the matrix of the phyllites although it is still finegrained. A great part of the gneiss minerals have, however, recrystallized to porphyroblasts of plagioclase, biotite and hornblende. The hornblende seems to dominate in the inner part of the core of the S anticlinorium whereas the gneisses of the outer part are purer biotite gneisses. One gets the following schematical longitudinal section through the Kristineberg anticlinorium.

W			E
Top of sequence			
phyllites, biotite-	sericite-	porphyroblastic gneisses,	fine-grained matrix
bearing, fine-grained;	chlorite-	biotite-	hornblende
amphibolites	schists	plagioclase	biotite-plagioclase

A comparison of the metamorphic facies of these rocks gives the following astonishing result. The paragenesis with hornblende, biotite and plagioclase of the gneiss core of the S anticlinorium indicates PT-conditions of the amphibolite facies during the formation. It is, on the other hand, more difficult to decide the metamorphic facies of the phyllites because of lack of critical mineral assemblages. The common occurrence of biotite and the general absence of chlorite point to PT-conditions of at least albite-epidote amphibolite facies. The basic volcanics e. g. those W of Vindelgransele, indicate amphibolite facies. The biotite of the phyllites is either parallel with the bedding or especially the recrystallized, microporphyroblastic biotite parallel with the cleavage. This fact seems to be rather conclusive proof of the age of the biotite. The formation of the biotite must be older than or contemporaneous with the formation of the cleavage and hence contemporaneous with the regional metamorphism. These facts show that PT-conditions of the amphibolite facies prevailed in the gneiss core as well as in the phyllites during the regional metamorphism. Even if the highest PT-conditions have been within the limits of the amphibolite facies there could have been differences in temperature and especially in the length of the time during which these high temperatures prevailed and these differences can have caused the variations in the grain size.

There are also other factors which can facilitate the growth of the grains besides the PT-conditions. This is clearly demonstrated by the fact that the coarsest rocks of the area are the sericite and chlorite schists which represent the lower PT-conditions of the greenschist facies. These low-temperature rocks form a broad zone between the gneisses and the phyllites in the S anticlinorium. The sericitization and chloritization are, as a rule, due to addition of water and water belongs to the volatiles which increase the transport of other ions and therefore accelerate the recrystallization of the rocks. The differential movements which cause the cleavage also facilitate the chemical reactions and the cleavage, furthermore, offers good paths for moving volatiles. The orientation of the sericite and chlorite parallel with the cleavages and principally with cleavage I, shows that the sericitization and chloritization took place contemporaneously with the formation of the cleavages and hence with the regional metamorphism. There is reason to point out in this connection that the cleavages have the same directions in the gneisses, sericite-chlorite schists, and phyllites. There is, therefore, no reason to assume that the cleavages are of entirely different ages in the different formations. The sericitization and chloritization must therefore be contemporaneous with the regional metamorphism.

The position of this zone with rocks in the greenschist facies between the phyllites and the gneisses metamorphosed in the amphibolite facies or at least alpite-epidoteamphibolite facies, is somewhat problematic especially as all the rocks have seemingly reached their present parageneses during the same phase of orogenic evolution. The structure of the area shows a comparatively flat-lying zone which had lower temperature and pressure between zones with higher PT-conditions (Fig. 17). The sericite schists plunge at an angle of about 25° under the phyllites to the W.

There seem to be at least three possible ways to explain the surprising distribution of the metamorphic facies in the present area. The first is that there are some errors in the now accepted doctrine of metamorphic facies. Our present knowledge of the limits of the stability fields of different minerals and mineral assemblages is imperfect especially regarding such water-bearing minerals as the chlorites the composition of which may vary very much. The influence of the partial pressure of water on the stability limits of the chlorites is almost unknown. Ramberg (1952) considers that Al-rich chlorites are stable at much higher temperatures than Al-poor ones. The great experimental difficulties in the synthesis of hydrous minerals have so far prevented a closer knowledge of their stability and we are restricted to observations of the parageneses observed in the field. Therefore a discussion of eventual errors in the now accepted limits of the different metamorphic facies seem to be rather pointless for the present. It seems probably that a high water pressure may facilitate the formation of hydrous minerals and displace the upper limits of the stability fields towards higher temperatures (Mc Namara 1966).

Another conceivable explanation is that regional metamorphism transformed all the rocks of the area into metamorphic rocks of the amphibolite facies. During the waning of this phases of orogenesis the temperature sank to the level of the greenschist facies. In other rocks the mineral assemblage of the amphibolite facies remained metastable but in the zone of sericite and chlorite schists the volatiles could move and recrystallize the rocks owing to the strong cleavage which offered good channel ways for the volatiles. The gneisses of the core have not been affected by the volatiles but this may depend on too high a temperature there; the core, lying deepest in the crust, has naturally had the highest temperature. The amphibolites and the phyllites were seemingly impermeable for the volatiles because of their fine grain, and therefore they have escaped their influence. This explanation has, however, a weak point. The megascopic, and microscopic examination indicates with a high degree of likelihood that the sericitization and chloritization were simultaneous with the formation of cleavage I and even with the formation of cleavage II. The metasomatic transformation of the acid volcanics into sericite schists must hence have been on the whole contemporaneous with the regional metamorphism and with the recrystallization of the phyllites and the gneisses under the PT-conditions of the amphibolite facies.

There seems to be one more process which could explain the lower temperature

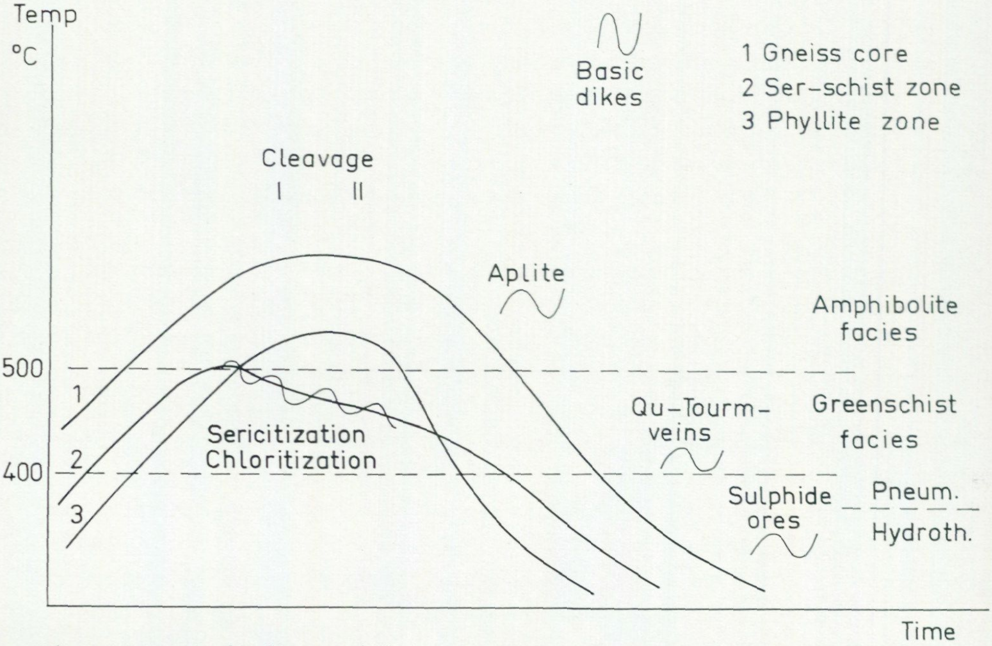

Fig. 18. Metamorphic history of the Kristineberg area in an age-temperature diagram.

of the sericite schist zone at the same time as the rocks above and below had a higher temperature. The sericite schists were strongly cleaved or schistose contrary to the surrounding rocks. Good possibilities were therefore available for the volatiles to move, their pressure falling considerably in the process. When the pressure fell the gases expanded causing the temperature to sink. This Joule-Thomson effect is seemingly the only process which is endothermic and can explain a decrease in temperature.

If the boundary between the greenschist facies and the amphibolite facies is at about 500° C (Winckler 1965) one can calculate that this temperature is reached at a depth of 15—20 kilometres. The pressure of the rocks at these depths is 4 000—5 500 bars whereas the pressure of a water column of the same hight is something between 1 000 and 1 500 bars owing to the low specific gravity of the water at high temperatures. The difference between the rock pressure and the pressure of the water column is the theoretical maximal reduction of pressure available for the Joule-Thomson effect. A pressure reduction of 1 000 bars is only $^1/_3$ or $^1/_4$ of this maximum and a reduction of this magnitude seems possible for water reaching a strongly jointed rock. The enthalpy of water under high pressure and high temperatures is only determined up to 1 000 bars and 1 000° C. A. decrease of the pressure from 1 000 bars to 500 bars at a temperature of 500° C means an increase in enthalpy of about 100 calories (Vukalovitch 1958). These calories are taken from the water itself and from the surroundings. In the case discussed here the water moves in thin cleavage joints and is in intimate contact with the country rock. The whole process is therefore more or less isothermal. The required 100 calories are able to lower the temperature of the water and the country rock noticeably. The specific heat of the water and of the country rocks is, under the discussed PT-conditions, in the range 0,25—0,50. At a pressure of 5 000 bars the required calories or the increase in enthalpy must be less than the above calculated value but this can partly be compensated for by a considerably greater decrease in pressure. As we do not know how much water has moved we cannot calculate this process. We can only show that the Joule-Thomson effect is probably of the required magnitude for explaining the decrease in temperature. The difference in temperature between the sericite schists and the surrounding rocks must not necessarily be greater than some tens of degrees if the temperatures in question lie close to but on either side of the boundary between the greenschists and the amphibolite facies.

Another question concerns the magnetic anomalies of the S anticlinorium. As mentioned above (p. 30) the anomaly does not coincide with the gneiss core but fits well in the fold structure of the overlying rocks. If the assumtion is correct that the anomaly shows the primary extension of the gneiss formation then sericitization has not been restricted to a certain stratigraphic formation but cuts through different formations. If this is true, then folding must have been almost finished when the sericitization ceased. If the explanation proposed here is correct the metasomatic processes, sericitization and chloritization, began during the formation of cleavage I and continued at least to the end of the folding although they were obviously waning during the formation of cleavage II.

In the N anticlinorium similar metasomatic processes have not been of as great importance as in the S one. In the gneiss core occur amphibolites, garnet gneisses and cordierite gneisses. The volcanic formation has almost similar parageneses with plagioclase, biotite and sometimes hornblende and furthermore subordinate amounts of sericite and chlorite. The skarn layers are commonly epidote-bearing. The overlying phyllites and amphibolites are similar to those of the S anticlinorium. The metasomatic processes have hence been restricted to the S anticlinorium where the cleavage is also much stronger developed.

The third kind of metamorphism is the formation of andalusite, cordierite and plagioclase in the sericite, and chlorite schists (p. 14 and Du Rietz 1953). It is a typical postkinematic recrystallization. Andlusite occurs as pseudomorphs after folded bundles of sericite (Fig. 9); the shape of the andalusite porphyroblasts is that of folds but there are no signs of deformation or stress in the andalusite. This mineral is considered to be an antistress mineral and a strong deformation of it seems therefore unlikely. The formation of these porphyroblasts must consequently have taken place after the deformation.

Du Rietz (1953) has already shown that the cordierite occurs in a zone farther away from the granite contact than andalusite. Unfortunately outcrops occur only in a part of the actual contact area and therefore it is not possibly to follow up these metmorphic zones. It is somewhat surprising that the andalusite occurs closer to the contact than the cordierite although cordierite in general is considered to represent a higher temperature than andalusite. A possible explanation is that the distribution of corderite and andalusite in the schists is controlled by the chemical composition of the rocks and does not depend on differences in the PT-conditions.

The formation of andalusite and cordierite in the vicinity of the granite contact points to a rising temperature probably in connection with the emplacement of the granite. No other plausible cause for the temperature increase has hitherto been found in the area. This is a further argument against a causal connection between the granite and the sericitization, the sericite being distinctly older than the formation of the andalusite.

W of Vindelgransele the phyllites are in contact with the granite but there the granite has caused feldspar and quartz porphyroblasts to form in the matrix of the brecciated phyllites. The shape of the contact and the type of contact metamorphism have hence developed in different ways in different parts of the area owing to different combinations of the co-operating factors.

THERMAL EVOLUTION

In the foregoing chapter the variations in temperature have already been touched upon. Here I want to discuss this question in more detail. After the deposition of the supracrustal rocks the temperature rose to the level of the amphibolite facies at the culmination of the regional metamorphism. It is hardly possible to discern older fluctuations in the temperature because the regional metamorphism has more or less completely destroyed any traces these may have left in the rocks. The temperature was, of course, not identical in the whole area because different parts represent different levels in the crust and the temperature naturally rose downwards. The gneiss core represents a level at least 5 kilometres deeper than the phyllites around the Storforsen rapid. The temperature gradient in the deeper parts of an orogen zone is, however, unknown but probably irregular and we can therefore only roughly estimate the temperature differences between these parts.

The sericitization and chloritization of the acid volcanics during the first folding stage signify a distinct lowering of the temperature. This decrease of temperature is difficult to estimate but we can establish that it fell below the upper limit of the greenschist facies. Especially in the case of such metasomatic processes it is obvious that the temperature of the moving fluids is identical with that of the country rock. This low temperature of the sericite schist zone lasted at least to the second folding stage when cleavage II was formed. After that it seemingly decreased still more. In the gneiss core and in the phyllites the temperature during the two folding stages was at the level of the amphibolite facies. Later it fell comparatively rapidly through the greenschist facies judging from the general lack of low temperature alteration products in the phyllites and gneisses.

After the formation of cleavage II the aplite was intruded in the area. The temperature of an aplite is markedly higher than that of the metasomatising fluids. A crystallizing aplite "magma" is necessarily hotter than the country rock for in either case it would not crystallize in the place in question. The intense reaction between the aplite and the gneiss resulting in a several metres thick zone of hybrids along the contact indicates that the gneiss probably was rather hot, at least there. The strong reaction can scarcely be explained as a result of a high concentration of volatiles for in this case one would expect a pegmatite instead of an aplite.

The basic dikes cutting the aplite and the gneisses are real magmatic rocks with a still higher temperature of formation than the aplite. Basic magmas, especially if they are rich in volatiles, have, as a rule, such a low viscosity that they can move considerable distances in fissures with cold walls. The basic dikes in the present area are recrystallized to such an extent that it is impossible to decide whether they have had chilled borders or not. The curving schistosity of the gneiss close to a basic dike (Fig. 15) indicates a plastic yielding of the gneiss to a shear movement either when the point was formed or when the dike was intruded. This plasticity is a sign of a comparatively high temperature or pressure but the temperature cannot be estimated sufficiently exactly. One can, however, establish that the basic dikes represent a temperature maximum for the supplied fluids and that this maximum scarcely coincides with the temperature maximum of the country rock. The latter maximum must have been simultaneous with the culmination of the regional metamorphism.

The following stage, the formation of the quartz-tourmaline veins, shows a decrease in the temperature of the supplied matter to the pneumalytic range. It seems reasonable to assume that the supplied matter of these often very thin veins had a temperature only slightly higher than the country rock. One can therefore establish that the temperature of the gneisses during this stage was near the limit of the pneumatolytic and the hydrothermal ranges or in the vincinity of the lower limit of the greenschist facies which is around 400° C (Winkler).

The subsequent formation of the sulphide ores took place under hydrothermal conditions judging from the parageneses of the ores. This points to a further decrease in temperature of the bedrock also. It would certainly be possible to divide the formation of the ores into several phases but they require much more detailed study than has been made for the present paper.

We can establish that the supplied matter — the metasomatic fluids, aplite, basic dikes, quartz-tourmaline veins and ore solutions — as regards temperature, form a curve with a maximum at the basic dikes (Fig. 19). The temperature of the country rock has its maximum much earlier. The temperature of such fluids which have penetrated the rocks along thin cleavage joints must be almost identical with the temperature of the country rock because of their intimate contact. Fluids which have formed thicker and more compact dikes, veins or ores might have had a much higher temperature than the country rock on intrusion.

If we suppose that there is a temperature gradient in the crust then we can assume that the hot fluids have come from hotter parts of the crust. The hotter the fluids, the deeper the levels from which they have probably come. The basic dikes must therefore have emanated from the deepest levels. Their chemical composition points in the same direction. A consequence of this is that the feeding channels must have been in connection with the deepest levels during the intrusion of the basic dikes. A joint in the crust is open if the pressure of the fluids or gases is greater than the lateral pressure on the walls of the point. Therefore the intrusion of fluids in joints implies either an increased pressure of the fluids or a decreased lateral stress on the joints. The increase of fluid pressure is caused by processes below or outside the present area and therefore a discussion of them must necessarily be more or less hypothetical. Magmatic processes generally pulsate e. g. the eruption of lavas, and the interval of this pulsation depends on the time required to build up a pressure great enough for exceeding the outer pressure and the tenacity of the country rocks. These questions have, to some extent, been discussed in an earlier paper (Edelman 1965).

Processes which can be responsible for a decrease of the lateral stress have taken place partly within the present area and are therefore to a greater degree subject to observation. Dikes and veins formed in dilated joints indicate a lowering of the lateral stress and hence may be indications of a contraction of the rocks owing to cooling for example. The brecciation of the aplite may be the result of such a shrinking especially as the brecciation is restricted to this aplite which has recrystallized later than the country rock. The basic dikes on the other hand all strike about SE indicating unilateral decrease of stress in a NE direction. They seem therefore to be related to tectonic movements or stress conditions. The cooling of the bedrock might, however, have contributed to the diminished stress.

The metamorphic evolution of the Kristineberg area can be summarized as follows. In connection with folding and the formation of two generations of cleavage, regional metamorphism took place at PT-conditions of the amphibolite facies. This means temperatures above 500° C (Winkler 1965). During the later part of the first fold phase temperatures in the volcanic formation of the S anticlinorium sank below the upper limit of the greenschist facies or below 500° C. This decrease in temperature is indicated by sericitization and chloritization in this zone and it seems to have a causal connection with this metasomatic process. During the second fold phase recrystallization was of the same kind but much less important. This phase was probably shorter and the flow of metasomatic fluids less.

The aplite indicates a new supply of matter at higher temperatures. In contrast to the potash-rich metasomatic fluids the aplite was rich in sodium and very poor in potassium. This marked difference in composition as well as in temperature shows that the fluids have come from different sources or that a thorough differentiation had taken place at great depths. The intrusion of the basic dikes means a still higher temperature for the supplied matter and a correspondingly deeper source. After that the temperature of the supplied matter fell through the pneumatolytic range of the quartz-tourmaline veins, to the hydrothermal level marked by the formation of the ores.

This history shows that there has been a long and diversified evolution from the metasomatic sericitization and chloritization to the formation of the sulphide ores. Geijer (1965) has recently remarked regarding the sericitization in the Öster-Silvberg district in Central Sweden, that the "alteration in question occurred before the emplacement of the ore". In the present area the metasomatic alteration and the emplacement of the ores both occurred at comparatively low temperatures, the former almost at the beginning, the latter at the end of the metamorphic evolution of the area. The genetic connection between the more or less regional metasomatism with sericitization and chloritization and the origin of the ores is therefore very doubtful. This does not mean that there could not have been a local metasomatism connected with the ores. The fact that the best preserved keratophyres have been found in the Kristineberg mine and close to the Kimheden ore indicates that the metasomatic rocks do not form any regular aureoles around the ores and that no genetic relation exists between the regional sericitization and the ores.

All the known ores lie, however, in the acid volcanic formation and as a rule in the sericitized parts. The N anticlinorium is characterized by a much more sporadic and much weaker sericitization. Also the known ores in this anticlinorium are few and insignificant. Hence there seems to be a certain correlation between the sericitization and the emplacement of the ores. As the regional sericitization is separated from the ore formation by a long succession of metamorphic events the sericitizing fluids can hardly be foreruners to the ore fluids. It seems more probable that the sericitizing fluids and the ore forming fluids used the same channels when moving upwards in the crust. The acid volcanic formation which in the S anticlinorium has a well developed cleavage, often of two generations, offered the best opportunities for different kinds of fluids to move. The sericitization and chloritization and the deposition of the sulphide ores are processes controlled by similar PT-conditions in similar tectonic environments but did not necessarily take place at the same time nor did the fluids necessarily emanate from the same source. In other words they need not be comagmatic.

GEOLOGICAL HISTORY

When summarizing the events one gets the following tentative geological history for the present area. The lowermost formation has seemingly been a siltstone of graywacke or subgraywacke composition indicating a comparatively rapid transport and sedimentation in a sinking basin. The crust did not resist the downwarping indefinitely but fractured. Along the fractures acid magmas rose to the surface giving rise to the acid volcanic formation. The deposition of limestones and probably also of quartzose sandstones during the same period shows that the relief of the adjacent land areas had become lower. The graphite or black schists are the result of poisonous conditions in the sea. Such conditions depend as a rule on a restricted water circulation in basins limited by shallow thresholds. They are, hence, proofs of certical movements, at least of the surrounding area.

These vertical movements opened again channelways through the crust and the magma now had a basaltic composition. The reservoirs of acid keratophyric magma were seemingly emptied and the opened joints reached the basaltic layer of the upper mantle. The nearest volcanic center seems to have been almost immediately N of the present area owing to the large masses of porphyritic volcanics there. Although the basic volcanic activity was of a comparatively short duration it continued during the following sedimentary phase. The sediments of this phase were graywackes and shales. This formation, the phyllites, is very thick and monotonous and equivalent to the alpine flysch. It indicates a continous and rapid erosion and transport pointing to a rapid upheaval of the adjacent land areas. After or during this phase of sedimentation the ophiolitic ultrabasic sheets or sills were intruded.

Whether the orogenic movements began already during the sedimentation of the phyllite-graywacke series is difficult to decide in the present area. The first fold phase had a stress direction about SSE. The anticlinoria were formed in outline during this phase. The temperature and the pressure rose and a regional recrystallization in the amphibolite facies took place. The strongly schistose acid volcanics of the S anticlinorium offered good possibilities for transport of pneumatolytic fluids. In the closespaced cleavage joints the pressure of these fluids decreased markedly and the expansion of these supercritical fluids caused a cooling of the country rock owing to the Joule-Thomson effect. The temperature of the acid volcanics was lowered under the upper limit of the greenschist facies and the rocks transformed to sericite and chlorite schists. The metamorphic recrystallization continued during the second fold phase. Then the stress changed about 30° to a direction almost N so that a second cleavage strikes E. It is noticeable that the cleavages disappear in the phyllites over the crests of the anticlinoria in the formations below. This indicates that the phyllites yielded quite passively to the orogenic stresses and that their upper part floated apparently undeformed over the compressed anticlinoria.

During folding the bedrock hardened as a result of recrystallization. The decrease in temperature after the regional metamorphism acted in the same direction. In the hardened rocks the cleavage surfaces partly lost their function as channelways for moving fluids which therefore often used other fractures. An albite aplite, probably related to the synorogenic plagioclase granites or the Jörn granite, intruded and formed a large dike or lens-shaped massif. After this aplite a basic magma with a still higher temperature intruded along joints striking SE. The higher temperature as well as the basic composition point to a deeper source area for this magma than for the aplite. The typical dike shape of these basic dikes compared with the aplite indicates again that the country rock become more brittle and colder during the interval between the intrusion of these rocks. The temperature of the rocks seemingly passed comparatively rapidly the range of the greenschist facies owing to the well preserved parageneses of the amphibolite facies.

After the intrusion of the basic dikes which represent the supply of fluids with the highest temperature and hence from the deepest sources after the emplacement of the ultrabasites, the lower parts of the feeding channels were closed and the following fluids from below formed pneumatolytic quartz-tourmaline veins. These were probably forerunners related to the hydrothermal ore fluids which are the last intrusions in the area. Many structures in the pneumatolytic veins and hydrothermal ores point to a comparatively high viscosity of the originating fluids. The most probable explanation of the high viscosity and low temperature of the fluids is that the intruding masses consisted of a crystal mush with an interstitial liquid rich in volatiles which acted as a lubricant. The volatiles of the ore fluids have probably caused metasomatic transformations such as sericitization and chloritization in the country rock of the ores. These transformations are of course in the cases in question difficult to distinguish from the older regional sericitization and chloritization.

The view presented here of the metamorphic evolution of the Kristineberg area is by no means considered the final solution to the problems. The exposures are all too few and scattered for proving the proposed hypotheses. Many questions are still left quite open, e. g. the puzzling magnetic anomalies which on the one hand show that the boundaries of magnetic anomalies do not always coincide with petrographic borders but on the other hand suggest they the premetamorphic extension of certain rocks.

Even if the age relations presented here between the metasomatic fluids and the ore fluids were misinterpreted I hope that the hypothesis proposed brings some new views about the connection between rock alteration and ore genesis. In that case the paper can have interest outside the Kristineberg area.

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