SVERIGES GEOLOGISKA UNDERSÖKNING

SERIE C NR 757 AVHANDLINGAR OCH UPPSATSER ÅRSBOK 72 NR 19

GOTTHARD WALSER

GEOLOGY OF THE HOTAGEN AREA JÄMTLAND CENTRAL SWEDEN

UPPSALA 1980

SVERIGES GEOLOGISKA UNDERSÖKNING

SERIE C NR 757 AVHANDLINGAR OCH UPPSATSER ÅRSBOK 72 NR 19

GOTTHARD WALSER

GEOLOGY OF THE HOTAGEN AREA JÄMTLAND CENTRAL SWEDEN

UPPSALA 1980

ISBN 91-7158-162-6

Adress:
Gotthard Walser
Sveriges geologiska undersökning
Box 801
951 28 Luleå

Kartan på sid. 12 godkänd ur sekretessynpunkt för spridning.
Statens lantmäteriverk 1979-12-17.

C DAVIDSONS BOKTRYCKERI AB, VÄXJÖ 1980

CONTENTS

Summary 4
Introduction 5
  Regional geology 6
  Previous work 6
  Present investigation 7
Bergsjön Complex 8
  Autochthonous unit 9
    Crystalline basement 9
    Sedimentary cover 10
  Lower parautochthonous unit 13
  Upper parautochthonous unit 14
  Structure 16
  Metamorphism 17
  Discussion 18
Rössjön and Lockringen Nappe Complexes 19
  Rössjön Nappe Complex 19
    Crystalline rocks 20
    Sedimentary units 22
  Lockringen Nappe Complex 24
    Lockringen I 24
    Lockringen II 24
    Lockringen III 25
  Structure 25
  Metamorphism 27
    Rössjön 27
    Lockringen 28
    Mineralogical evolution and metamorphic zonation 29
    Cataclastic rocks 31
    Time relationships 32
  Discussion 33
Seve-Köli Nappe Complex 34
  Northern area 35
  Southern area 38
  Structure 38
    Correlation 40
  Metamorphism 40
  Discussion 45
Conclusion 46
  Sedimentation 46
  Tectonic and metamorphism 47
  Metamorphic facies series 48
Acknowledgements 52
Résumé français 52
References 55

SUMMARY

Gotthard Walser: Geology of the Hotagen area, Jämtland, central Sweden. SGU C 757. Uppsala 1979.

The Hotagen area is situated within the Caledonian belt of central Sweden, on the border with Norway, about 100 km north of Östersund. Approximately 350 km^2 were mapped on a scale of 1:20 000.

In the area studied, metamorphic nappes override parautochthonous and autochthonous units. Structurally, the pre-Caledonian acid basement and late Precambrian to Ordovician metasediments can be divided into four main complexes:

The *Bergsjön Complex* comprises basement crystalline rocks of granite and porphyry, and a sedimentary cover of quartzites, black shales, limestone, and greywackes. An autochthonous unit, with a reduced and incomplete sedimentary suite, and two parautochthonous units are distinguished. An important tectonic boundary of the décollement type is located at the base of the parautochthon. The rocks have undergone two phases of deformation. The main phase (F_1) produced a fracture cleavage. A characteristic feature of the Bergsjön Complex is the very low grade of metamorphism.

The *Rössjön Nappe Complex* overrides the Bergsjön Complex on the northern flank of the Hotagen culmination. Four thrust sheets are distinguished, all consisting of Precambrian acid crystalline rocks and late Precambrian meta-arkoses. The Rössjön rocks have been subjected to three phases of deformation. F_1 produced a flat-lying slaty cleavage which was crenulated during F_2. The metamorphic grade of the Rössjön Complex is low (greenschist facies) and inverted. Both a chlorite and a biotite zone are described.

The *Lockringen Nappe Complex* overlies the Bergsjön Complex south of the lakes Rörvattnet and Lockringen. The Complex consists of three tectonic sub-units and is very similar to the Rössjön Nappe Complex in petrography: with granite, porphyry and meta-arkoses. The tectonic evolution of the Lockringen Complex is the same as for the Rössjön Complex although the configuration of the metamorphic zones is different. The grade of metamorphism decreases from bottom to top in the two lower nappes, and increases again in the upper nappe. This latter unit is possibly equivalent to the Särv Nappe.

The *Seve-Köli Nappe Complex* is the uppermost tectonic unit of the region, with only the lower part of the Seve rock sequence outcropping, this being a volcano-sedimentary suite with amphibolitic lenses and minor amounts of marble. The age of these rocks is unknown. Four phases of deformation affected the Seve rocks. F_1 is only detected in thin section with remnants of an S_1 surface in the garnets, or as an earlier cleavage crenulated by F_2. This second phase formed the main regional cleavage which was deformed by F_3 (crenulations) and F_4 (open folds). The mineralogical assemblages are characteristic of the epidote-amphibolite facies. The peak of metamorphism occurred between F_1 and F_2.

In conclusion, the structural evolution of the Hotagen rocks is described. Caledonian deformation and metamorphism of the Seve rocks began during the Middle Silurian, possibly along a subduction zone, and the metamorphism reached its maximum at this time. During F_2, the Seve rocks were uplifted and thrust eastwards over the Rössjön and Lockringen Complexes. Thrusting of the metamorphic nappes over the Bergsjön Complex and the formation of the décollement within the latter took place prior to F_3. This phase was followed by gentle folding of the nappe complexes in conjunction with the doming of the Olden anticline. The nappes are thought to have been transported very considerable distances eastwards, in the order of 70 (lower units) to over 400 km (Seve).

INTRODUCTION

The Hotagen region is situated within the Caledonian mountain range, in the county of Jämtland, Sweden, about 100 km north of Östersund on the border with Norway (Fig. 1).

The present study is based on fieldwork which was carried out during the summers of 1972–1974. The area, approximately 350 km², was mapped on the scale of 1:20 000 using aerial photographs. The Swedish part of the area lies within the topographic maps 20E Hotagen and 21E Håkafot. Forests and lakes as well as bogs, till and other Quaternary deposits occupy the low terrain where exposure is poor. The bedrock, however, is quite well exposed on the high terrain. Altitudes of up to 1 000 m are reached in the western part of the area.

The aim of this investigation was to obtain a detailed map of a restricted area where some of the main Caledonian nappes are superimposed on an autochthonous basement, to describe the tectonic and metamorphic relationships within and between the units distinguished, and, if possible, to establish the structural evolution of the area.

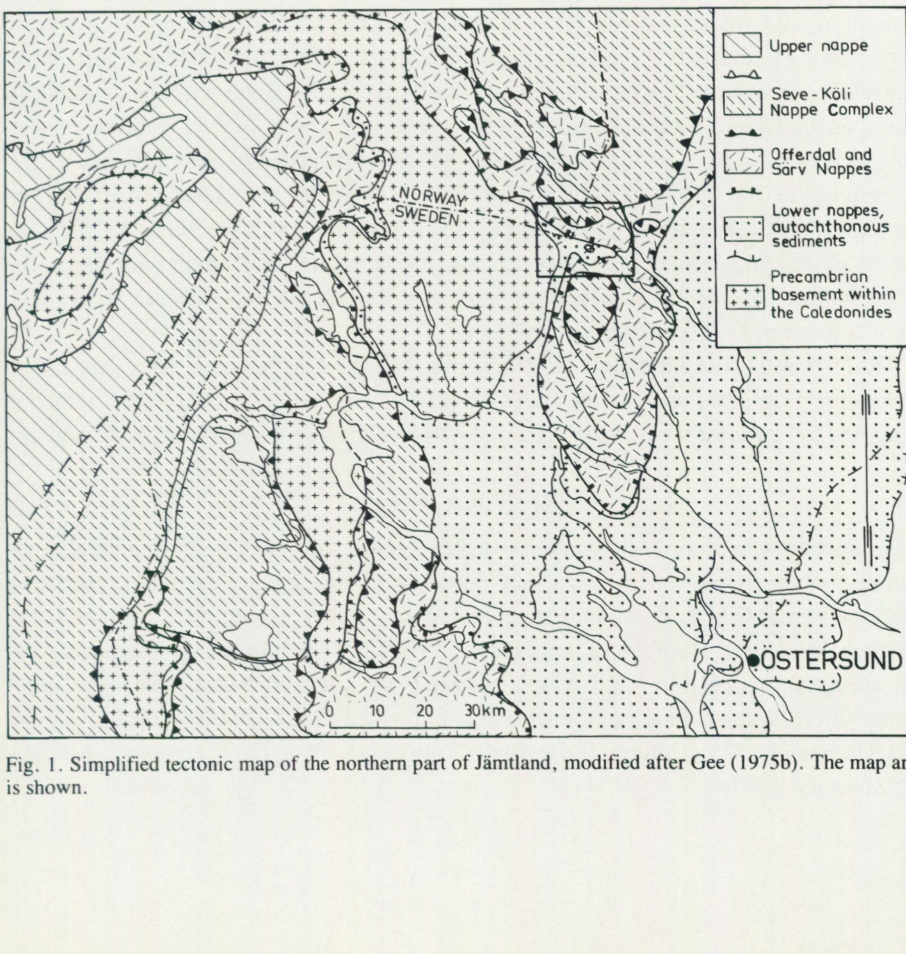


Fig. 1. Simplified tectonic map of the northern part of Jämtland, modified after Gee (1975b). The map area is shown.

General rock descriptions, structural and metamorphic analyses are given, based on hand specimen and microscope observations. Detailed accounts are given in another study (Walser 1976). The work described in this paper is a general investigation which may form the basis for future, detailed investigations within the area.

REGIONAL GEOLOGY

The superimposition of major tectonic units, from a weakly metamorphosed autochthonous basement to the basal part of the metamorphic Seve-Köli Nappe Complex, is the most interesting feature of the area (Fig. 1). The Seve sequence consists of a complex of gneisses, schists and amphibolites of unknown age and metamorphosed in the lower to the upper amphibolite facies (Gee 1975b). The nappe is wedge-shaped, thinning westwards (Zachrisson 1973). Outside the area described, the Seve sequence is overlain by Köli schists, low grade metasedimentary and metavolcanic rocks of Lower Palaeozoic age. The Seve-Köli Nappe Complex overrides the Offerdal, or Granite-Mylonite Nappe, composed of Precambrian crystalline basement (granites and porphyries) and probably late Precambrian meta-arkoses. The Särv Nappe, which also has a wedge-shaped geometry thinning westwards, lies between these two tectonic complexes, and is characterised by arkosic metasediments containing swarms of dolerite dikes (Strömberg 1955, 1969). This nappe is locally very thin. All these units belong to Törnebohm's metamorphic allochthon, or to Asklund's Great Seve Nappe. They have been thrust over parautochthonous units, for example the Olden Nappe (Asklund 1938, 1960), composed of Precambrian crystalline basement with a sedimentary cover of late Precambrian to Ordovician age. According to the literature, the Olden Nappe overrides the Jämtlandian Nappes (Asklund 1960) which are characterised by a décollement style (Gee 1975a), the Lower Palaeozoic sedimentary sequence, and the Jämtland Supergroup with thin slices of crystalline basement. These nappes rest upon the autochthonous Baltic Shield with its thin cover of Cambro-Silurian sediments.

More recently, the Jämtlandian, Olden and Offerdal Nappes have been grouped in an Eastern Complex, and the Särv and Seve Nappes in a Western Complex which is supposed to be rooted west of the present day Norwegian coastline (Gee 1975a and b).

PREVIOUS WORK

The Caledonides of central Scandinavia have been studied for approximately one hundred years. It was in this area that Törnebohm first applied the nappe theory in 1888 and established the main structures more or less as they are known today (Törnebohm 1896). With the exception of Högbom (1920), however, these ideas were not accepted at that time, and it was not until the nineteen-thirties that new major contributions to the geology of the area were published (Asklund 1933, 1960; Asklund and Thorslund 1935; Kulling 1941, 1942; Thorslund 1960; Du Rietz 1943; Kautsky 1953; Strand 1961).

Once the main geological relationship were more or less established, it was possible to carry out more precise investigations of the stratigraphy, nappe subdivisions, structural development, mechanism of nappe translation, crustal shortening, localisation of root zones etc. (Gee 1972, 1974; Gee and Zachrisson 1974; Gee et al. 1974; Ramberg 1966; Strömberg 1955, 1961, 1969, 1974; Stålhös 1956, 1958; Zachrisson 1969, 1973). More recently, in the light of the plate tectonic theory, modern interpretations have been proposed to explain the evolution of the Caledonides of central Scandinavia (Gale and Roberts 1972, 1974; Gee 1975a and b).

For many years, the Scandinavian Caledonides was a classic area for the development of the concept of progressive metamorphism (Goldschmidt 1915; Vogt 1927; Barth 1938). More recent investigations have been concerned with the internal units of the orogeny and with structural investigations (Roberts 1968; Roberts et al. 1970; Henley 1970; Trouw 1973; Zwart 1974; Stephens 1977; Sjöstrand 1978).

Apart from Törnebohm's (1896) and Högbom's (1884, 1920) maps, only two maps have been published of the area, namely the geological map of the Pre-Quaternary rocks of Sweden (Magnusson et al. 1960) on the scale of 1:1 000 000, and the map covering the Norwegian part of the present investigation on the scale of 1:50 000. The latter map was the work of Foslie (see Oftedahl 1956), giving the rock types in a petrographically well defined manner, but the field relationships are often obscure. This map was useful, however, at the beginning of the present investigation.

PRESENT INVESTIGATION

Three superimposed tectonic complexes are recognised. The middle complex is subdivided into a northern and a southern part, the differences and similarities are discussed in the text. Each complex has its own characteristics and was studied from stratigraphic, petrographic, tectonic, and metamorphic point of view. The complexes are, from upper to lower (enclosures I and II):

A. *The Seve-Köli Nappe Complex,* which is allochthonous and of higher metamorphic grade, lies at the top of the tectonic pile as it appears in the Hotagen area. It consists of various metasediments with lenses of amphibolite. In the northern part of the map area, it overrides the Rössjön Nappe Complex, and to the south the Lockringen Nappe Complex.

B. *The Rössjön-Lockringen Nappe Complexes*

a) The Rössjön Nappe Complex, which is allochthonous and metamorphic, consists of a pile of crystalline slices with intercalated sedimentary units. The Rössjön Complex overrides the Bergsjön Complex, and is situated to the north of the Hotagen culmination.

b) The Lockringen Nappe Complex is very similar to the preceding one in rock composition and tectonic level. It overrides the Bergsjön Complex on the south side of the culmination, and is also divided into several units.

TABLE 1. Classification of the cataclastic rocks, after Higgins (1971, p. 3).

Approximate volume percent porphyroclasts in rocks *with* fluxion structure. or Approximate volume percent fragments in rocks *without* fluxion structure.	Rocks *without* primary cohesion	Rocks *with* primary cohesion				Approximate size of *most* porphyroclasts in rocks *with* fluxion structure. or Approximate size of *most* fragments in rocks *without* fluxion structure.
		Cataclasis dominant over neomineralization-recrystallization			Neomineralization-recrystallization dominant over cataclasis	
		Rocks *without* fluxion structure	Rocks *with* fluxion structure		Rocks *with* fluxion structure	
>50	Fault breccia	Microbreccia	Protomylonite		Mylonite gneiss (mylonite schist)	Visible to naked eye
<50, 30, >10			Mylonite	Phyllonite (variety)		>0.2mm
<10	Fault gouge	Cataclasite	Ultramylonite		Blastomylonite	<0.2mm

All rocks are gradational

C. *The Bergsjön Complex* consists of autochthonous and parautochthonous (in a much broader sense than in the Alpine usage) units. The rocks are affected by a very low grade of metamorphism. This Complex appears in a culmination with a local E–W trend located in the central part of the map area. The Bergsjön Complex is partly an eastern extension of the Olden massif.

The spectacular development of cataclastic rocks is a striking feature of the Hotagen area. These processes affected all the nappe complexes to a greater or lesser extent. They are, however, especially characteristic for the Rössjön and Lockringen Nappe Complexes, these being equivalent to the Granite-Mylonite Nappe of previous authors (e.g. Asklund 1960).

Cataclastic metamorphism is described by most metamorphic petrologists as taking place at low temperatures where recrystallisation is insufficient. Such processes, however, might well develop deeper in the earth's crust where recrystallisation is still active, for example along discrete thrust planes developing under metamorphic conditions (Trouw 1973; Zwart 1974). The understanding of the cataclastic processes is still very restricted and consequently the nomenclature is generally vague and confused. The classification proposed by Higgins appears to be one of the more coherent ones (Higgins 1971) and is followed in this paper (Table 1).

The literature contains many discussions concerning the classification and subdivision of the metamorphic facies. The scheme proposed by the International Commission for the Geological Map of the World (Zwart et al. 1967) is used here.

BERGSJÖN COMPLEX

The Bergsjön Complex lies at the base of the Caledonian tectonic pile in the Hotagen area. Three tectonic subunits, separated by important thrust boundaries are recognised within the Complex. These are, 1, an autochthonous, crystalline basement with a thin sedimentary cover, 2, a lower parautochthonous division of sedimentary nappes of décollement style with very thin slices of basement, and, 3, an upper, parautochthonous division involving mainly crystalline rocks with subordinate remnant of a sedimentary cover.

AUTOCHTHONOUS UNIT

CRYSTALLINE BASEMENT

The autochthonous crystalline basement consists predominantly of granites which are intruded by dikes of porphyry and coarse-grained dolerite. The granite is a coarse-grained variety which is sometimes porphyritic. It is light grey in colour due to a minor content of dark minerals. Microcline-perthite (60%), quartz (30%) and oligoclase (10%) are the main mineral constituents. Biotite is the main mafic mineral in the well preserved zones. The mineralogy is characteristic for an alkali-feldspar granite, according to the IUGS' classification.

Porphyry dikes intrude the coarse-grained Olden granite of the autochthonous unit of the Bergsjön Complex. The dikes have been studied at two localities along the Grubbdalsån river (20E, 9b). The more interesting locality is the first outcrop of crystalline rocks along the river, about 2.5 km west of the lakes St. Kingen and Rörvattnet. The second locality is situated about 3 km west of the first. The dikes are thin, subvertical and orientated N–S (Fig. 2). The rock is fine-grained, massive and

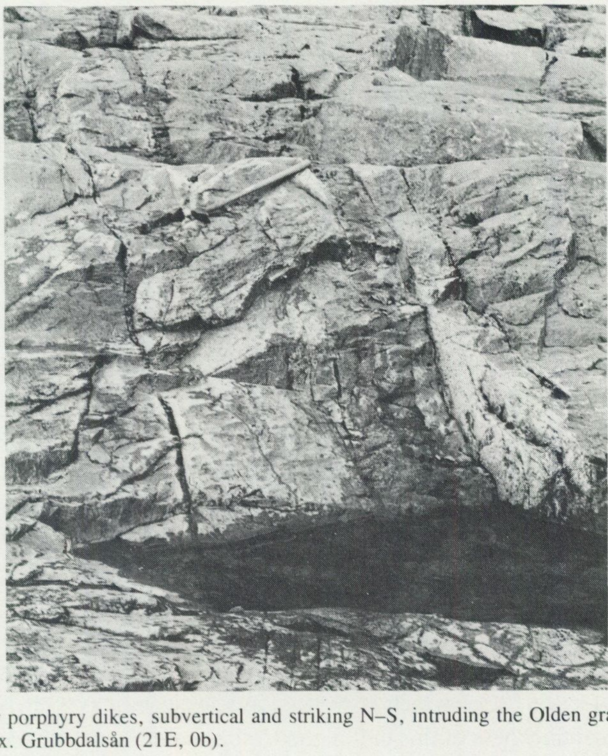


Fig. 2. Dark grey porphyry dikes, subvertical and striking N–S, intruding the Olden granite. Autochthon, Bergsjön Complex. Grubbdalsån (21E, 0b).

black in colour. The texture is felsophyric with an important cataclastic overprinting. These porphyries are of a mineralogical and chemical dacitic composition. Recrystallisation of quartz has taken place. The existence of these dikes is interesting if they are related to the porphyries which cover large areas in the central parts of the Olden massif. Time relationships within the granite could be solved. But no conclusions can be drawn at present as evidences of metavolcanites intruded by granite have been reported elsewhere (M. Wilson pers. comm.).

In many places, the crystalline basement was subjected to an important deformation, mainly of the cataclastic type. Some mylonites are present but protomylonites are more frequent (cf. classification, Table 1). The granite, however, is always clearly identified. Epidote-zoisite, chlorite, titanite, and calcite are present in the deformed rocks, and quartz is recrystallised. Perthite seems to be more abundant, and the oligoclase is albitised.

The autochthonous crystalline basement constitutes the SW part of the area mapped (Olden massif) and also outcrops in two places along the western and southwestern shores of lake Bergsjön (20E, 9c).

SEDIMENTARY COVER

The sedimentary sequence of the Bergsjön Complex (Fig. 3) was more strongly affected by deformation, especially cataclasis, than the crystalline basement. The stratigraphic column is highly disturbed, and no fossil evidence is preserved. However, the stratigraphy of comparable sequences in adjacent areas of the Caledonides (Jämtland) is nowadays well established (Asklund 1960; Thorslund 1960; Gee 1972; Gee et al. 1974; Strömberg 1974; Gee 1975). Gee (1975) has classified the sediments into four groups which belong to the Jämtland Supergroup (Table 2).

The autochthonous sedimentary sequence in the Hotagen area is well exposed in a section of the Grubbdalsån river (Fig. 4) west of lake Rörvattnet, and along the road which lies parallel with the river. The sediments are partially deformed and imbricated, and their total thickness does not exceed 15 m.

The series begins with 20 cm of basal conglomerate which has a normal sedimentary contact with the underlying crystalline basement (Fig. 5). Dark silts, about 30 cm, a second conglomeratic horizon, 15 cm, and a further 50–60 cm of dark silts overlie the basal conglomerate. The conglomerates are polygenic, poorly sorted, with rounded and angular elements from 1 mm to 5 cm in size. The components are only slightly deformed. The constituent rock types are hornblende schists, quartzite, granite and porphyry, with individual grains of quartz and feldspar, and characteristic phosphoritic nodules. The cement is argillitic and slightly ferruginous.

The conglomerates and silts are overlain by typical rusty, pyritic and graphitic dark shales. These almost certainly belong to the widespread Middle Cambrian-Tremadocian black alum shale facies which is well known in Scandinavia. It is impossible to determine the real thickness of this unit in the Hotagen area, but it can be up to 3–4 m.

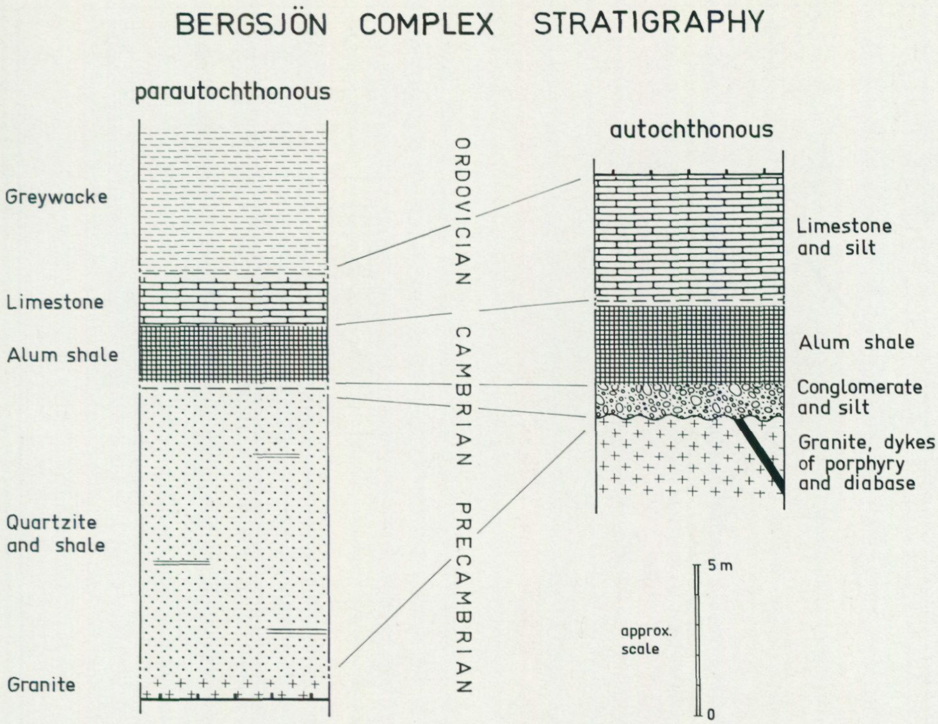


Fig. 3. Compared stratigraphy of the autochthonous and parautochthonous sedimentary sequences, Bergsjön Complex, Hotagen area.

TABLE 2. Jämtland stratigraphy, after Gee (1975a).

GROUP	FORMATION	LITHOLOGY	AGE	
ÄNGE	EKEBERG	Graywacke and shale	Llandoverian	Silurian
	BANGASEN	Shale		
	BERGE	Limestone		
	EDE	Quartzite		
TASJÖN	NORRAKER	Graywacke and shale	Tremadocian to Ashgillian	Ordov.
	FJÄLLBRÄNNA	Black shale and bituminous limestone	Middle Cambrian to Tremadocian	Cambrian
SJOUTÄLVEN	GÄRDSJÖN	Quartzite and shale	Varangian to Middle Cambrian	
	DABBSJÖN	Tillite and shale with outsized clasts	Varangian	
RISBÄCK	KALVBERGET	Dolomite	pre-Varangian	Precambrian
	MANGMANBERGET	Feldspathic sandstone		
	TVÄRSELET	Siltstone and fine sandstone		
	STORA RAIJAN	Feldspathic sandstone		
CRYSTALLINE BASEMENT			about 1800-1000 m.y.	

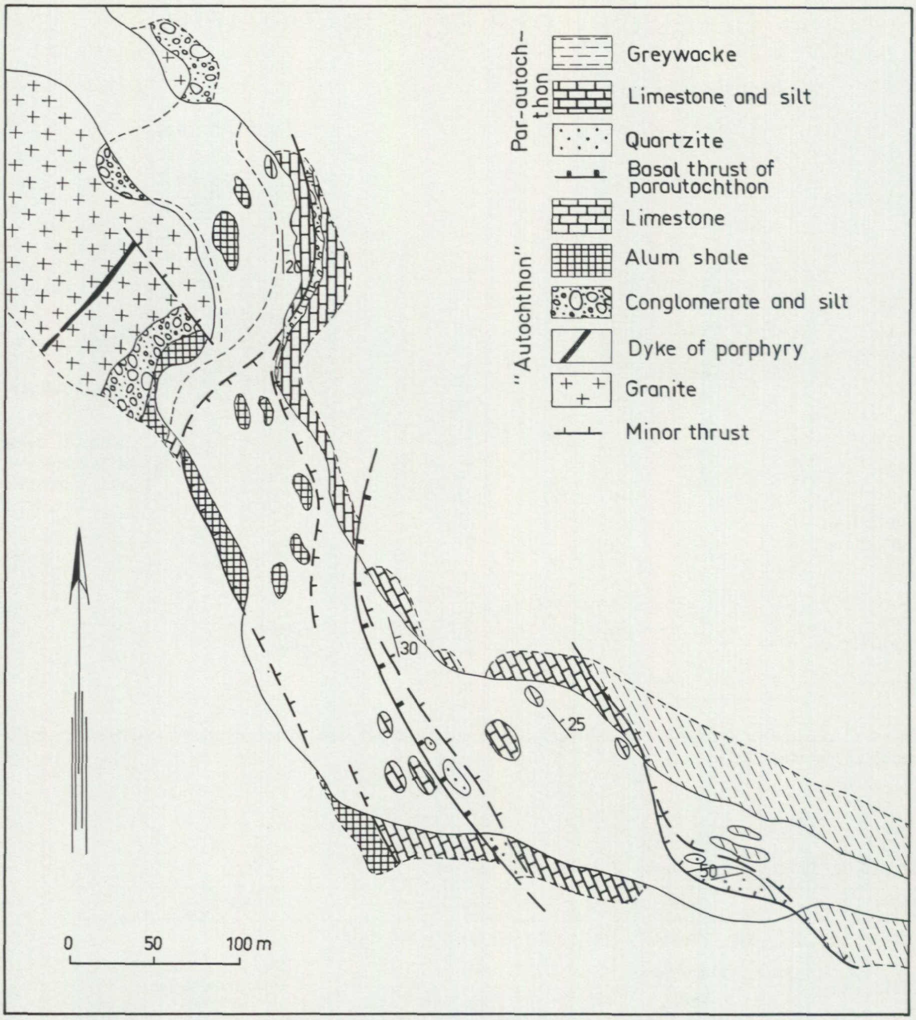


Fig. 4. Schematic map of the contact zone between the Precambrian basement and the autochthonous Cambro-Ordovician sedimentary cover. Autochthon, Bergsjön Complex. Grubbdalsån (20E, 9b).

The alum shales are overlain by an essentially calcareous unit which is 5–6 m thick in the section studied. The unit begins with alternating layers of silts and limestones which vary in thickness from 1 cm to 0.5 m. The limestones dominate upwards, and they are correlated with the Orthoceras limestone (Asklund 1960). It is impossible to evaluate precisely the thickness of the calcareous unit because of deformation and extensive recrystallisation of calcite.

The autochthonous sedimentary sequence is tectonically repeated twice in the Grubbdalsån section.

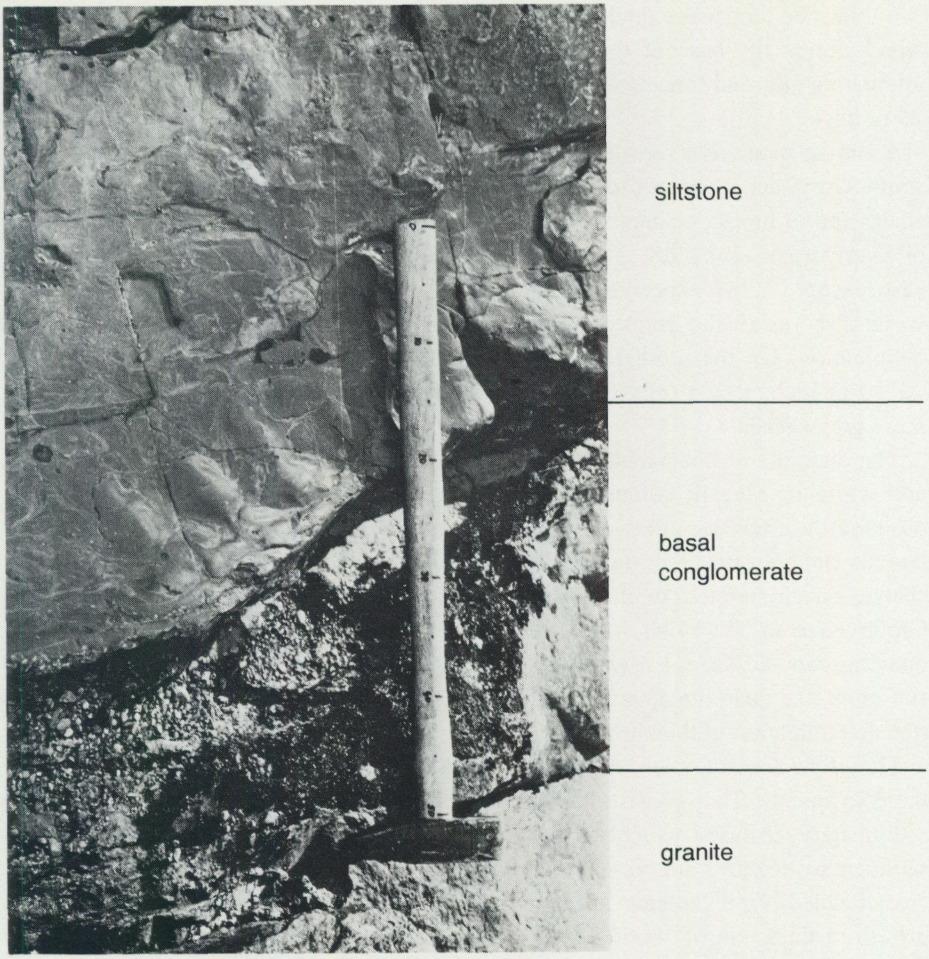


Fig. 5. Primary sedimentary contact between the granitic basement and the autochthonous sediments. Autochthon, Bergsjön Complex. Grubbdalsån (20E, 9b).

LOWER PARAUTOCHTHONOUS UNIT

The lower parautochthonous unit consists predominantly of a sedimentary sequence which is somewhat different from that of the underlying autochthonous unit. The unit as a whole is characterised by a décollement tectonic style. The lowest unit of the parautochthonous sedimentary sequence is a quartzite which is probably older than the conglomerate at the base of the autochthonous sequence. The quartzite is overlain by a monotonous succession of greywackes. Intercalations of poorly preserved alum shales and limestones are found at some localities.

The parautochthonous sequence is best exposed in the Grubbdalsån river where the following succession is observed (Fig. 4):

– A thin slice, one metre thick, of white, fine-grained, massive and deformed quartzite which forms the base of the first tectonic sub-unit. The quartzite is overlain by alternating silts and limestones passing up into pure limestone. This sub-unit is about 20 m thick.

– A similar quartzite overrides the limestone and thins to the NW but thickens to the south. Greywackes directly overlie the quartzite in the Grubbdalsån river, but alum shales and/or limestone intercalations are found at other localities (e.g. north and west of Svarttjärnen, 20E, 9b). The greywackes occupy the major part of the unit to the east, except for two exposures of autochthonous basement on the western and south-western shores of lake Bergsjön. These greywackes have been traced around the Olden culmination. On the northern side of the window, quartzite occurs again in cliffs, 20–30 m high, tectonically on top of the greywackes. This quartzite is overlain by more greywackes.

The quartzite of this parautochthonous sequence is generally fine-grained, massive and white or blue in colour. Channel-shaped, micro-conglomeratic zones can be observed in a few localities. Only a few shale intercalations, with brown-green fine laminae are preserved e.g. on the southern flank of Höbergsfjället (21E, 0b). No green shales, conglomerates, or the basal tillite which is characteristic of the Sjoutälven Group (Gee et al. 1974) have been encountered. The apparent thickness of the quartzite can vary from 1 m to about 30 m in the highest tectonic sub-unit. In the lower sub-units, the quartzite appears to thicken eastwards, but deformation prevents accurate determination of thickness.

The greywackes are very monotonous and no stratigraphy has been established for these sediments. They consist of alternating layers of sand and silt with well-preserved sedimentary features which facilitate polarity and structural investigations. The sedimentary features are typical for turbidites, with graded bedding at the base, and cross-bedded, fine laminae at the top. The greywackes may have a maximum, preserved thickness of about 50 m. They are the youngest deposits within the area studied, but they have not yielded any fossils.

This lower, parautochthonous unit contains some thin slices of crystalline basement, predominantly granite, which are found below the quartzite e.g. near Rötviken. Precambrian acid volcanic rocks are also represented in a few localities, but they are not easily distinguished from the overlying massive quartzite and may easily be overlooked.

UPPER PARAUTOCHTHONOUS UNIT

Crystalline rocks characterise this unit, with granite and porphyry in fairly equal proportions, intruded by subordinate coarse-grained dolerite dikes.

There are two varieties of granite. The more frequent type is comparable with the Olden granite (i.e. poor in dark minerals) except for an important reduction in grain size due to cataclasis. The percentage of quartz decreases in some places, and the rock tends towards a syenite. The An content varies from 20% in the well preserved rocks, to albite in the crushed zones. The potash feldspar is microcline-perthite which often forms well-preserved eyes. The mafic minerals are muscovite and biotite, the latter being generally altered to chlorite. Idiomorphic crystals of epidote and sphene are more abundant than in the lower tectonic units. The second type of granite is comparable with a monzogranite and contains amphibole. Porphyry in the upper parautochthonous unit occupies approximately the same volume as the granite. The relationship between the two rock types is obscured by deformation which is generally concentrated along the contact zones. The porphyry is characteristically grey-pink, sometimes dark, fine-grained, extremely massive, and in some places with a discrete tectonic layering. In the well preserved rocks, there is no difficulty in recognizing phenocrysts of feldspar which are clearly pre-schistosity. The primary texture is felsophyric. These Precambrian acid volcanics are predominantly of a rhyolitic or rhyodacitic composition. Intermediate terms of a dacitic composition occur also, with a characteristic dark colour, but they are not frequent.

There is little mineralogical difference between the main porphyry and the main granite types. Microcline-perthite, plagioclase and quartz are the major constituents, in various proportions, and mafic minerals are rare. Epidote, sphene, calcite, and muscovite are relatively frequent in the deformed zones. The porphyry can easily be taken for quartzite in the parautochthonous units, especially within zones of intense deformation and ''melange''.

The acid igneous rocks of the upper tectonic unit are intruded by coarse dolerites which do not penetrate into the overlying sediments.

Similar bodies are also present in the crystalline rocks of the autochthonous unit and the lower parautochthonous units, but they seem to be less abundant than in the upper parautochthonous unit. The dolerites are deformed and look like boudins which are crushed and metamorphosed (lower greenschist or ''sub-greenschist'' facies) along the contacts, but often well preserved in the core. Here it is easy to identify a sub-ophitic primary texture, with Ti-augite and labradorite as essential constituents and late magmatic hornblende and biotite. The bodies are fairly abundant, but the pattern of intrusion is not apparent.

Finally, the upper parautochthonous unit contains remnants of a sedimentary cover of quartzite and greywackes. The main occurrence of these sediments is found on the southern flank of Högbergsfjället, west of lake Kingen, with a thickness of some 50 m. Good exposures of the sediments are also found about 1 km north of Rötviken. Here they are reduced to 2–3 m. In the central part of the area, north of Rörvattnet, the sediments are very crushed and never exceed 1 m in thickness. In spite of the strong cataclasis, however, the sediments are easily compared with those of the lower parautochthonous unit.

STRUCTURE

Detailed field investigations revealed three different main tectonic units, an autochthonous unit, a lower parautochthonous unit and an upper parautochthonous unit, within the Bergsjön Complex, all characterised by a similar sedimentary cover. The structures are dominated by thrusting accompanied by the development of a fracture cleavage and followed by large-scale open folding.

A fracture cleavage, S_1, has developed in most of the rocks, except for the thick and massive quartzite horizons. S_1 is particularly well developed in the greywackes where the structural relationships are well exposed. There is always a marked angle between the primary S_0 and secondary S_1 surfaces. The orientation of the latter varies around E–W (strike), 40°N (dip, 20–80°). Folding of the bedding, with S_1 as the axial plane, is common. F_1 probably accompanied the décollement translation. This phase of deformation was not very homogeneous since S_1 is not equally well developed in all the rocks. The F_1 folds are asymmetric with irregular axes (NE–SW to N80°W) and with a general vergence towards SE–S. The S_1 cleavage appears to be parallel with the main foliation in the overlying nappe complexes, but the exact relationships are not observed as the contacts consist of extremely crushed rocks between slices of basement at the northern limit of the Bergsjön Complex, and between incompetent mylonitic greywackes and phyllonitic meta-arkoses south of the Rörvattnet and Lockringen lakes. No conclusive correlation can therefore be made.

F_2 produced very open, cylindrical folds but no cleavage, and deformed the thrust planes within the area investigated. F_2 is probably related to the doming of the Olden massif and the development of major antiforms and synforms (e.g. the Offerdal Synform) after the emplacement of the Caledonian thrust pile.

Large, subvertical faults, trending more or less N–S, cut the various tectonic units as well as the thrust planes. They were therefore formed after the emplacement of the nappes and may be the result of the adjustment of a brittle basement to F_2, or they may be related to the Scandinavian Tertiary uplift.

Special attention should be drawn to the tectonic position of the crystalline rocks within the lower, essentially sedimentary parautochthonous unit. These crystalline rocks are associated with the quartzites at the base of the tectonic sub-units, or they occur in the core of what is here interpreted as overturned and thrust anticlinal structures (cf. profiles CC' and DD'). In a few cases, the ''floating'' nature of these basement relics appears quite convincing in the field. The best locality lies 400 m to the north of the road between Rötviken and Rörvattnet, 2 km east of Rörvattnet (20E, 9d). Other outcrops are found along the road to Stensjön lake, north of Svarttjärnen lake (20E, 9b), or on the southern flank of Höbergsfjället (21E, 0b). In the latter area, it is clear that the basement implications become gradually more important from the lower to the upper tectonic units. In other cases, however, the tectonic position of such basement rocks is not very clear from field evidence. For example, the granite and porphyry outcropping in Rötviken and further west, are here interpreted as a crystalline slice, thicker than usual for the Hotagen area, which lies at the base of the parautochthon. Factors favouring a parautochthon position are: the elongated geometry of the body which follows the general structures within the parautochthon as distinct from the autochthonous antiforms; the petrographic composition (presence of granite and porphyry); differences in texture and degree of cataclasis as compared with the typical Olden granite.

Other interpretations could be: the existence of thrust planes with short translations (kilometre scale or less) and rooting quite locally, involving the Olden basement as well as the Bergsjön sedimentary cover, and implying that the Jämtland décollement does not override the Olden massif; or, imbrication of the ''autochthonous'' basement after the emplacement of the parautochthonous units, which involved the latter and disrupted the décollement thrust plane. The results of mapping in the Hotagen area, however, do not favour these latter interpretations.

METAMORPHISM

A very low grade of metamorphism has developed in the autochthonous and parautochthonous units, in association with the cataclastic processes in which comminution is the dominant feature in comparison with recrystallisation. Fine-grained chlorite and muscovite are almost ubiquitous in the fine-grained pelitic sediments. The mineralogical transformations are incipient in the medium- to coarse-grained crystalline rocks. Oligoclase is present in the granites in the well preserved areas, and labradorite and Ti-augite in the greenstones. As a rule, the metamorphism is restricted to many discrete shear zones where phenoblasts of calcite, quartz, epidote and sphene have developed. The assemblage albite+chlorite+iron-rich epidote+actinolite is occasionally found in the mafic rocks. Minerals typical of very low grade metamorphism, such as lawsonite, prehnite or pumpellyite have not been observed. From the evidence available, it cannot be inferred that greenschist facies conditions prevailed within the Bergsjön Complex. Iron-rich epidote (pistacite) can easily co-exist with actinolite during very low grade metamorphism, as has been reported from other areas (Winkler 1976). The Ca-Al minerals, and possible pumpellyite, are known to be unstable when the CO_2 content of the fluid phase is relatively high, being replaced then by minerals such as calcite, pyrophyllite, clay minerals and quartz. A distinction between areas of very low grade and low grade metamorphism cannot therefore be established on the basis of mineralogical associations (Winkler 1976). More detailed investigations of clay minerals, phyllosilicates and graphitic sediments could provide new information.

The metamorphism of the Bergsjön Complex is attributed to the process of overriding by the allochthon. In the light of present knowledge, however, it cannot be stated whether the allochthon provided a specific heat flow to produce an inverted metamorphic sequence within the Bergsjön Complex. The load of overlying nappes (before erosion) combined with a normal heat flow of about 20–30° C/km would, however, appear to be sufficient to produce the low grade of metamorphism which can thus be classified as of the burial type.

DISCUSSION

The three tectonic sub-units within the Bergsjön Complex can be differentiated not only on their crystalline rock content, but also on differences in their sedimentary sequences.

The autochthonous sedimentary sequence, which is very thin (10–15 m), lies conformably on the crystalline basement with a basal conglomerate. The conglomerate and silts, when compared with the stratigraphy of the Jämtland Supergroup (Gee et al. 1974), may well represent the highest member of the Gärdsjön Formation, also referred to in the literature as the Höberg conglomerate (Strömberg 1975). This conglomerate is widespread in Jämtland. The overlying black shales of the autochthonous unit of the Bergsjön Complex can be correlated with the ''Orthoceras'' limestone (Thorslund 1960) or with the Kalkberget Formation (Gee et al. 1974).

The absence of the late Precambrian and early Cambrian quartzite in the autochthonous sedimentary sequence has to be explained either by non-deposition, the Hotagen area being emerged at this time, or by erosion following intermittent emersions, the equivalent Gärdsjön Formation being characterised by several transgressive and regressive sedimentary cycles. Similar processes can also explain the absence of the (probably) Ordovician greywackes. In this case, however, an alternative hypothesis is that the limestone and shale unit, particularly the calcareous upper part, represents a chronostratigraphic equivalent of the greywackes (Norråker Formation) from a more shallow water environment.

The middle tectonic unit contains only thin slices of granite in a few localities, and is characterised by the development of sediments which can be correlated with those of the Jämtland Supergroup: the quartzite and shales are probably equivalent to the upper part of the Gärdsjön Formation (Gee et al. 1974) and the greywackes are equivalent to the Norråker Formation with some crushed remnants of the Fjällbränna Formation (black shales) in between. These sediments therefore range in age from late Precambrian, or Cambrian, to Ordovician.

The upper crystalline unit is more controversial. The unit contains many slices of basement which have been detached and thrust, similar to the overriding nappe complex, but sediments of ''Bergsjön'' affinities are also present.

Facies variations cannot be easily demonstrated due to the tectonic overprinting. On a regional scale, however, if one accepts the décollement hypothesis as well as a general east-southeastwards nappe translation, one can deduce that the sedimentary sequence was thicker and more complete to the west-northwest, with the deposition of quartzite, alum shales, limestone and greywackes.

An important fact to point out is the similarity between the autochthonous sequence in the Hotagen area and the thin autochthonous deposits in the Tåsjön–Ormsjön area which underlie the major décollement surface of the Jämtlandian Nappes with the overriding quartzite of the Gärdsjön Formation (Gee et al. 1974). These similarities would suggest that the major Jämtlandian décollement is present in the Hotagen area as well and that it does not root beneath the Olden massif (Gee 1975a and b) neither within the area studied nor for some considerable distance westwards (cf Foslie's map).

Olden Nappe: Even if important Caledonian deformation does occur within the Olden massif, it is the writer's opinion that these rocks were not displaced over great distances, and can well be considered as autochthonous. It should be added that recent investigations further to the southeast (Schenk 1975) raised doubt as to the reality of the Olden Nappe, at least in the sense of Asklund. The existence of the Olden Nappe (Asklund 1960) is therefore strongly doubted.

Offerdal Conglomerate: Some attention should be paid to the so-called Offerdal Conglomerate which should be a striking feature of the Hotagen area according to the geological map of the pre-Quaternary rocks of Sweden (Magnusson et al. 1960). This conglomerate is characteristic of the southern rim of the Ansätten klippe (Törnebohm 1896) and similar formations appear in other areas within the county of Jämtland (Högbom 1920; Asklund 1938; Strömberg 1975). Two main theories arose about the age and the tectonic position of this conglomerate. Asklund (1938, 1960) regarded it as a Silurian deposit, the youngest part of the sedimentary sequence belonging to the Olden nappe. But several authors favour a late Precambrian age and attribute it to the Offerdal Nappe (Törnebohm 1896; Högbom 1920; Strömberg 1975). On the other hand, recent detailed mapping in the Hotagen-Ålviken area (SE of the area described here) has demonstrated the existence of an inverted sedimentary sequence. Conglomerates, which were earlier interpreted as the Offerdal Conglomerate of Silurian age, are actually conglomerates belonging to the Gärdsjön Formation of Varangian to Middle Cambrian age (Schenk 1975). The occurrence of micro-conglomeratic lenses in the parautochthonous quartzite of the Hotagen area apparently led to a similar misinterpretation.

RÖSSJÖN AND LOCKRINGEN NAPPE COMPLEXES

As Rössjön and Lockringen Nappe Complexes have a number of similar characteristics, they are treated together.

RÖSSJÖN NAPPE COMPLEX

The Rössjön Nappe Complex has similarities with the underlying Bergsjön Complex in the composition of its crystalline sole which also consists of granite and porphyry intruded by greenstones. There are many differences, however, concerning the sedimentary cover, metamorphism and structures. The rocks of the Rössjön Complex cover most of the area mapped. Three rock types outcrop in equal proportions, granite, porphyry and meta-arkose. Metadolerites are subordinate. The primary relationships between the different rock types are obscure because of the concentration of tectonic movements along the contacts. The contact basement–sediment is sometimes exposed but never primary.

The Complex is divided into four tectonic sub-units, all of which are similar except for the uppermost unit which seems to have been subjected to a slightly different tectonic and metamorphic evolution. The most interesting features of this Complex are the cataclastic phenomena which are particularly well developed, all stages from a fresh rock to a ''glassy'' crypto-crystalline ultra mylonite are frequently observed. The four thrust sheets each consist of Precambrian acid crystalline basement and a late Precambrian meta-arkose unit.

CRYSTALLINE ROCKS

In the area described, there are few primary differences between the granites of the Rössjön and Bergsjön Nappe Complexes, especially those of the upper parautochthonous unit. The same syenogranite, poor in mafic minerals, and the very subordinate monzogranite with amphibole are found. The effects of the regional and dynamical metamorphism, however, allow the allochthonous granites to be distinguished from the parautochthonous granites. One of the main distinguishing features is that the granites of the Rössjön Complex are schistose, and this schistosity lies parallel with the main schistosity in the intercalated sediments. Primary textures are often quite well preserved in many localities where cataclasis was minimal, preservation being due to the coarse granulometry of this rock type, but mineralogical changes due to regional metamorphism are, however, important. The textures are generally blasto-hypidiomorphic or blasto-allotriomorphic. The main mineral constituents are microcline-perthite, quartz and albite. The mafic minerals include neo-crystallised biotite in the upper tectonic units, muscovite (two generations), chlorite (retrogressed from primary biotite in the lower tectonic units), epidote (very common and developed from plagioclase), actinolite (developed from primary hornblende), sphene and calcite.

Like the granite, the allochthonous porphyries of the Rössjön Complex can only be distinguished from the parautochthonous porphyries of the Bergsjön Complex on the basis of structure and metamorphic evolution. These flinty and fine-grained rocks are grey or pale-pink in colour, sometimes with phenoblasts deformed by a well-developed schistosity. They always exhibit a light compositional layering parallel to the main schistosity and it is not always possible to distinguish a metaporphyry from a meta-arkose. In localities where the rock is well preserved, the texture is blasto-felsophyric: deformed phenocrysts of plagioclase (albite), quartz and microcline lie in a fine-grained matrix. Phenoclasts of microcline are abundant and form eyes of about 0.5 cm in size. This type of grano-porphyroblastic texture is very often superimposed on the primary texture and sometimes obliterates it completely. A variety of typical cataclastic textures are very well developed in all these fine-grained porphyries and

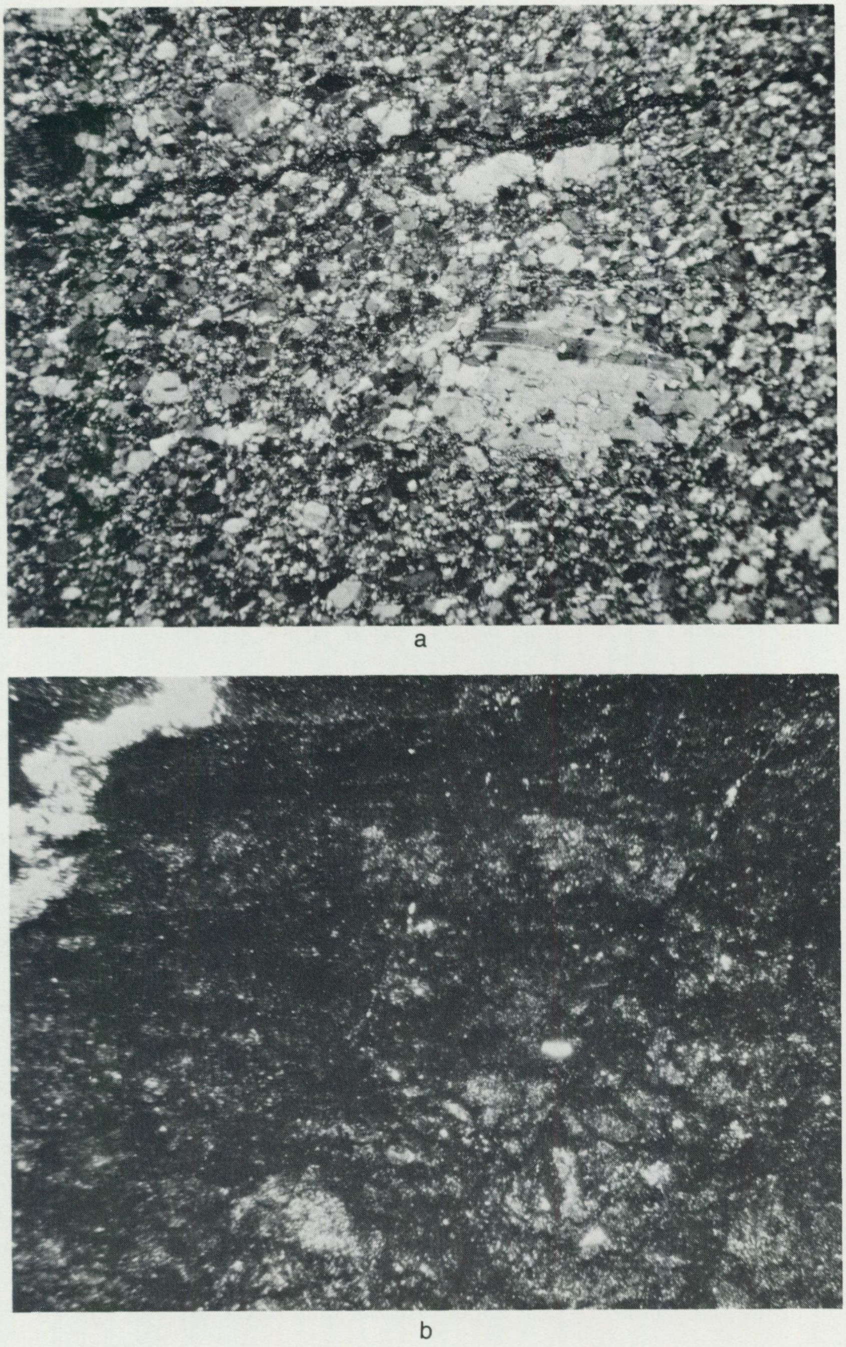


Fig. 6. Two extreme terms of cataclasis, Rössjön Nappe Complex. a=a well-preserved blasto-felsophyric porphyry (thin section, crossed nicols, 40 X). b=a flinty ultra-mylonite of the same type of porphyry (thin section, crossed nicols, 40 X).

they may obscure completely the primary textures (Fig. 6). The porphyries are predominantly of a rhyolitic to rhyodacitic composition.

Coarse-grained dolerite lenses which have been deformed to a greater or lesser extent intrude the crystalline rocks of the Rössjön Complex. They are similar to those of the Bergsjön Complex apart from their metamorphic evolution. The basic rocks have not been seen to intrude the overlying metasediments, and they are not more abundant than in the Bergsjön Complex. From a textural and mineralogical point of view, these rocks can be subdivided into two categories. The subdivision is based on the effects of the regional metamorphism, no primary differences exist. Within the lower tectonic units, the dolerite is fine- to medium-grained with a blasto-subophitic texture. In a few localities, it grades into a blasto-hypidiomorphic texture, but this type is always associated with and subordinate to normal dolerite. There are relics of Ti-augite but the basic plagioclase is saussuritised and transformed to albite and epidote. The augite and hornblende are usually uralitised and replaced by actinolite, chlorite and titanite. Biotite is partly present and partly replaced by chlorite.

Within the upper tectonic units, recrystallisation is complete and relics of augite are exceptional. The texture is grano-nematoblastic, and the paragenesis, more or less unstable, comprises the main constituents albite, actinolite, epidote, chlorite and the minor minerals biotite, muscovite, calcite, sphene, apatite, ilmenite.

SEDIMENTARY UNITS

The Rössjön Nappe Complex can be differentiated in the field from the Bergsjön Complex by intercalations of very characteristic and exclusively meta-arkosic sediments. These sediments cover a considerable part of the area mapped. The primary relationships between the sediments and the basement have not been observed, the contacts being always deformed. It is probable that these sediments were deposited on the basement (Gee 1975), and in some localities, for example near lake Lillsjön, coarsening of the grain size near the contact can be observed.

The meta-arkoses have the same appearance over the whole Hotagen area. They are pale-grey in colour and show a characteristic regular alternation of quartzo-feldspathic and pelitic layers. The thickness of the quartzo-feldspathic layers varies from about 5 cm to 0.5 m, and for the pelitic layers from a few mm up to 5 cm. This alternation is emphasised by the main schistosity which makes the rock very fissile along the bedding planes. The sedimentary origin of the rocks cannot be questioned. In many localities, unequivoqual sedimentary structures have been observed (cross bedding, Fig. 7). The apparent thickness of the unit is very variable within and between the different tectonic slices: from 2 or 3 m in the lowest slice west of lake Kingen, to 100 or 150 m in the uppermost slice NW of lake Sausjön. These are only rough estimations.

In the field, the meta-arkoses show very few variations. The pelitic content seems to increase from the lower to the upper tectonic units, but very detailed investigations

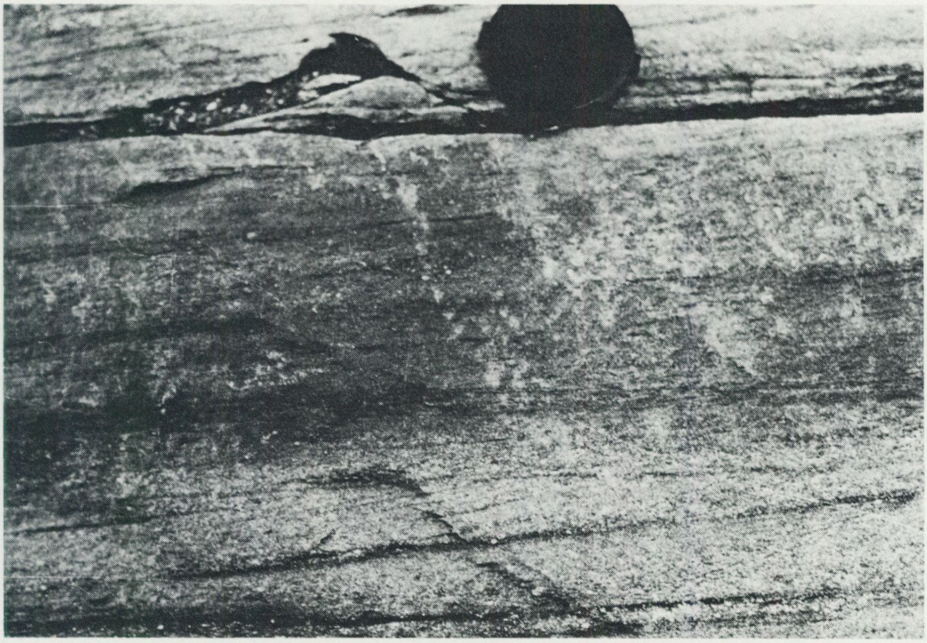


Fig. 7. Cross-bedding in meta-arkoses of the Lockringen Nappe Complex. Roadcut north of Tallsjön (20E, 9b).

have not been carried out and no conclusions can be drawn. Under the microscope, it is possible to trace a textural evolution and two categories are defined: meta-arkoses with a blastosedimentary texture (Rössjön I, II and III), and meta-arkoses with a grano-lepidoblastic texture (Rössjön IV). Planimetric analyses have revealed that most samples plot in the field between arkoses and subarkoses (or feldspathic quartzites) (Pettijohn et al. 1972). As the pelitic material increases, the rock tends to an arkosic wacke.

Quartz, microcline and plagioclase (albite) are the main constituents in a quartz, muscovite and chlorite matrix. Biotite, often retrogressed, is present in the more intensely metamorphosed parts. Rock fragments are very scarce, and calcite is generally not frequent, with some exceptions. Accessory minerals are epidote, mainly pistacite, and titanite, sometimes in splendid idiomorphic crystals.

These cross-bedded meta-arkoses are roughly comparable with the Risbäck Group (Gee et al. 1974; Gee 1975) which corresponds to the well known, but ambiguous, ''sparagmites'' (Gee 1972). These arkosic sediments of terrestrial to shallow water origin are older than the well known Varangian tillite (668 ma ±29, Pringle 1972). Similar sediments are known and studied in many parts of the Scandinavian mountain range (Asklund et al. 1935; Strömberg 1955; Stålhös 1956, 1958; Asklund 1958; Holtedahl 1960, 1961; Kulling 1961; Bjørlykke et al. 1967; Gee 1972; Gee et al. 1974) but never from an unambiguous autochthonous position (Gee 1975).

LOCKRINGEN NAPPE COMPLEX

The Lockringen Nappe Complex lies to the south of the Lockringen and Rörvattnet lakes, and consists of a pile of tectonic units which are very similar to the Rössjön Nappe Complex, that is, slices of acid crystalline basement intruded by dolerite and with meta-arkosic sedimentary intercalations. This Complex overrides the Bergsjön Complex and plunges southwards under the Seve-Köli Nappe Complex.

Three tectonic units are distinguished:
– The lowest unit (Lockringen I) is only composed of strongly retrogressed and cataclastic meta-arkoses.
– The middle unit (Lockringen II) has a ''normal'' composition with a basal granite-porphyry and an overlying meta-arkosic sequence.
– The upper unit (Lockringen III) is very thin and consists of crushed meta-arkoses associated with basic rocks.

The rocks types are similar to those of the Rössjön Nappe Complex, and only the differences will be discussed.

LOCKRINGEN I

Lockringen I consists only of strongly deformed meta-arkoses, and in the western part of the area mapped, it is sometimes difficult to distinguish these from the underlying greywackes. The greywackes are themselves affected by cataclasis which becomes more and more intense towards the major thrust contact. Nevertheless, the contact is generally well marked in the topograghy and easy to follow, especially on the aerial photographs. Near the lake Tallsjön, the transition to the overriding Lockringen II unit has been drawn where the almost completely retrogressed metasediments pass into well preserved and more typical meta-arkoses. Eastwards, the Lockringen I unit is intercalated between slices of acid crystalline rocks (profile CC').

From a petrographic point of view, the texture of Lockringen I is typically metamorphic, that is, grano-lepidoblastic. The rock is entirely recrystallised. The paragenesis consists of quartz, albite, biotite, muscovite, and, in the pelitic layers, a few garnets (cf. metamorphism). Accessory minerals include relics of clastic microcline in the quartzo-feldspathic layers, epidote, generally a zoned and twinned pistacite, titanite, ilmenite, zircon and apatite.

The rocks of this unit, which lie at the base of a major nappe, were submitted to an intense cataclasis accompanied by diaphtoresis, and are thus now phyllonites sensu-stricto (Higgins 1971).

LOCKRINGEN II

In composition, the middle unit is exactly similar to any sheet of the Rössjön Nappe Complex, viz. a thin basement slice composed of granitic and porphyritic rocks, intruded by coarse-grained dolerite, and with fairly thick meta-arkose. This unit can be distinguished only on the basis of its metamorphic evolution.

Porphyry is found at the base of the unit from lake Rörvattnet to lake Lockringen. Further east, the porphyry disappears and only granite is present. The thickness of the crystalline rocks varies from zero to 300 m. Westwards, from the eastern end of lake Rörvattnet, only typical meta-arkoses are present. The maximum apparent thickness of these sediments reaches approximately 300 m.

The porphyry of this Nappe Complex is not significantly different from similar rocks of the Rössjön Nappe Complex. The Lockringen type looks very monotonous within the area mapped. The only characteristic mineral observed is a green, slightly retrogressed biotite.

The thin granitic zone has the typical texture of augen gneiss, in this case of definite cataclastic origin. In the field, the contacts between the augen gneiss-granite and the proto-mylonitic meta-arkoses appear generally to be gradational, with a transition zone where the development of proto-mylonitic or mylonitic textures was intense in both types of rock. Identical textures were recorded in some parts of the upper sheet of the Rössjön Nappe Complex. The main mineralogical difference from the granites of the Rössjön Complex is the presence of a green retrogressed secondary biotite. Some primary microcline crystals often constitute aggregates or augen.

LOCKRINGEN III

Towards the top of the Lockringen Nappe Complex, some tens of metres of metamorphic arkoses occur, in which a fine-grained, cataclastic amphibolitic layer appears lying parallel to the main schistosity. The main outcrop lies near the SW extremity of lake Lockringen on the road which runs along the southern shores of lakes Lockringen and Rörvattnet. This rock is interpreted as being originally a dolerite dike, possibly equivalent to the Ottfjäll dolerites intruded into the metasediments of the Särv Nappe as described in Härjedalen (Strömberg 1955, 1969; Asklund 1961). This hypothesis is supported by the fact that the Särv Nappe lies in a similar tectonic position just beneath the Seve-Köli Nappe Comlex. The meta-arkoses are metamorphosed to a higher grade than the underlying similar sediments. They contain red biotite, often retrogressed to chlorite by cataclasis.

STRUCTURE

The two nappe complexes Rössjön and Lockringen have similar rock compositions consisting of Precambrian crystalline basement and late Precambrian meta-arkoses. They also exhibit a similar tectonic style and an identical structural evolution which allows them to be distinguished from the other tectonic units.

Both nappes are built up of a pile of thin sheets. Every lithological contact now forms a tectonic boundary. Only the major, proven thrust planes are indicated on the map, for example where granite is seen to override metasediments. The Rössjön

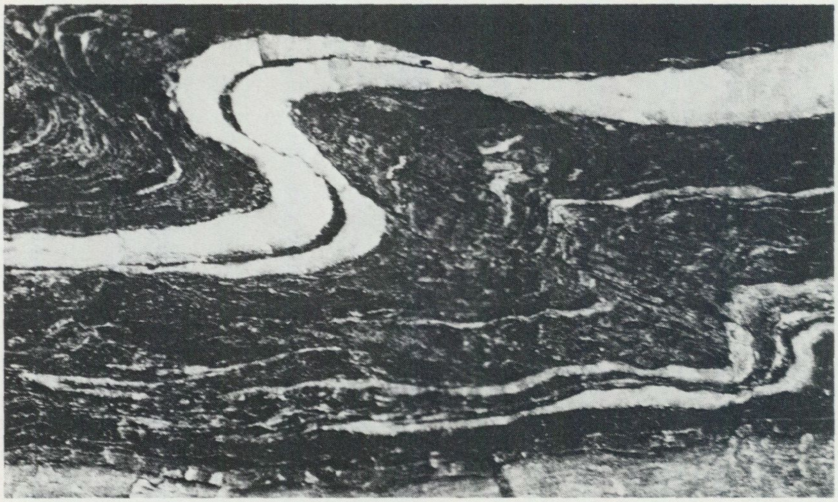


Fig. 8. Asymmetrical post-schistosity (S_1) folds (F_2), with development of a crenulation cleavage (S_2) in a pelitic layer of a meta-arkose. Rössjön Nappe Complex. North of Hotagen (20E, 9e).

Nappe Complex is divided into four thrust sheets and the Lockringen Complex into three sheets.

Cataclastic rocks, apparently not always diaphtoritic, are developed along the contacts but are thought to be older than those located near the main basal thrust plane (cf. metamorphism).

In the Rössjön-Lockringen Nappe Complexes, three phases of deformation are distinguished, all essentially recorded within the meta-arkoses.

F_1: A very regular and flat-lying slaty cleavage, S_1, has developed in all rock types. The cleavage is emphasised in the meta-arkoses by the alternation of dark meta-pelitic and white quartzo-feldspathic bands which are interpreted as the primary bedding S S (Fig. 7): as a rule, S_1 is parallel to S S. Folds of the bedding, with S_1 as the axial plane, were observed only rarely, being deformed by F_2. The main, prominent lineation in the area, which is roughly normal to the general strike of the Caledonian belt in Scandinavia, or parallel to the direction of translation of the various nappes, probably belongs to this phase and has a very constant orientation of N60°W. Various opinions have been published about the origin of the lineation (Kvale 1953; Cloos 1971; Trouw 1973; Ramsay 1960) but a discussion on this subject is beyond the scope of this study.

F_2: The S_1 surface is affected by a later F_2 phase which produced irregular crenulations of S_1 in the sediments, especially in the more pelitic zones where a crenulation cleavage has developed. In the more massive, quartzo-feldspathic layers, this phase of deformation is not readily apparent with some spectacular exceptions (Fig. 8). In the acid crystalline rocks, F_2 appears to have caused only discrete fractures. The axial planes are generally orientated NE–SW and have a steep to subvertical dip to the NW. F_2 occurred after the thrusting of the Seve-Köli Nappe Complex over the Rössjön and Lockringen Nappe Complexes since the thrust plane is deformed by this phase.

F_3: The third phase of deformation is only indicated by large open oscillations which correspond fairly well with those produced by F_2 within the Bergsjön Complex, and which are related to the formation of the major antiforms (e.g. Olden massif) and synforms. F_3 in the Rössjön and Lockringen Complexes, and F_2 in the Bergsjön Complex may certainly be correlated even if the structural relationships with the underlying tectonic units are not observed. Thrusting of the metamorphic allochthon over the Bergsjön Complex is pre-F_3. Subvertical, N–S faults, identical to those described previously, are observed, for example east of lake Stortjärnen (21E, 0c) where porphyries and meta-arkoses lie in abnormal juxtaposition. The thrust planes are also faulted. These faults can easily be observed on the aerial photographs.

Correlations: There is little doubt that F_3 in the Rössjön and Lockringen Complexes and F_2 in the Bergsjön Complex can be correlated. Correlation of F_2 in the former with F_1 in the latter is uncertain. The upper complexes could have been translated over the parautochthon during this phase which produced crenulations and apparently a second generation of mylonites under lower metamorphic conditions (cf. metamorphism).

METAMORPHISM

The rocks of the Rössjön and Lockringen Complexes were metamorphosed before translation over the Bergsjön Complex as they exhibit a higher grade of metamorphism than the latter. The contacts of the Rössjön and Lockringen Complexes with the underlying autochthon and parautochthon are different, however, from a metamorphic point of view: the garnet-bearing arkoses of the Lockringen Nappe Complex directly overlie very low grade greywackes to the south, whereas there is no large jump in metamorphic grade between the rocks of the Rössjön and Bergsjön Complexes to the north. The metamorphic zonation is different. These are the most important differences between the two similar units.

RÖSSJÖN

On the northern flank of the autochthonous-parautochthonous window, the rocks of the Rössjön Nappe Complex, with parageneses of the quartz-albite-muscovite-chlorite subfacies (Winkler 1976), override the cataclastic rocks of the Bergsjön Complex in which chlorite, muscovite and locally epidote, at least, indicate ''sub-greenschist'' facies conditions (cf. discussion p. 17).

Albite is always present within the allochthon in place of labradorite or oligoclase; even in the more coarse-grained rocks, recrystallisation is complete. The presence in the Rössjön Nappe Complex of relics of basic plagioclase resulting from an unequal development of the greenschist paragenesis was considered; for example in the basic rocks SW of lake Lillsjön (20E, 9e). Nevertheless, the area around this lake is considered here to represent a window of the Bergsjön Complex, because a heterogeneous development of greenschist facies conditions is a well established fact in this latter unit. The rocks of the Rössjön Nappe Complex are otherwise characterised by deeper mineralogical transformations, even if relic textures can be recognised in a few localities. The metamorphic grade increases upwards: the characteristic assemblage biotite+phengite appears in the pelitic schists of the two upper tectonic sheets. The limit of this biotite zone follows exactly the tectonic boundaries. Metamorphic conditions therefore probably reached their peak before thrusting.

LOCKRINGEN

In contrast with the contact between the Rössjön and the Bergsjön Complexes, the textonic boundary between the Lockringen and Bergsjön Complexes exhibits a marked jump in metamorphic conditions. The metamorphic grade of the Lockringen Nappe Complex from the base upwards decreases at first and then increases again. Garnet is present in the pelitic layers of the meta-arkoses of the lower tectonic unit (Fig. 9).

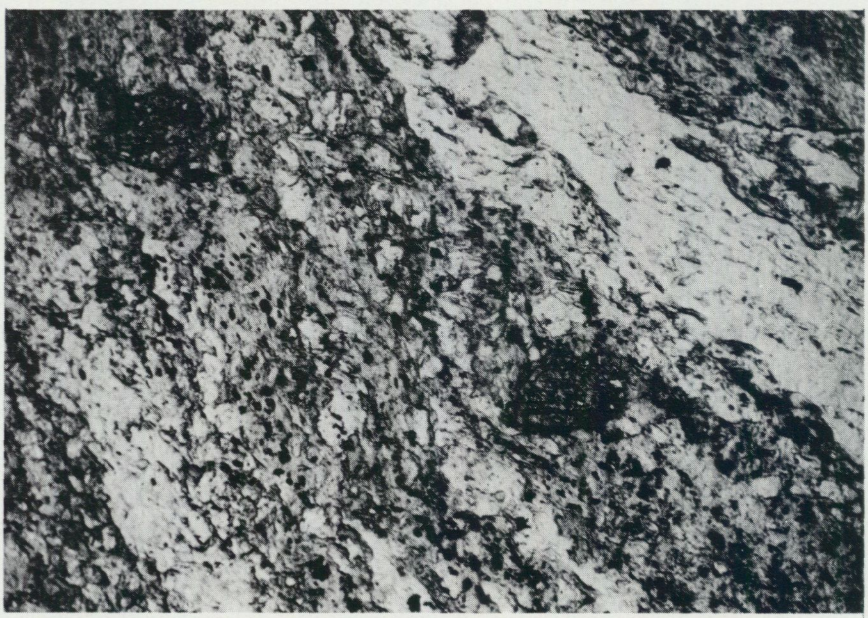


Fig. 9. Highly retrogressed garnets in meta-arkoses of the mylonitic basal part of the Lockringen Nappe Complex (thin section, parallel nicols, 80 X). Lockringen Nappe Complex. North of Tallsjön (20E 9b).

Blue-green hornblende apparently occurs in the mafic rocks of the crystalline part of the second unit. No garnet was found in the sedimentary rocks of the second unit, only biotite and, towards the top, muscovite and chlorite. The rocks of the very thin upper unit, Lockringen III, contain parageneses characteristic of the biotite zone. A normal metamorphic sequence is therefore demonstrated within the two lower units of the Lockringen Complex which probably correspond to a fairly high pressure type. The peak of this metamorphism clearly occurred prior to the thrusting of Lockringen allochthon over autochthon. The question is whether the metamorphism in the Lockringen Complex occurred after a pre-F_1 tectonic phase (more or less equivalent to the Seve F_1) which could be indicated by an overprinting of the mineralogical zonation on the already existing tectonic boundaries. Such a pre-F_1 phase must be suspected, even if it is not really demonstrated in the area studied. If one considers the model proposed by Zwart (1974) for the development of inverted metamorphic sequences, there are many instances where rocks already metamorphosed under identical physical conditions are now superimposed and separated by a tectonic plane and exhibit an apparent continuity.

MINERALOGICAL EVOLUTION AND METAMORPHIC ZONATION

The characteristic plagioclase within the allochthon is albite, in the pelitic and the quartzo-feldspathic rocks as well as in the basic rocks. The albite-epidote-calcite-muscovite assemblage results from the transformation of the original basic plagioclase. The epidote (pistacite) is generally zoned with a decreasing Fe content from the centre out, indicating increasing metamorphic conditions during crystallisation. The chlorite belongs to the ripidolite field, this being common to many metamorphic zones (Miyashiro 1973). In the chlorite zone, this mineral is an Fe, or an Fe-Mg variety (Albee 1962). In the basic rocks, the chlorite results mainly from the transformation of the pyroxene and it is slightly more magnesium rich. When biotite appears, the ratio Fe/Fe+Mg decreases slightly but Fe-Mg chlorite is still the more common variety. No chlorite is observed in the metasediments of the biotite zone which contain clastic microcline.

From measurements of the refractive indices and 2V angles, the white mica is apparently a phengite with a characteristic faint pleochroism. This mineral indicates high pressure conditions, especially if it persists in the higher facies, since under low and medium pressure metamorphism it disappears by reactions with amphibole or other associated minerals (Miyashiro 1973). The appearance of biotite in the pelitic rocks defines the beginning of the biotite zone. The crystallisation of this mineral, however, depends largely on the chemical composition of the rocks as, for instance, it is already present in metabasic rocks of the chlorite zone. Pleochroic variations, green or red, can be observed. These variations were interpreted in other areas as a result of progressive metamorphism (Wiseman 1934), but here they are more probably due to diaphtoritic effects. The diagnostic association is quartz+biotite+muscovite±chlo-

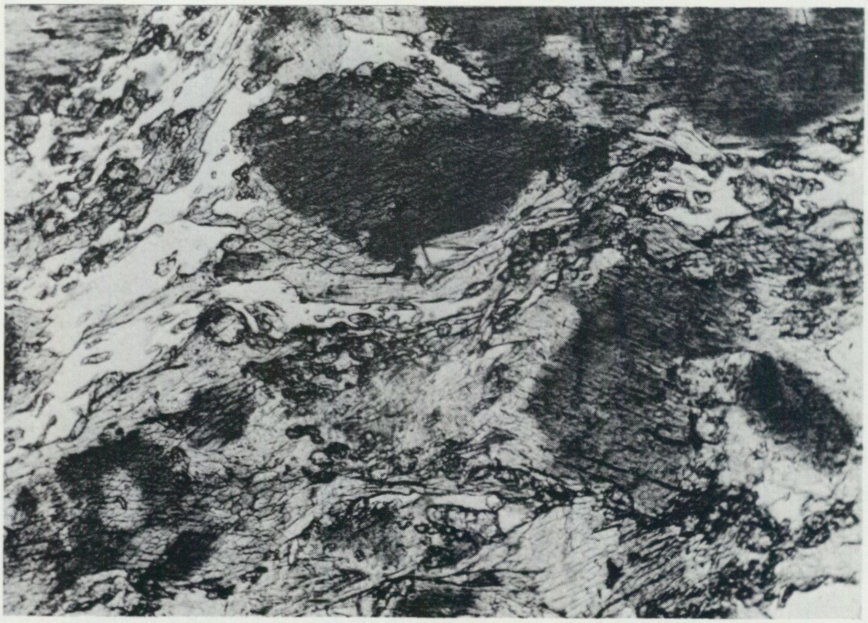


Fig. 10. Amphibolite of the Lockringen II unit showing zoned amphiboles. The inner parts correspond to a blue-green hornblende and the rims to a pale actinolite (thin section, parallel nicols, 30 X). Lockringen Nappe Complex. North of Lockringen.

rite. The mafic rocks of the two complexes contain actinolite which replaces the primary pyroxene and brown hornblende. An interesting fact is the coexistence of two different amphiboles in the crystalline part of the Lockringen II unit, these being a blue-green hornblende surrounded by a pale actinolite with lower refractive indices (Fig. 10). In some specimens, a sharp contact appears between the two minerals which could indicate a miscibility gap resulting from specific, but unsolved, metamorphic conditions (Shido et al. 1959; Ernst 1968; Miyashiro 1973).

Garnet is present in the Lockringen I unit, which is meta-arkosic in composition. This mineral is generally strongly crushed and retrogressed and consequently difficult to identify accurately (Fig. 9).

Relics of Ti-augite are observed in specimens from many outcrops of basic rocks. Two zones are defined based on the presence of critical minerals and on the characteristic parageneses: a chlorite zone and a biotite zone. A third garnet zone is strongly suspected, based on the existence of garnet and hornblende (co-existing with actinolite), but no quantitative criteria allow this to be established as a fact. The following main associations are encountered:

Chlorite zone

pelitic rocks: muscovite-chlorite-quartz-albite-epidote-sphene-calcite-tourmaline (rare).

quartzo-feldspathic rocks: quartz-albite-microcline (clastic)-muscovite-epidote-sphene.

basic rocks: albite-epidote-actinolite-chlorite-sphene-calcite-biotite-quartz.

Biotite zone

pelitic rocks: biotite-muscovite-chlorite-quartz-albite-epidote-sphene-calcite.

quartzo-feldspathic rocks: quartz-albite-microcline (clastic)-biotite-muscovite-epidote-sphene.

basic rocks: albite-actinolite-epidote-chlorite-sphene-biotite-calcite-quartz.

The assemblages encountered in both these zones are common to most of the different facies series. The absence of andalusite in the metapelites, the absence of stilpnomelane particularly in the metabasites, the appearance of biotite before garnet and the association with pre-Caledonian acid basement (Miyashiro 1973) all suggest a medium pressure facies series. The presence of phengite seems to indicate affinities with a fairly high pressure series.

CATACLASTIC ROCKS

Rocks resulting from an important dynamo-metamorphism, which is contemporaneous with the emplacement of the various nappes, are particularly well developed within both complexes: protomylonites, mylonites and ultramylonites are abundant, as well as blastomylonites (Table 1). Many of these rocks are formed under similar P-T conditions.

Cataclastic rocks of the first generation are well exposed in the upper tectonic units. In the rocks of the thrust zone which separates Rössjön III from Rössjön IV, the grain size is reduced but no retrogressive replacement of the minerals took place even if they are deformed. Such conditions also prevailed in the phyllonitic zone separating the Seve from the Rössjön Nappe Complex (with the exception of garnet). This indicates a syn-metamorphic process, or more probably, P-T conditions which were just beginning to decrease (Zwart 1974). These thrust zones are not very spectacular in the field, in contrast with those of the second generation.

The process of comminution predominates largely during recrystallisation within the movement zones of the second generation, and typical ultramylonites are observed (Fig. 6). These zones developed between and within the different tectonic sheets. Some recrystallisation occurred with an irregular distribution: idioblastic minerals of a

Fig. 11. Joints contemporaneous or posterior to F_2 filled up with quartz and chlorite in a meta-arkose (thin section, parallel nicols, 40 X). Rössjön Nappe Complex. North of Lillsjön (21E. 0e).

typical lower greenschist facies association appear like epidote, sphene, chlorite, muscovite, or quartz. Frequently they fill up joints which cut across the cataclastic flux structure (Fig. 11) showing that greenschist facies conditions persisted after the thrusting. In other respects, these flux structures are not deformed in the same way as the mylonitic zones of the first generation. They are consequently thought to post-date F_1 and to be, probably, syn-F_2 (Rössjön and Lockringen), contemporaneous with the general thrusting of the metamorphic allochthon over the parautochthon and autochthon.

TIME RELATIONSHIPS

The time relationships during the metamorphism with successive phases of folding seem to be quite simple (Fig. 12): two different mineral assemblages can be seen, these being most evident in the biotite zone. The first one, a biotite-muscovite-quartz-chlorite assemblage in the pelitic schists, is contemporaneous with F_1 as unstrained phyllosilicates outline the main slaty cleavage (S_1). These minerals are strongly deformed by F_2 folds. The existence of a possible pre-F_1 phase should nevertheless be suspected, perhaps occurring under similar physical conditions and producing identical assemblages. Minerals of the lower greenschist facies are developed locally in joints and in cataclastic zones which are post-F_1 and possibly syn-F_2: quartz, chlorite, epidote, and idiomorphic porphyroblasts of sphene and muscovite. The distribution of

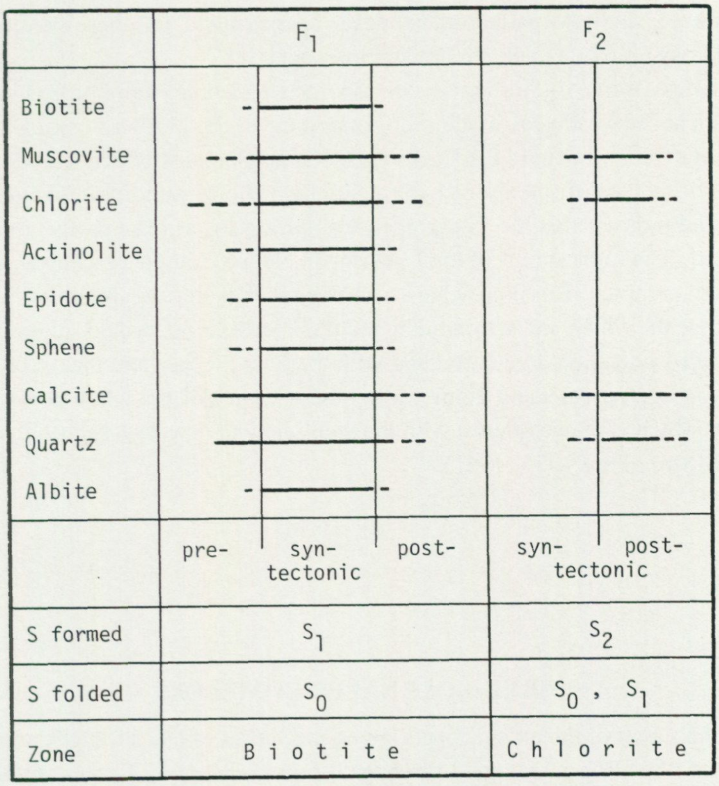


Fig. 12. Relationships between the metamorphism and the folding phases in the rocks of the biotite zone, Rössjön Nappe Complex.

the latter minerals is irregular. The peak of metamorphism was felt during F_1. The sequence being inverted, thrusting within the Rössjön and Lockringen Nappe Complexes and over the Bergsjön Complex took place during F_2 with the development of cataclastic rocks under lower greenschist facies conditions. At this time, the Seve unit was already in place, the thrust plane between the Rössjön–Lockringen and the Seve Nappe Complexes being folded by F_2.

DISCUSSION

The Rössjön (to the north) and the Lockringen Nappe Complexes are similar in many respects. They appear to lie at the same tectonic level, that is, overriding the autochthonous and parautochthonous units of the Bergsjön Complex, and beneath the Seve-Köli Nappe Complex. Both have the same tectonic style characterised by a pile of rather thin sheets with basement implications. Both are composed of the same rock types: granite, porphyry and greenstone of assumed Precambrian age, and sedimentary units of arkoses and feldspathic sandstones (''sparagmites'' or, more specifically, the Risbäck Group) of presumed late Precambrian age.

Nevertheless, some dissimilarities are recorded which are more or less significant. The basement implication is much more important in the northern complex. Igneous rocks are very subordinate in the Lockringen Nappe Complex which tends, in the area investigated, to consist mainly of metasediments. The metamorphic parageneses are different and indicate that the Lockringen Complex was, at least partly, more deeply transformed. The highest unit of the Lockringen Nappe Complex has no equivalent in the northern complex (Rössjön) where no basic rocks were found within the meta-arkosic sediments which lie at a similar tectonic level. This would suggest that the Lockringen III unit should be correlated with the Särv Nappe, and that in the Hotagen area, the Särv Nappe dies out along the southern shores of the lakes Lockringen and Rörvattnet which is in accordance with the well known (?) wedge-shaped geometry of this nappe (Strömberg 1955, 1961).

SEVE-KÖLI NAPPE COMPLEX

In the northern part of the area mapped, along the shores of lakes Rengen and Valsjön, and south of lakes Rörvattnet and Lockringen, rocks of a very different unit than those previously described are found. They belong to the well-known Seve-Köli Nappe Complex (Helfrich 1967; Zachrisson 1969, 1973; Trouw 1973; Zwart 1974; Gee 1975b).

This Nappe Complex is traditionally divided into two major lithological, and in general also tectonic, units. The upper Köli unit, consists of low-grade schists of possible Lower Palaeozoic age (Gee 1975a). The lower Seve unit has a characteristic and well-demonstrated wedge-shaped geometry, thinning westwards (Zachrisson 1973). Locally, the metamorphic rocks belonging to this complex are of sedimentary and basic volcanic origin: mica-schists, meta-arkoses, quartzites, graphitic phyllites, metatuffites, greenschists. None of the acid igneous rocks characteristic of the underlying tectonic complexes are present, and thus there is no basement implication. The only, presumably, igneous rocks present are the amphibolitic lenses within the sediments, a feature typical of this complex compared to the lower ones.

The sequences represented in the northern and southern areas of outcrop are not identical. The author's attention was mainly concentrated on the northern, more diversified area, and the southern area was only briefly investigated. The two areas are treated separately and then compared.

NORTHERN AREA

The rocks are described as they outcrop from south to north (from bottom to top of the sequence).

Mica-schists: The base of the nappe consists locally of pelitic metasediments. They override the meta-arkoses of the Rössjön Nappe Complex. At some localities, a gradational zone between the meta-arkoses and pelitic metasediments seems apparent, but these two rock types can be differentiated and mapped separately all along the contact on the basis of lithology or structure. A well defined metamorphic limit follows this contact precisely and appears not to be an isograd. A major thrust boundary is therefore traced between the mica-schists and the meta-arkoses. The rock is grey in colour and generally fine grained except at a few localities where the grain size is medium. These metapelites are extremely schistose, often with a wavy appearance typical of phyllonites (Knopf 1931; Waters et al. 1935). Macroscopic garnet and epidote phenoblasts are visible. The texture is grano–lepidoblastic and no relic texture is retained. The main minerals, in decreasing order of abundance, are quartz, muscovite, biotite, and albite, with epidote (pistacite), calcite, garnet (almandine), and sphene as accessories. As a rule, the schists are strongly crushed and retrogressed into chlorite-schists: they are real diaphtorites (Knopf 1931; Higgins 1971).

The apparent and estimated thickness of this unit varies from a few metres on the eastern shore of Valsjön, to 150 m on the western shore of the same lake. Westwards the thickness decreases slightly.

Dolomitic marble: A thin and fugitive horizon of dolomitic marble overlies the mica-schists. It outcrops beautifully at a unique locality on the western shore of lake Valsjön, about 200 m before the northern extremity of the lake (Fig. 13). It is certainly present in Valsjöbyn, in a topographic depression. Westwards it disappears under the overriding quartzites. In outcrop, the marble is 3 m thick and consists of decimetre-thick dolomitic limestone layers, with a basic lens lying parallel to the main schistosity (S_2). The marble is white, yellowish on the weathered surfaces, and fine grained. The main constituents are dolomite and calcite. The rock contains minor amounts of rounded quartz grains and white mica on the schistosity surfaces.

The basic rock is green in colour, fine grained and weakly schistose. The texture is grano-nematoblastic and the main constituents, in decreasing order of abundance, are blue-green hornblende, epidote, albite, and chlorite. Accessories or diaphtoritic minerals are quartz, retrogressed green biotite, chlorite, actinolite, and calcite.

Quartzite and greenschists: A mixed sequence, predominantly quartzitic in the lower part and dominated by basic schists in the upper part, overlies the marble. This unit starts with 10 to 15 m of massive arkose and feldspathic quartzite, a well-banded rock with alternating layers of quartzitic or quartzo-feldspathic and pelitic composition. Towards the top, quartzite alternates with subordinate calcareous impure quartzite,

Fig. 13. Well-layered dolomitic marble in the Seve sequence, with an intercalated amphibolitic lense. Seve-Köli Nappe Complex. Right shore of Valsjön (21E, 0d).

quartzitic phyllite, metatuffite, and pure greenschist in layers of a decimetre to a metre in thickness. The schists also contain amphibolitic lenses of presumably igneous origin. The quartzitic unit has a total apparent thickness of about 25 m.

Overlying the quartzitic unit is a similar succession, approximately 25 m thick, but quartzite, usually impure, is subordinate and greenschists and garnet-bearing metatuffites dominate. Other rock types present are calcareous metatuffite and quartz-phyllite. All kinds of transitions exist and this sequence is in fact built up of material of volcanic and terrigenous origin in various proportions, with lenses of amphibolite. Petrographically the rocks are similar to the schists described later. The quartzites and schists, together with the underlying marble horizon, are cut out by the overriding quartzites with a strongly mylonitic contact zone.

Quartzite and quartz-phyllite: This unit consists of alternating massive quartzites and quartz-phyllites. The zone is well marked in the topography and separates lake Valsjön from the Rengen lake. The sequence starts with a white, massive and pure quartzite, about 20 m thick, which contains a few, thin calcareous horizons near its base. Thirty to forty metres of quartz-phyllite, locally graphitic or calcareous, overlies the quartzite. Syn-schistosity F_2 folds were recorded within this unit. Numerous amphibolitic lenses are included in the schists, these being generally from 10 to 50 m long. The schists are overlain by 5 to 15 m of a white, pure and massive quartzite, and this is topped by an often graphitic quartz-phyllite with amphibolite lenses. Galena impregnations occur in the quartzite in the stream section between lakes Rengen and Valsjön. The total thickness of the unit as a whole varies from 100 to 150 m.

Arkosic quartzite and greenschist: A 5 or 6 m thick unit which only outcrops on the southern shore of lake Rengen, consists of arkosic quartzite alternating with garnet-bearing greenschists in layers of 0.5–1 m thick.

Phyllite and metatuffite: This sequence, which is about 30 to 50 m thick, consists of various rocks of clastic and volcanic origin. The presence of a small sulphide mineralisation is of particular interest. The following rock types, in 1 m thick layers, make up the sequence:

dark, quite pure quartzite, often micaceous;

grey quartz-phyllite with biotite hardly visible;

black and preferentially deformed graphitic phyllites;

calcareous phyllite in minor proportions;

one quartz micro-conglomerate, 1 m thick, associated with the pyrrhotite mineralisation;

a grey or green coloured, fine-grained and schistose rock of presumably tuffitic origin, more or less pure according to the content of clastic material. The minerals are, in decreasing order of abundance, albite, amphibole (hornblende and actinolite), quartz, calcite, epidote (clinozoisite), biotite, chlorite, garnet, and sphene. The garnets occur as poikiloblasts, often as large as nuts;

many amphibolite lenses were mapped within this unit, as in all the schist zones.

Greenschists: The uppermost rock type within the area investigated is a greenschist. This term is used here to describe a green coloured rock of basic composition with a fine and well marked schistosity. The rock is certainly a metamorphosed tuffite with very few terrigenous elements. All transitions between ''tuffite'' and ''greenschist'' exist. The main constituents are albite and chlorite. In decreasing order of abundance, epidote, blue-green hornblende, actinolite, and calcite are also observed with biotite and muscovite in minor amounts. The texture is grano–lepido–nematoblastic. These greenschists lie directly over a phyllonitic mica-schist with minute graphitic layers. At the contact, a rock of gneissic appearance with phenoblasts of K-feldspar occurs which may well represent a thrust plane.

Amphibolite: These amphibolites are quite different from the greenstones previously described because they are associated with the Caledonian metasediments. They are massive and homogeneous, and only weakly schistose compared to the surrounding rocks. Their grain size is fine to medium, and their colour is dark green. Garnet is visible at a few localities. An interesting fact to note is that amphibolites appear only within the schistose rocks and never within the massive quartzites. The texture is grano–nematoblastic and no relic texture was recorded. An igneous origin is probable if one considers their particular mode of occurrence.

The most important minerals present are albite and amphibole (hornblende plus actinolite). In decreasing order of abundance, chlorite, epidote, muscovite, biotite, garnet, sphene, calcite, and quartz are present. This is a typical, unstable metamorphic paragenesis.

These amphibolites have a typical basaltic chemical composition and might represent subalkaline tholeiites (unpublished SGU-material). They have no spilitic character and show continental affinities.

SOUTHERN AREA

To the south of lakes Rörvattnet and Lockringen, the Seve-Köli Nappe Complex overrides the Lockringen Nappe Complex and consists essentially of interstratified meta-arkoses and greenschists. The small area investigated does not give a complete picture of the nappe sequence in this southern part of the map.

Meta-arkoses. In hand specimen, these rocks are not different from the arkoses previously described. The quartzo-feldspathic layers contain quartz, albite, clastic microcline, and biotite, or quartz, albite, muscovite, biotite, and chlorite. The pelitic layers are more interesting because they contain garnet in addition to muscovite, biotite, quartz, and albite. This fact distinguishes these rocks from the underlying meta-arkoses which belong to a lower metamorphic facies.

Greenschists. Pure greenschists are also found with the metamorphic arkoses. Albite, two generations of different calcic amphiboles, epidote, and chlorite are the main constituents, with subordinate biotite, generally retrogressed, sphene, calcite, and quartz.

STRUCTURE

The rocks of this complex are poorly exposed and cover a small part of the area investigated. They have undergone an extremely intense post-crystalline deformation, and earlier phases can only be traced in garnet inclusions or in rocks which escaped complete transformation.

The lower boundary of the Nappe Complex is the thrust contact between the Seve phyllonitic garnet mica-schist and the Rössjön or Lockringen meta-arkoses of lower metamorphic grade. The thrust contact is clearly post-metamorphic, and it is deformed by a tectonic phase common to the Seve-Köli, the Rössjön and the Lockringen Complexes. Within the Seve-Köli Complex, two zones of shearing are recognised and interpreted as thrust planes.

Four phases of deformation are recognised:

F_1 – The first phase is never visible in the field. It can be deduced from syn- to post-kinematic garnets porphyroblasts around which the S_2 cleavage is curved.

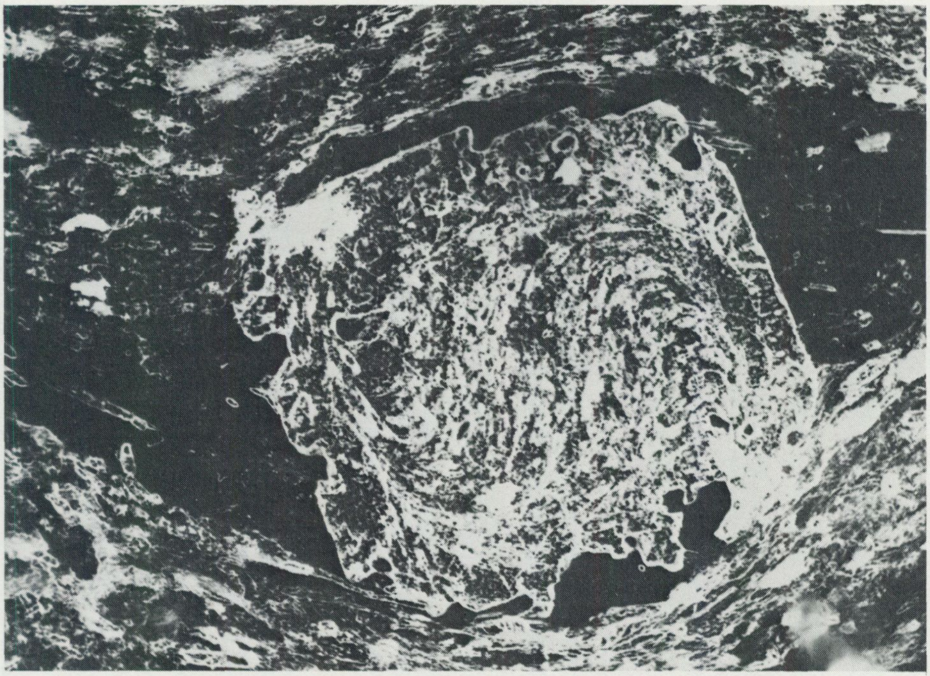


Fig. 14. Garnet from the mica-schists of the Seve sequence. The crystal started to grow during F_1 and continued in the space of time between F_1 and F_2. It is surrounded by S_2 (thin section, negativ print, parallel nicols, 40 X). Seve-Köli Nappe Complex. South-western shore of Valsjön.

Inclusions within such garnets are not continuous with the external surfaces (Fig. 14). Further indications are the remnants of S_1 between the differentiated mica-layers developed from the crenulation cleavage S_2 (Fig. 15).

F_2 – The second phase produced the main surface within the Seve schists, a crenulation cleavage outlined by the orientation of undulose mica crystals and surrounding the hornblende and garnet porphyroblasts. Very few F_2 folds were recorded. They are isoclinal with sub-horizontal axes. They are too scarce, however, to give any precise information on their axial direction. The cleavage is flat-lying and appears to be parallel to the compositional layering.

F_3 – The S_2 surface is deformed by crenulations of a similar type to those produced by the F_2 phase within the Rössjön and Lockringen Nappe Complexes and they also affect the thrust plane between the Seve and the underlying units. In some places a crenulation, or fracture cleavage has developed. Axes are generally orientated N 60 E and the axial planes are subvertical. F_3 consequently took place after thrusting of the Seve unit over the Rössjön and Lockringen Nappe Complex.

A fourth phase related to the doming of the Olden massif and similar to the F_2 phase of the Bergsjön Complex is observed.

CORRELATION

F_4 is certainly common to all the Nappe Complexes and post-dates the final emplacement of the Caledonian Nappes. As the thrust planes and accompanying mylonites between and within the allochthonous complexes are folded by F_3, there is no doubt about a correlation with F_2 in the Rössjön and Lockringen Complexes. The allochthon, as a whole, was already formed at this time and probably being translated over the parautochthon during this phase. It makes sense to correlate the main F_1 phase of the Rössjön and Lockringen with the very important F_2 in the Seve-Köli. The thrust plane separating these complexes was probably formed during F_2 as it produced a gap in the metamorphic assemblages which are, at least partly, older (cf. Metamorphism). Moreover these thrusts, the main cleavage and the mylonitic zones lie parallel and are folded by F_3 in all three complexes. Time relationships with metamorphism and mylonitization corroborate such an interpretation. A pre-F_1 phase in the Rössjön or Lockringen Complexes, corresponding to F_1 in the Seve, was not observed.

METAMORPHISM

The appearance of red garnets in the pelitic schists and, to some extent, in the mafic rocks from the base of the Seve-Köli Nappe Complex is obvious in the field. There is a distinct gap from the lower-grade underlying units, and the garnet boundary follows the thrust plane. The main parageneses observed in the Seve schists are:

pelitic rocks:	biotite–muscovite–quartz–albite–almandine–chlorite–epidote–sphene–calcite.
basic rocks:	hornblende–actinolite–albite– epidote–almandine–biotite–chlorite–quartz.

Garnets are always present in the metapelites and their distribution is regular. Garnet is only sporadic in the amphibolites and the basic schists. This fact is common in many metamorphic areas and will be discussed below. The rocks described as metatuffites are characterised by garnet poikiloblasts of nut size. The garnet shapes are variable and exhibit xenoblastic as well as idioblastic habits.

Poikiloblasts of blue-green hornblende, with irregular crystal boundaries due to post-crystalline deformation, appear in the metabasites. The hornblende apparently co-exists with actinolite. Such an association was discussed in the section dealing with the Lockringen Complex. Albite is often zoned and deformed. The epidote is generally an iron-rich pistacite, but clinozoisite also occurs. Two generations of chlorite exist.

Fig. 15. Mica-schists of the Seve sequence. a and b=Differentiated layering developed from a crenulation cleavage (S_2, horizontal). Oblique remnants of an earlier (S_1) cleavage (thin sections, a=crossed nicols, 30 X; b=negativ print, parallel nicols, 10 X). Seve-Köli Nappe Complex. South-western shore of Valsjön (21E, 1d).

a

b

The first one is contemporaneous with the main phase of metamorphism and is a Mg-Fe variety. The decrease in the Fe content is explained by the development of the Fe-rich minerals biotite and garnet (Ernst 1968; Atherton 1968). The white mica is a phengite in the metapelites and a pure muscovite in the metabasites.

Biotite, which is generally present, exhibits a green pleochroism in some specimens due to post-crystalline cataclastic retrogressive effects. These assemblages, especially the almandine–chlorite–muscovite association in the metapelites, are diagnostic for the almandine low-grade zone (Winkler 1976), which corresponds in the international classification (Zwart et al. 1967) to the epidote–amphibolite facies. The association albite–epidote–hornblende excludes a low pressure facies series, but does not permit any distinction between medium or high pressure series.

As in many areas of regional metamorphism, the metamorphism in the area investigated is polyphased and this fact is particularly evident in the schists of the Seve-Köli Nappe Complex, even if the various mineral assemblages are not very diversified. The relationships between the metamorphism and the successive phases of folding are especially interesting.

These relationships are particularly well illustrated by the garnet and phyllosilicate textures.

Garnets exhibit several different geometries. The main types are:

a. A few xenoblastic garnets without, or with non- or poorly-orientated inclusions can be observed. They are often fractured and elongated along an early plane which is deformed by the main crenulation cleavage S_2 (pre F_1 garnets ?).
b. Xenoblastic garnets with S-shape syn-kinematic texture. The S_2 surface is deflected around these grains (syn. F_1).
c. This type also bears S-shaped textures, but the outer contours are subidioblastic or idioblastic. Quartz inclusions become coarser from the inner to the outer zones of these crystals. S_2 is also curved around garnets of this type (syn- and post-F_1; Fig. 16).
d. Small, idioblastic, inclusion-free garnets often appear as eyes coarser-grained than the surrounding matrix (post-F_1; Fig. 17).

According to these observations, it can be stated that garnet crystals started to develop before or early during F_1. Growth continued during F_1 with P and T increasing (types b and c). The peak of this metamorphic phase came at the end of the first phase of deformation (types c and d) and then decreased.

Remnants of S_1, crenulated by S_2, are outlined by muscovite and biotite (Fig. 15). These minerals are, however, clearly recrystallized and generally strain-free in the F_2 folds. The third generation did not accompany any major recrystallisation and took place under lower-grade conditions as indicated by fractures, filled mainly with quartz, chlorite and occasionally epidote. The local chloritization of garnet and biotite probably occurred during this phase.

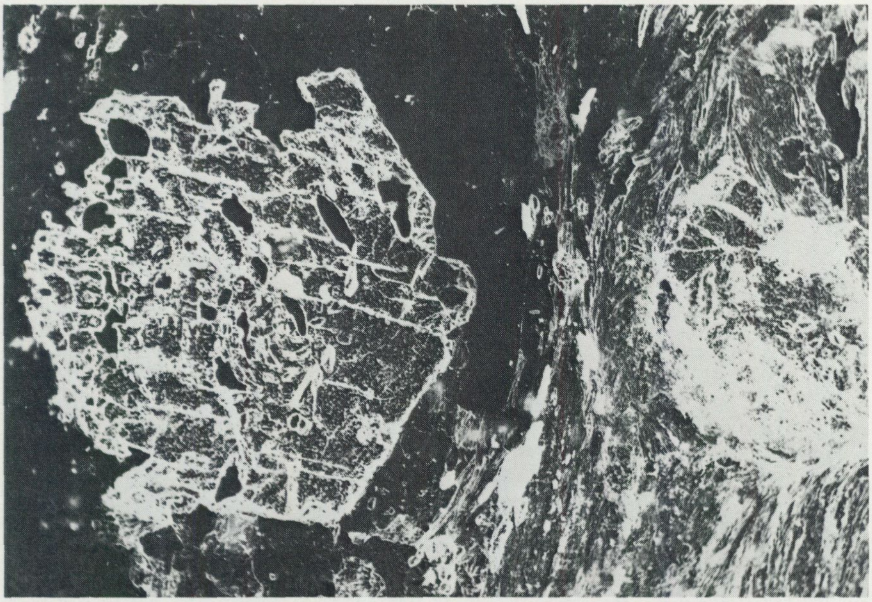


Fig. 16. Garnets in a mica-schist of the Seve sequence. To the left, a well-preserved garnet of type c), with an inner S-shape texture (syn-F_1) and a sub-idiomorphic rim (post-F_1); the inclusions become coarser from the inner to the outer zone of the crystal but the rim is inclusion-free. To the right, a garnet strongly crushed and retrogressed during F_2 (thin section, negativ print, parallel nicols, 30 X). Seve-Köli Nappe Complex. South-western shore of Valsjön.

Fig. 17. Possible post-F_1 small idioblastic garnet in Seve mica-schists. The crystal is in a medium-grained zone preserved of the phyllonitization contemporaneous of F_2 (thin section, parallel nicols, 30 X). Seve-Köli Nappe Complex. South-western shore of Valsjön (21E, 0b).

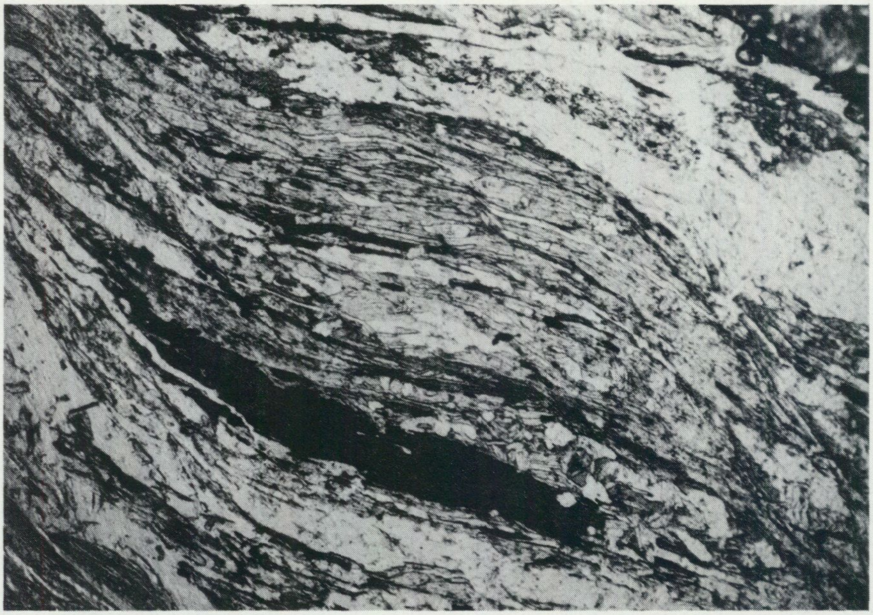


Fig. 18. Deformed but unretrogressed porphyroclast of biotite in a F_2 mylonitic zone, indicating a syn-metamorphic cataclastic process (thin section, parallel nicols, 10 X). Seve-Köli Nappe Complex. South-western shore of Valsjön

It is very interesting to investigate the mylonitic zone which separates the Seve-Köli from the Rössjön. The grain size has been strongly reduced relatively to the overlying rocks, but retrogressive replacement of biotite (Fig. 18) does not seem to have taken place, at least to any great extent. These rocks are phyllonites but cannot be considered as diaphtorites (Higgins 1971). The metamorphic grade, characteristic of the biotite zone (in accordance with the preceding conclusions), is similar in both the mylonitic zone and the rocks lying above or below. The mylonitization was consequently a syn-metamorphic process. Temperatures, however, were decreasing and the peak of metamorphism was reached early, apparently between F_1 and F_2, with garnets starting to grow during F_1, continuing possibly during F_2, (Fig. 19).

Even if the early tectonic, and metamorphic, history of the Rössjön and Lockringen Nappe Complexes is uncertain and definitive conclusions are unlikely, the thrusting of the Seve-Köli Complex over the former probably took place during F_2 (F_1 in the underlying complexes), thus inverting the metamorphic sequence. These conclusions are in accordance with detailed investigations in other areas of the Swedish Caledonides (Trouw 1973; Zwart 1974).

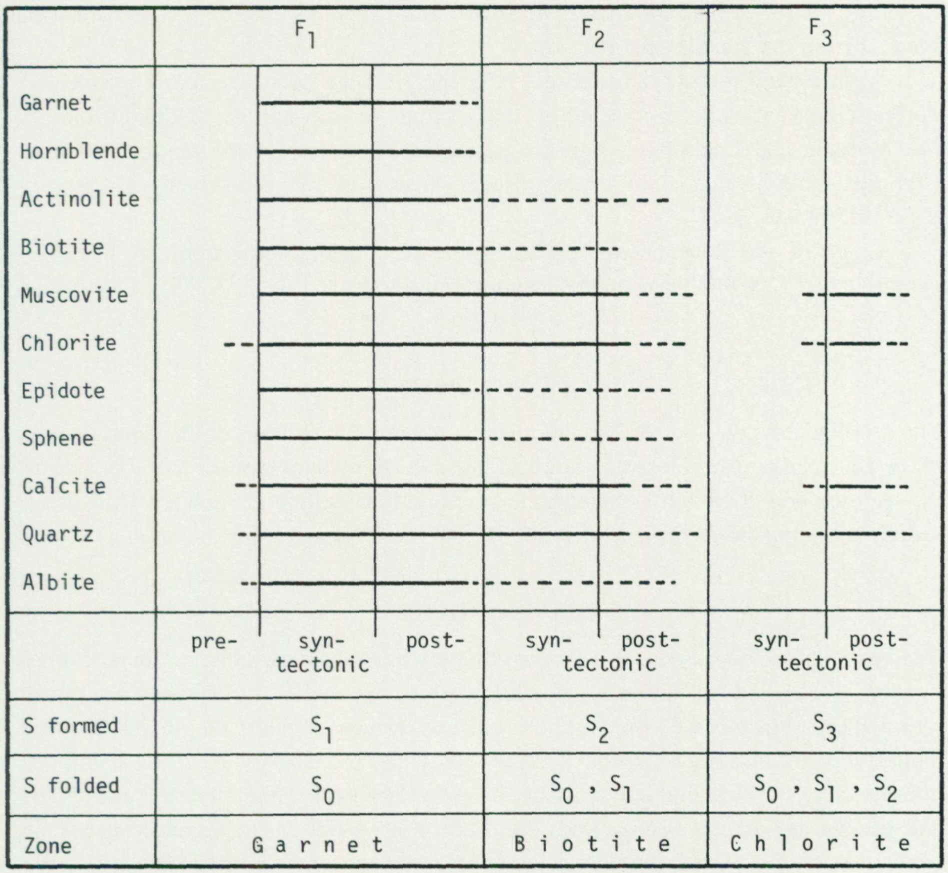


Fig. 19. Time relationships between the metamorphism and the folding phases in the Seve-Köli Nappe Complex, Hotagen area.

DISCUSSION

The Seve-Köli Nappe Complex in the Hotagen region consists mainly of a volcano-sedimentary sequence, with mixed rock types containing various proportions of volcanic and sedimentary origin. All transitions exist: meta-arkoses, mica-schists and quartzites on the one hand and greenschists on the other. Some calcareous horizons and one dolomitic marble were recorded also. Numerous amphibolitic bodies are associated with the more schistose metasediments. Another characteristic feature is the complete absence of basement, acid or otherwise. The metamorphic grade is higher than in the lower tectonic complexes, and the structural evolution is different.

The stratigraphic column cannot be correlated in detail at a large scale. However, similarities with the basal part of the Seve sequences in other areas are apparent (Kulling 1972; Trouw 1973; Zwart 1974). The basal part is, as a rule, of a lower metamorphic grade than the major part of the unit. This observation is in accord with the fact from the area described.

It is interesting to note that the rock sequences cannot be strictly correlated in the northern and southern areas of outcrop. This is true, not only for the middle thrust units (the Rössjön and Lockringen Nappe Complexes), but also for the upper Seve-Köli Complex. Complicated tectonic relationships which have not been solved must explain these differences.

The age of the Seve unfossiliferous sequence remains conjectural. A late Precambrian and Cambrian age can be assumed but not proved (Gee 1975b).

CONCLUSION

The lithological, petrological, structural and metamorphic features of the Hotagen area allow four Nappe Complexes to be distinguished. Several abnormal contacts outline the tectonic boundaries, for example, Precambrian crystalline rocks upon Palaeozoic sediments, jumps in metamorphic grade and inverted metamorphic zonations.

SEDIMENTATION

The sedimentary rocks of each tectonic complex have their own distinct depositional history. Cross-bedded arkoses and feldspathic sandstones constitute the entire sedimentary sequences of the Rössjön and Lockringen Nappe Complexes. Though their age is not nowadays precisely known, they can probably be correlated with the lithologically similar Jämtlandian Risbäck Group (Gee et al. 1974) of late Precambrian and pre-Varangian age, about 900–700 M.a. (Gee 1975a). No direct evidence of deposition on the underlying acid crystalline basement was observed because of the concentration of differential movements along the contacts between rocks of different competence during thrusting. The arkoses are, however, thought to be autochthonous, or slightly parautochthonous, relative to the local crystalline rocks. The age of the latter is unknown.

The position of the Seve sediments in the stratigraphic column is undetermined. It has been suggested that the arkosic and amphibolitic basal part of the Seve (southern part of the map area) may be related to the Särv Group (Strömberg 1969), which in turn may be correlated with the Risbäck Group; but there is no local evidence to confirm such a hypothesis. A volcano-detrital suite, with minor amounts of marble, completes the local sequence.

The Bergsjön Complex is entirely devoid of pre-Varangian deposits. The stratigraphies of the autochthon or the parautochthon are slightly different (Fig. 3). The autochthonous sequence is about 15 metres thick and lies directly on the granitic basement with a basal conglomerate. Alum shales and alternating limestones and silts rest upon the conglomerate. These sediments are thought to range in age from the Middle Cambrian to the Lower Ordovician. Sedimentation apparently started earlier in the parautochthon, and the stratigraphic column is composed of quartzite and shales, possibly Lower Cambrian (top of the Gärdsjön Formation, Gee et al. 1974), black shales and limestone, very crushed, and deposition ended with Ordovician greywackes (Norråker Formation, Gee et al. 1974). The quartzites were probably deposited on a crystalline basement represented locally by rare ''floating'' granitic slices.

TECTONIC AND METAMORPHISM

Typical structural and metamorphic features allow partial understanding of the orogenic history of the Caledonian belt in this region. Deformation first affected the more internal units, that is the Seve rocks, and produced a slaty cleavage. A synkinematic metamorphic mineral assemblage typical of the epidote-amphibolite facies was formed. The regional metamorphism reached its peak at the end of this first phase of folding in the interval of time between F_1 and F_2 (Fig. 19). This phase of metamorphism affected not only the Seve-Köli Nappe Complex but possibly also the Rössjön and Lockringen Nappe Complexes.

The nappes of the metamorphic allochthon (Zachrisson 1973) were formed more probably during F_2 (Seve) with the development of a crenulation cleavage and of blasto-mylonites in the thrust zones separating the Seve from the Rössjön and Lockringen Complexes. The mylonitization in the Seve rocks took place under upper greenschist facies conditions, as biotite is deformed but preserved and not transformed into chlorite. Temperatures were already decreasing during this period which followed the peak of the metamorphism. The zonation was consequently inverted, except within some units, such as Lockringen I and II.

It is difficult to know exactly what happened previously in the Rössjön and Lockringen Nappe Complexes. It is certain, however, that at least during F_1 ($=F_2$ Seve), the pre-Caledonian basement was mobilized and thrust under metamorphic conditions.

After the formation of the metamorphic allochthon, the tectonic forces were still important within the Caledonian belt. The nappes already formed were transported eastwards for considerable distances under low temperature and pressure conditions. During the thrusting, the rocks were mylonitized, but with a predominance of comminution over recrystallisation: spectacular protomylonites, mylonites and ultramylonites were developed, mainly in the rocks belonging to the Rössjön and Lockringen Nappe Complexes. Movements occurred along the previous thrust zones but also along newly formed thrust zones giving rise to numerous imbrications. The underlying rocks themselves were folded and thrust with the formation of a fracture cleavage. The significance of the major Jämtlandian décollement (Gee 1975a and b) of Varangian quartzites with rare basement implications at its base has to be stressed. According to local observations, this décollement does not root beneath the crystalline Olden massif. Rooting or cut out beneath the overlying nappes, does not occur until some considerable distance to the west (Foslie's map 1956) and this implies a large deplace-

a

ment, certainly more than a hundred kilometres! The Olden massif with its thin, lower Palaeozoic sedimentary cover is thought, in the writer's opinion, to correspond to the ''passive'' Baltic shield and to be really autochthonous, but with important Caledonian deformation. The existence of the Olden Nappe (Asklund 1960) therefore cannot be supported any longer.

A very low grade metamorphism developed in the Bergsjön Complex. It is due to the overloading of the allochthon and may thus be of the burial type. Late major antiforms and synforms, with more or less N–S striking folds axes, deformed all the previous structures and produced final Caledonian inprint on the region.

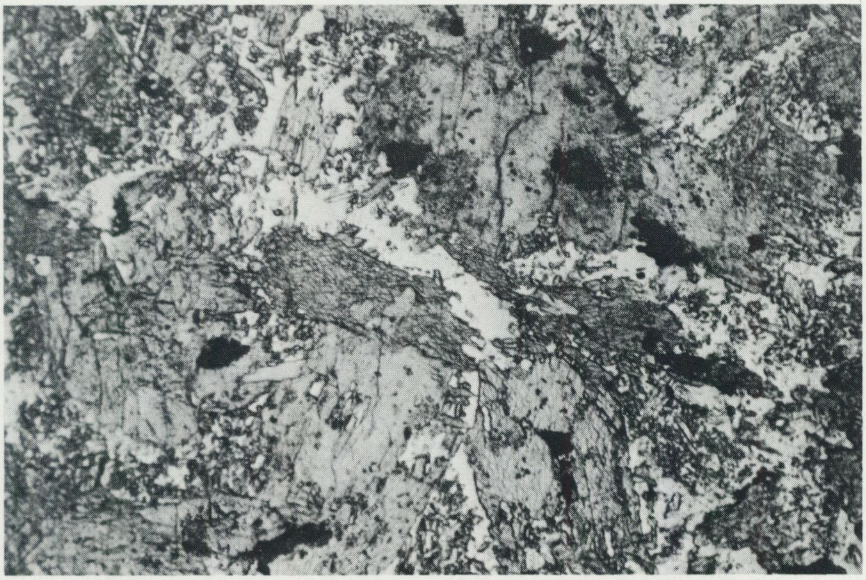
According to previous authors, these movements occurred from the Middle Silurian (Seve), through the Upper Silurian (Rössjön and the two lower units of the Lockringen) to the Lower Devonian (Bergsjön). (See Gee and Wilson 1974, 1976; Gee 1975a and b; Roberts 1971.)

METAMORPHIC FACIES SERIES

Within the investigated area, it is not appropriate to speak of progressive metamorphism: tectono-metamorphic boundaries instead of real isograds separate the different zones. Moreover it cannot be proved that the peak of the metamorphism occurred at the same time within the four nappe complexes. Consequently, one can suppose that the rocks of these complexes did not follow strictly the same path on a P-T diagram.

However, it can be said that the parageneses, existing in the metapelites and the metabasites (Fig. 20) of the different tectonic units (Fig. 21), and leading to the

b



c

Fig. 20. Textural changes in response to increased metamorphic grade in basic rocks of the Hotagen area. a=Dolerite from the upper unit of the Bergsjön Complex with a well-preserved sub-ophitic texture (thin section, parallel nicols, 10 X). Bergsjön Complex. Eastern shore of Hästskotjärnen (20E, 9c). b=Strongly saussuritized and deformed metadolerite from the chlorite zone of the Rössjön Nappe Complex, with a fugitive blasto-ophitic texture (thin section, parallel nicols, 10 X). Rössjön Nappe Complex. North-west of Rössjön (21E, 0d). c=Amphibolite from the garnet zone (?) of the Lockringen Nappe Complex with a typical grano-nematoblastic texture (thin section, parallel nicols, 10 X). Lockringen Nappe Complex. North of the Lockringen (20E, 9d).

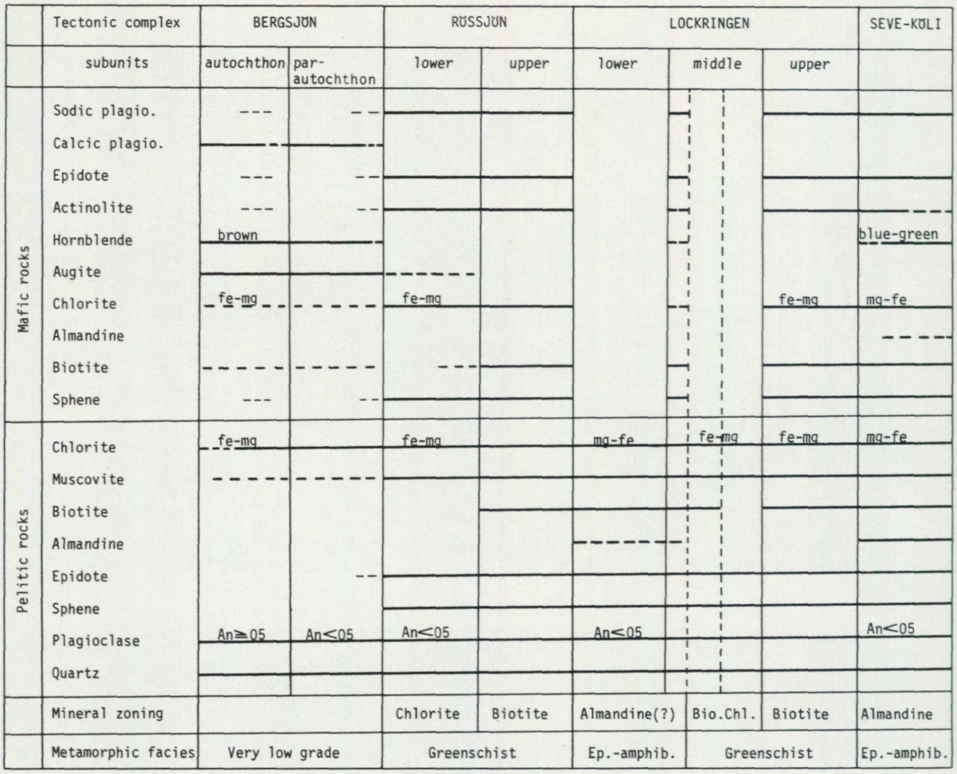


Fig. 21. Mineral distribution in rocks of the tectonic units of the Hotagen area.

recognition of three metamorphic zones (Fig. 22), are characteristic of a medium pressure facies series, with some affinities to fairly high pressure series. This kind of baric type requires geothermal gradients around 20° C/km. Thus the depth of burial was probably the main factor on which depended the distribution and the evolution of the metamorphic mineral assemblages. This burial was most probably due to the downthrusting of the Seve rocks into a westerly dipping subduction zone which was active during the Lower Silurian (Trouw 1973).

The model described in this account is in accordance with most of the up-to-date observations in the Scandinavian Caledonides. The subhorizontal attitude of the major thrust planes, the thinness and the general geometry of the various nappes, thinning and wedging out westwards, the post-metamorphic thrusting, the metamorphic medium-pressure facies series are all typical Caledonian characteristics. The tectonic evolution described is schematic, as numerous problems could not be clarified in such limited area. In spite of the almost total obliteration of primary features caused by the particularly well-developed cataclastic processes, the Hotagen area provides an impressive summary of the orogenic history of the Central Scandinavian Caledonides.

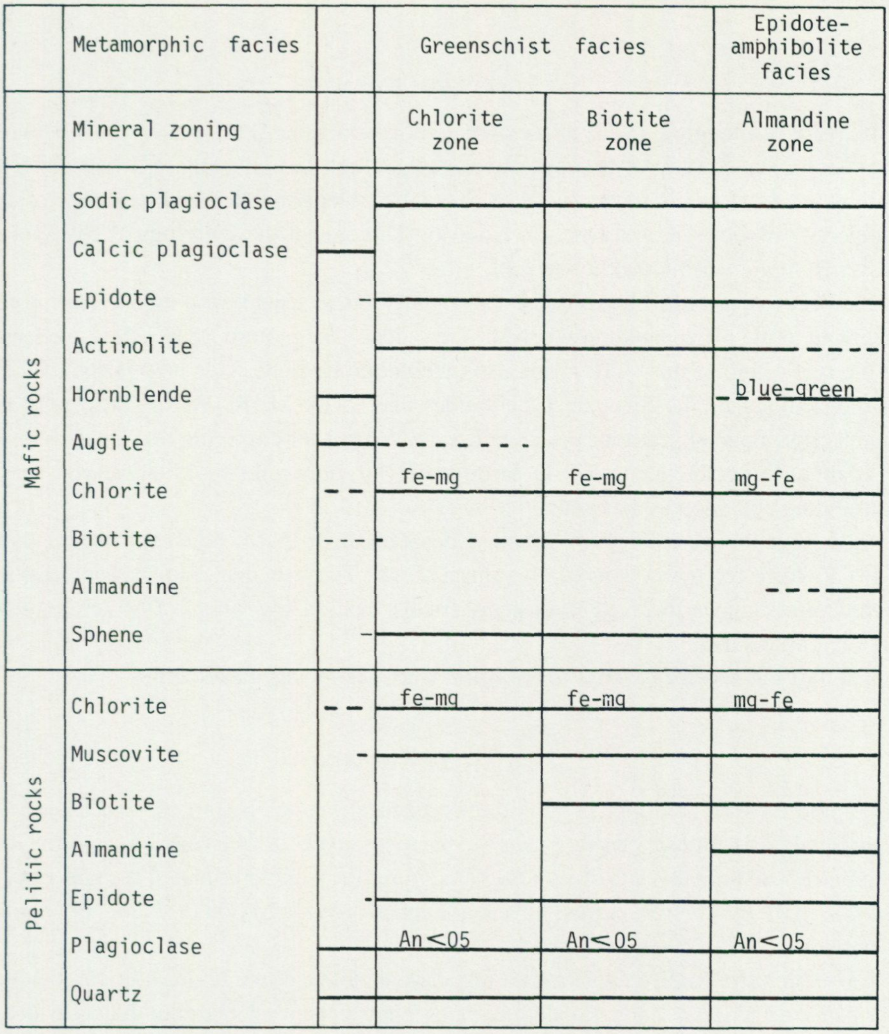


Fig. 22. Typical assemblages and progressiv mineralogical changes in the metamorphic zones of the Hotagen area.

ACKNOWLEDGEMENTS

This work is a tangible result of the cooperation established for several years between the Geological Survey of Sweden (Sveriges geologiska undersökning) and the University of Geneva, initiated by Prof. F. Jaffe, Department of Mineralogy of the University of Geneva, and Doc. G. Kautsky, Director of the Petrological Division of SGU. Both are warmly acknowledged.

In Sweden I should like to thank particularly Dr E. Zachrisson whose help in the field and in the office and knowledge of the Caledonian geology were a decisive factor in the realisation of this work. I am also indebted to Dr D. G. Gee who introduced me to the geology of the Swedish Caledonides and to Dr M. R. Wilson who read the manuscript. Special gratitude is due to Carole Wilson for correcting the English text.

I cannot forget the late Dr K. -E. Strömgård who, during the first field season, was a stimulating and friendly adviser.

In Geneva thanks are due to Prof. R. Chessex and Dr D. M. Steen and especially to Prof. F. Jaffe for many constructive discussions. The valuable contributions and the technical assistance received from many friends at the Department of Mineralogy are greatly appreciated.

The last but nicest flower is for Mireille whose help was inestimable.

RÉSUMÉ FRANÇAIS

La région de Hotagen dont la géologie est décrite dans ce travail est située dans les Calédonides de Suède centrale, sur la frontière avec la Norvège, à environ 100 kilomètres au nord de la ville d'Östersund, province du Jämtland. La carte couvre environ 350 kilomètres carrés, levés à l'échelle du 1:20'000 à l'aide de photos aériennes.

Le but de cette étude était d'obtenir une carte détaillée d'une région clef ou quelques unes des principales nappes calédoniennes chevauchent le bouclier baltique de la marge orientale de l'orogène. Les principales roches cartographiées sont des granites et des laves acides recouverts de méta-sédiments d'âge Précambrien supérieur à Paléozoïque inférieur. Le texte qui suit résume l'essentiel des résultats obtenus. Pétrographie, métamorphisme et structures de la région de Hotagen sont les principaux points abordés.

Grâce à des différences de lithologie, de proportions relatives des roches et à la présence de contacts anormaux, quatre unités tectoniques majeures ont été distinguées. Une de ces unités est en partie parautochtone (ou autochtone) et en partie allochtone (Complexe du Bergsjön), tandis que les trois autres sont des nappes métamorphiques (Complexes de Nappes du Rössjön, du Lockringen et de Seve-Köli). Toutes ces unités sont elles-mêmes fragmentées en un certain nombre d'écailles.

Pour les Complexes de Nappes du Rössjön et du Lockringen, ainsi peut-être que pour celui de Seve-Köli (?), la sédimentation débute au Précambrien supérieur (environ 950 à 650 M.a.) par des dépôts de nature essentiellement arkosique. Cette sédimentation s'effectue sur un socle cristallin acide pour les deux premiers complexes nommés. L'âge de ce cristallin n'est pas connu. Le soubassement sur lequel les sédiments de Seve se sont déposés n'apparaît pas (décollement). La séquence sédimentaire ''autochtone'' et parautochtone ne contient pas de sédiments de cet âge. La suite de la colonne stratigraphique est peu claire pour l'allochtone. Aucun sédiment postérieur aux arkoses n'existe dans les complexes du Rössjön et du Lockringen. Dans Seve-Köli cette colonne se poursuit par une série volcano-détritique (méta-tuffite, phyllite, quartzite) à laquelle se mêlent des amphibolites. L'âge de cette séquence est indéterminé.

A l'intérieur du Complexe du Bergsjön, les premiers sédiments recouvrant le cristallin sont des quartzites, parfois conglomératiques. Au front des Calédonides l'âge de ces roches, non fossilifères, s'étend de 650 M.a. environ, date de la glaciation varangienne, jusqu'au Cambrien, sans doute le Cambrien moyen. Seule la partie supérieure de cette unité quartzitique est représentée dans la région décrite. Il est important de noter que ces quartzites ne sont, localement tout au moins, jamais en contact avec le socle cristallin ''autochtone'' (massif d'Olden) mais qu'il existe des éléments granitiques de très petite dimension à la base de ce décollement majeur. Par-dessus les quartzites viennent des shales sombres (environ Cambrien moyen à Tremadocien), des calcaires (Ordovicien inférieur) et enfin des greywackes (Ordovicien). La couverture ''autochtone'' du socle cristallin précambrien avec lequel elle est en contact par un conglomérat est caractérisée par une séquence très réduite courant du Cambrien moyen (alum shales) à l'Ordovicien inférieur (calcaire).

La synthèse des observations structurales et métamorphiques nous permet de reconstituer l'histoire orogénique de la région décrite. L'activité tectogénique affecte tout d'abord les unités les plus internes. Elle déforme les roches du Complexe de Nappes de Seve-Köli et les emmène en profondeur avec production d'une schistosité de flux. A la suite de cette phase le métamorphisme régional atteint son maximum d'intensité et développe une série de faciès de type pression intermédiaire indiquant un gradient géothermique ''normal'' de 20° à 25°/kilomètre environ. Observons qu'il n'est point besoin d'un flux de chaleur exceptionnel pour engendrer un tel métamorphisme mais qu'il suffit d'enfouir les roches à une profondeur suffisante. Cet enfouissement est dû aux forces tectoniques et s'effectue soit à la suite d'une simple mais profonde dépression de Seve à laquelle s'ajoute la surcharge due à l'arrivée des nappes supérieures (''Upper Nappes''); soit à la faveur d'une zone de subduction. Cet enfouissement affecte sans doute non seulement les roches de Seve mais encore celles des unités du Rössjön et du Lockringen.

Une seconde phase tectonique ramène les roches en direction de la surface et occasionne une décroissance progressive des conditions de métamorphisme. Au cours de cette phase de très importants charriages se produisent conduisant à la formation du Complexe de Nappes de Seve-Köli, puis du Rössjön et du Lockringen. Le socle cristallin acide ante-Calédonien est lui-même mobilisé à la base de la Grande Nappe Seve. La formation de ces nappes s'effectue dans des conditions de métamorphisme d'une intensité encore relativement importante, au moins du niveau de la zone à biotite pour le plan de chevauchement entre Seve-Köli et Rössjön ou Lockringen. Les déformations sont marquées dans ces trois complexes par le développement d'une surface d'un type intermédiaire entre schistosité de flux et de crénulation. Les chevauchements provoquent une inversion générale des zones métamorphiques, avec subsistance à l'intérieur de certaines unités tectoniques d'une zonalité normale.

Les forces tectoniques restent cependant importantes à l'intérieur de la chaîne calédonienne. Les nappes déjà formées sont charriées en direction de l'E sur des distances considérables, dans des conditions de pression et de température bien moindres que précédemment. Ce charriage entraîne la multiplication des imbrications, notamment au niveau des roches du socle, impliquées dans le chevauchement ainsi que le développement de textures cataclastiques spectaculaires, surtout à la base de cet allochtone. Au cours de cette avancée les unités chevauchées sont elles-mêmes plissées et écaillées. Les plissements sont dans l'ensemble de type crénulation ou pli-fracture. Dans le parautochtone surtout une véritable schistosité se développe parallèlement aux plans axiaux. Un fait important à considérer est le décollement majeur qui se situe à la base des quartzites varangiennes. Ce décollement s'effectue au-dessus d'un socle passif recouvert d'une mince séquence sédimentaire. Ce décollement ne s'enracine pas (Gee 1975a et b) ni ne disparaît (coupé par un plan de chevauchement supérieur) dans la région de Hotagen, ni même avant une distance indéterminée en direction de l'W. Le déplacement est donc considérable. Un métamorphisme de faible intensité apparaît dans les unités parautochtones, dû à la surcharge causée par les grandes nappes sus-jacentes.

D'après des études effectuées à une échelle plus vaste l'essentiel de ces mouvements ont eu lieu au Silurien inférieur et moyen (Gee et Wilson 1974; Gee 1974).

Par la suite une phase tectonique, marquée par de vastes bombements et dépressions, avec des axes orientés en gros NS, a donné aux structures de la région leur aspect actuel.

Le modèle obtenu finalement concorde avec la plupart des observations effectuées dans les Calédonides scandinaves. L'aspect subhorizontal des plans de chevauchements majeurs, la faible épaisseur relative des nappes ainsi que leur géométrie en forme de coin s'amincissant puis disparaissant en direction de l'W, constituent des caractéristiques calédoniennes. L'évolution tectonique présentée est très schématique, de nombreuses questions ne pouvant être résolues dans le cadre d'une étude locale. Cependant malgré l'oblitération massive due au développement particulièrement important des phénomènes cataclastiques, la région de Hotagen n'en constitue pas moins un résumé saisissant d'une partie de l'histoire orogénique des Calédonides.

REFERENCES

GFF=Geologiska Föreningens i Stockholm Förhandlingar
NGT=Norsk Geologisk Tidsskrift
NGU=Norges geologiska undersökning
SGU=Sveriges geologiska undersökning

ALBEE A. L., 1962: Relationship between the mineral association, chemical composition and physical properties of the chlorite series. – Amer. Mineral. 47, 851–870.

ASKLUND, B., 1933: Vemdalskvartsitens ålder. – SGU C 377.

– 1938: Hauptzüge der Tektonik und Stratigraphie des mittleren Kaledoniden in Schweden. – SGU C 417.

– 1958: Le problème Cambrien-Eocambrien dans la partie centrale des Calédonides suédoises. – Colloques internationaux du C. N. R. S., Paris.

– 1960: Studies in the thrust region of the Southern Part of the Swedish mountain chain. – Guide to excursion n. A 24 and C 19. Intern. Geol. Congr. 21st Copenhagen, Rep. Session, Norden.

– 1961: The extension of the Serv nappe in the Scandinavian mountain chain. – SGU C 584.

ASKLUND, B., and THORSLUND, P., 1935a: Fjällkedjerandens bergbyggnad i norra Jämtland och Ångermanland. – SGU C 382.

– 1935b: Stratigrafiska och tektoniska studier inom Föllingeområdet i Jämtland. – SGU C 388.

ATHERTON, M. P., 1968: The variation in garnet, biotite, chlorite composition in medium grade pelitic rocks from the Dalradian, Scotland, with particular reference to the zonation in garnet. – Contr. Mineral. Petrol. 18, 347–371.

BARTH, T. W. F., 1938: Progressive metamorphism of sparagmites rocks. – NGT, 9, 271–303.

BJÖRLYKKE, K., ENGLUND, J. O., and KIRKUSHMO, L. A., 1967: Latest Precambrian and Eocambrian stratigraphy in Norway. – NGU 251, 5–17.

CLAESSON, S., 1976: The age of the Ottfjället dolerites of Särv Nappe, Swedish Caledonides. – GFF 98, 370–374.

CLOOS, E., 1971: Microtectonics along the western edge of the Blue Ridge, Maryland and Virginia. – The John Hopkins Press, Baltimore and London.

DU RIETZ, T., 1943: Kvartsitskollorna i Ormsjö-Tåsjötrakten. – SGU C 448.

– 1960: Tectonic conditions in the front range of the Swedish Caledonian from Lake Malgomaj to Lake Hotagen in Central Norrland. – SGU C 568.

ERNST, W. G., 1968: Amphiboles, crystal chemistry, phase relations and occurrence. – New-York, Springer-Verlag.

GALE, G. H., and ROBERTS, D., 1972: Paleogeographical implications of greenstone petrochemistry in the southern Norwegian Caledonides. – Nature Phys. Sci. 238, 60–61.

– 1974: Trace element geochemistry of Norwegian Lower Paleozoic basic volcanites and its tectonic implications. – Earth Planetary Sci. Letters 22, 380–390.

GEE, D. G., 1972: The regional geological context of the Tåsjön uranium project, Caledonian front, Central Sweden. – SGU C 671.

– 1974: Comments on the metamorphic Allochthon in Northern Tröndelag, Central Scandinavian Caledonides. – NGT 54, 435–440

– 1975a: A tectonic model for the central part of the Scandinavian Caledonides. – Am. Jour. Sci. 275A, 468–515.

– 1975b: A geotraverse through the Scandinavian Caledonides – Östersund to Trondheim. – SGU C 717.

GEE, D. G., and WILSON, M. R., 1974: The age of orogenic deformation in the Swedish Caledonides. – Am. Jour. Sci. 274, 1–9.

GEE, D. G., and ZACHRISSON, E., 1974: Comments on stratigraphy, faunal provinces and structure of the metamorphic allochthon, Central Scandinavian Caledonides. – GFF 96, 61–66.

GEE, D. G., KARIS, L., KUMPULAINEN, R., and THELANDER, T., 1974: A summary of Caledonian front stratigraphy, Northern Jämtland and Southern Västerbotten, Central Swedish Caledonides. – GFF 96, 389–397.

HENLEY, K. J., 1970: The structural and metamorphic history of the Sulitjelma region, Norway, with special reference to the nappe hypothesis. – NGT 50, 97–136.

HIGGINS, M. W., 1971: Cataclastic rocks. – U. S. Geol. Survey Prof. Paper, 687.

HÖGBOM, A. G., 1910: Studies in the post Silurian thrust region of Jämtland. – GFF 31, 289–346.

– 1920: Geologisk beskrivning över Jämtlands län. – SGU C 140.

HOLTEDAHL, O., (Editor), 1960a: Geology of Norway. – NGU 208.

– 1960b: Stratigraphy of the Sparagmite Group including ''the sandstone divisions of Finnmark'', geology of Norway. – NGU 208, 111–127.

– 1961: The "Sparagmite Formation" (KJERULF) and "Eocambrian" (BRÖGGER) of the Scandinavian peninsula. – Congr. Geol. Intern. Compt. Rend. 20th, Mexico.

– 1964: The Caledonides of Norway. Tectonics of Europe. – Congr. Geol. Intern. Moscow, 74–83.

KAUTSKY, G., 1953: Der geologische Bau des Sulitelma-Salojauregebietes in den nordskandinavischen Kaledoniden. – SGU C 528.

KNOPF, E. B., 1931: Retrogressive metamorphism and phyllonitisation. – Am. Journ. Sci., Ser. 5, 21, 1–27.

KULLING, O.,1941: Om södra Lapplandsfjällens bergbyggnad. – GFF 63, 101–116.

– 1942: Grunddragen av fjällkedjerandens bergbyggnad inom Västerbottens län. – SGU C 445.

– 1961: On the age and tectonic position of the Valdres Sparagmite. – GFF 83, 210–214.

– 1972: The Swedish Caledonides, in T. STRAND and O. KULLING, Scandinavian Caledonides. – Wiley Interscience.

KVALE, A., 1953: Linear structures and their relation to movement in the Caledonides of Scandinavia and Scotland. – Q. J. G. S.. 109, 21–50.

MAGNUSSON, N. H., THORSLUND, P., BROTZEN, F., ASKLUND, B., and KULLING, O., 1960: Description to accompany the map of the Prequaternary rocks of Sweden. – SGU Ba 16.

MIYASHIRO, A., 1973: Metamorphism and metamorphic belts. – George Allen and Unwin Ltd. London.

OFTEDAHL, CHR., 1956: Om Grong culminasjion og Grongfeltets skyvedekka. – NGU 195, 57–64.

PETTIJOHN, F. J., POTTER, P. E., and SIEVER, R., 1972: Sand and sandstone. – Springer-Verlag, Berlin-Heidelberg-New York.

PRINGLE, I. R., 1972: Rb-Sr age determinations on shales associated with the Varanger ice age. – Geol. Mag. 109, 465–472.

RAMBERG, H., 1966: The Scandinavian Caledonides as studied by centrifugated dynamic models. – Bull. Geol. Inst. Uppsala, 43, 1–72.

RAMSAY, J. G., 1960: The deformation of early linear structures in areas of repeated folding. – Journ. Geol. 68, 75–93.

– 1967: Folding and fracturing of rocks. – McGraw-Hill Book Co, New York.

ROBERTS, D., 1967: Structural observations from the Koppera-Riksgrense area and discussion of the tectonics of Stjördalen and the N. E. Trondheim region. – NGU 245, 64–220.

– 1968: On the occurrence of sillimanite in the Gula Schist Group, Trondheim region. – NGT 48, 171–177.

– 1971: Timing of Caledonian euorogenic activity. – Nature, 232.

ROBERTS, D., SPRINGER, J., and WOLFF, F. C., 1970: Evolution of the Caledonides in the Northern Trondheim region, Central Norway. A review. – Geol. Mag. 107, 133.

SCHENK, V., 1975: Geologie der Kaledoniden am Hotagen See, Zentral-Schweden. – SGU C 715.

SHIDO, F., and MIYASHIRO, A., 1959: Hornblendes of basic metamorphic rocks. – Tokyo Univ. Fac. Sci. J., Sec. 2, 12, 85–102.

SJÖSTRAND, T., 1978: Caledonian geology of the Kvarnbergsvattnet Area, northern Jämtland, central Sweden. – SGU C 735.

SPRY, A., 1969: Metamorphic textures. – Pergamon Press.

STÅLHÖS, G., 1956: The Sparagmite Series and the Vemdal quartzite of the Hede region, Härjedalen. – Bull. Inst. Geol. Univ. Uppsala. 34, 297–368.

– 1958: Fjällrandens Sparagmit och Kvartsitformationer. – GFF 76, 209–225.

STEPHANSSON, O., 1976: A tectonic model of the Offerdal-Olden area, Jämtland. – GFF 98, 112–119.

STEPHENS, M. B., 1977: Stratigraphy and relationships between folding, metamorphism and thrusting in the Tärna-Björkvattnet area, northern swedish Caledonides. – SGU C 726.

STRAND, T., 1961: The Scandinavian Caledonides, a review. – Am. Journ. Sci. 259, 161–172.

STRAND, T., and KULLING, O., 1972: Scandinavian Caledonides. – Wiley Interscience.

STRÖMBERG, A. G. B., 1955: Zum Gebirgsbau des Skanden im mittleren Härjedalen. – Bull. Inst. Geol. Univ. Uppsala 35, 199–246.

– 1961: On the tectonics of the Caledonides in the southwestern part of Jämtland, Sweden. – Bull. Inst. Geol. Univ. Uppsala 39.

– 1969: Initial Caledonian magmatism in Jämtland area, Sweden. North Atlantic Geology and Continental Drift, Memoir 12. – The Am. Ass. of Petroleum Geologists.

– 1974: Kaledonisk tektonik i Jämtland. – GFF 96, 125–129.

– 1975: The conglomerate-bearing Rensjönäset Group in the Caledonides of western Jämtland, Sweden. – SGU C 714.

TÖRNEBOHM, A. E., 1896: Grunddragen av det centrala Skandinaviens bergbyggnad. – Kongl. Vet. Ak. Förhandl. 10.

TROUW, R. A. J., 1973: Structural geology of the Marsfjällen area, Caledonides of Västerbotten, Sweden. – SGU C 689.

TURNER, F. J., 1968: Metamorphic petrology, mineralogical and field aspects. – McGraw-Hill Co, New-York.

VOGT, T., 1927: Sulitjelmafeltets geologi og petrographi. – NGU 121.

WALSER, G., 1976: Géologie et Pétrographie de la Région de Hotagen, Jämtland, Calédonides de Suède Centrale. – Unpublished thesis, University of Geneva, 167 p.

WATERS, A. C., and CAMPBELL, C. D., 1935: Mylonites from the San Andreas Fault zone. – Am. Journ. Sci., Ser. 5, 29, 473–503.

WELIN, E., CHRISTIANSSON, K., and NILSSON, O., 1972: Rb-Sr radiometric ages of extrusive and intrusiv rocks in northern Sweden. – SGU C 666.

WINKLER, H. G. F., 1976: Petrogenesis of metamorphic rocks. – Springer-Verlag, Berlin-Heidelberg-New York.

WISEMAN, J. D. H., 1934: The central and south west Highland epidiorites: a study in progressive metamorphism. – Q. J. G. S. 90, 354–417.

ZACHRISSON, E., 1964: The Remdalen syncline. – SGU C 596.

– 1969: Caledonian geology of northern Jämtland – southern Västerbotten. – SGU C 644.

– 1971: The structural setting of the Stekenjokk ore bodies, central Swedish Caledonides. – Econ. Geol. 66, 641–652.

– 1973: The westerly extension of Seve rocks within the Seve-Köli Nappe Complex in the Scandinavian Caledonides. – GFF 95, 243–251.

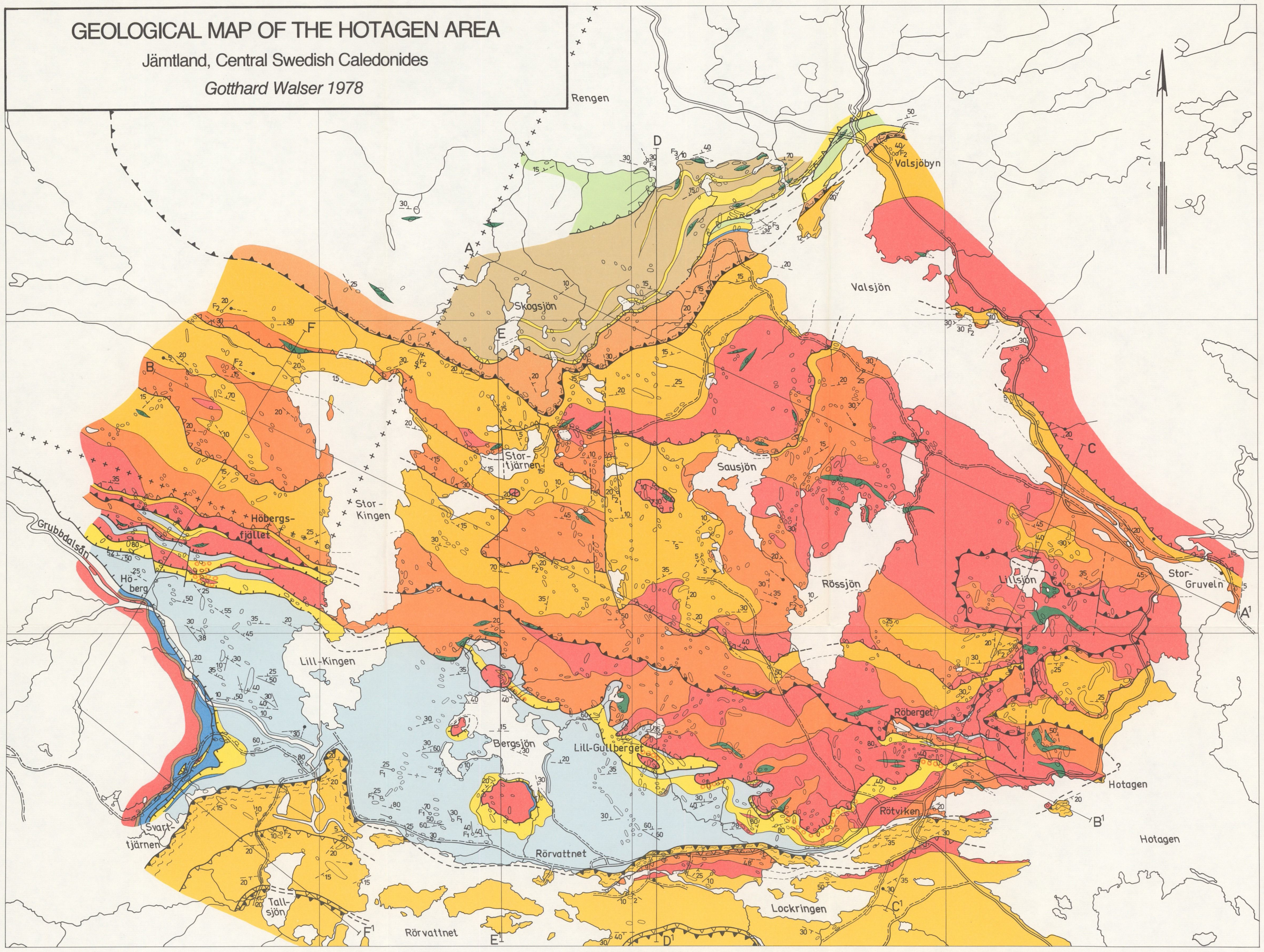
ZWART, H. J., 1974: Structure and metamorphism in the Seve-Köli Nappe Complex (Scandinavian Caledonides) and its implications concerning the formation of metamorphic nappes. – Géologie des domaines cristallins, Liège, 129–144.

ZWART, H. J., CORVALAN, J., JAMES, H. C., MIYASHIRO, A., SAGGERSON, E. P., SOBOLEV, V. S., SUBRAMANIAM, A. P., and VALLANCE, T. G., 1967: A schema of metamorphic facies for the cartographic representation of regional metamorphic belts. – IUGS, Geol. Newsletter 2, 57–72.

GEOLOGICAL MAP OF THE HOTAGEN AREA

Jämtland, Central Swedish Caledonides

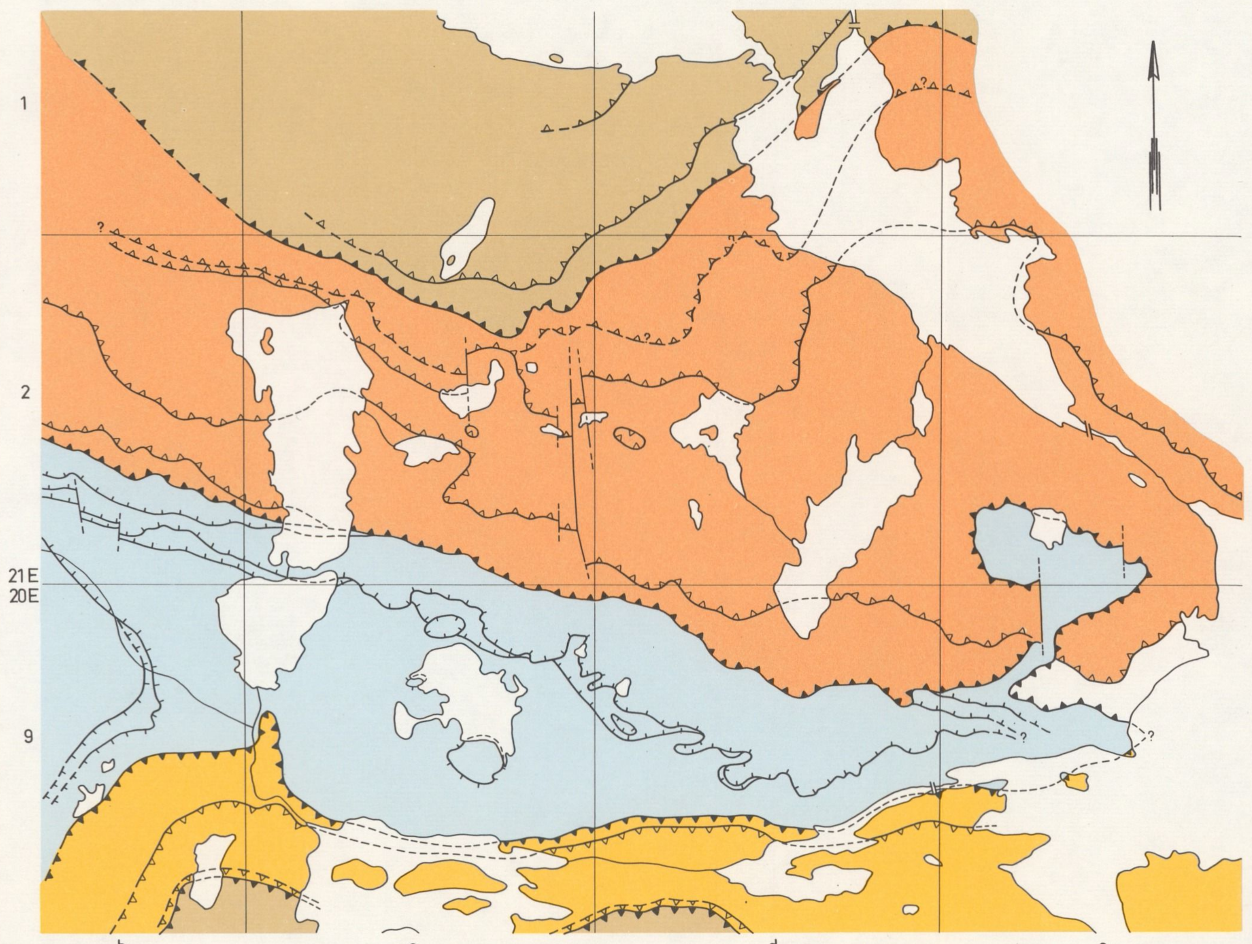
Gotthard Walser 1978



Scale 1:50 000

0 — 4 km

TECTONIC UNITS OF THE HOTAGEN AREA

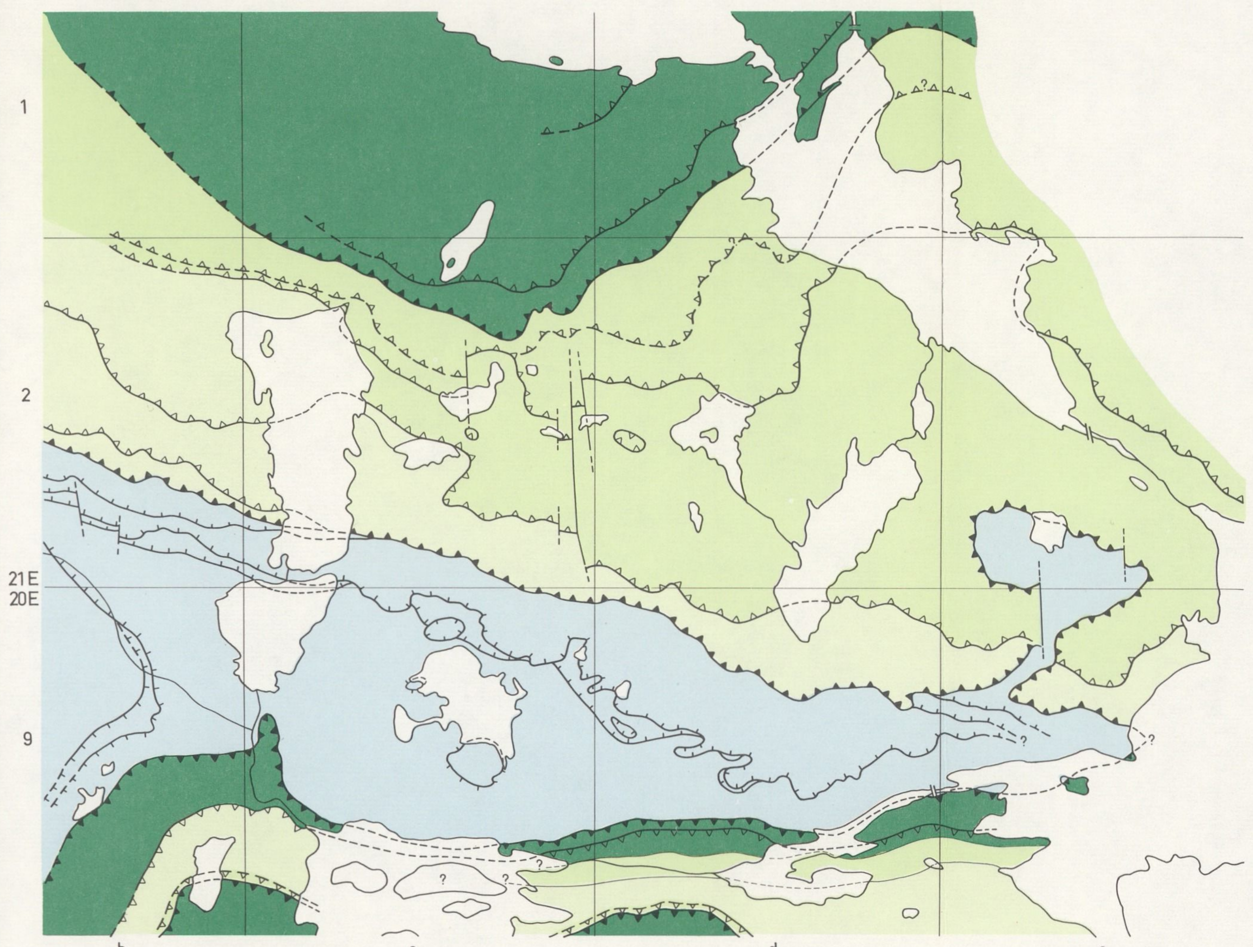


Scale 1:100 000

0 — 4 km

- Seve-Köli Nappe Complex
- Lockringen Nappe Complex
- Rössjön Nappe Complex
- Bergsjön Complex
- Fault
- Minor thrust, allochthon
- Major thrust, allochthon
- Thrust, parautochthon

METAMORPHIC ZONES, HOTAGEN AREA



Scale 1:100 000

0 — 4 km

- Garnet zone — epidote-amphibolite Facies
- Biotite zone — greenschist Facies
- Chlorite zone — greenschist Facies
- Very low grade metamorphism (subgreenschist Facies)
- Fault
- Minor thrust, allochthon
- Major thrust, allochthon
- Thrust, parautochthon

LEGEND

SEVE-KÖLI NAPPE COMPLEX

- Amphibolite
- Quartz phyllite or tuffite
- Greenschist or tuffite
- Quartzite
- Dolomitic marble
- Mica schist
- Meta arkose
- Mylonite

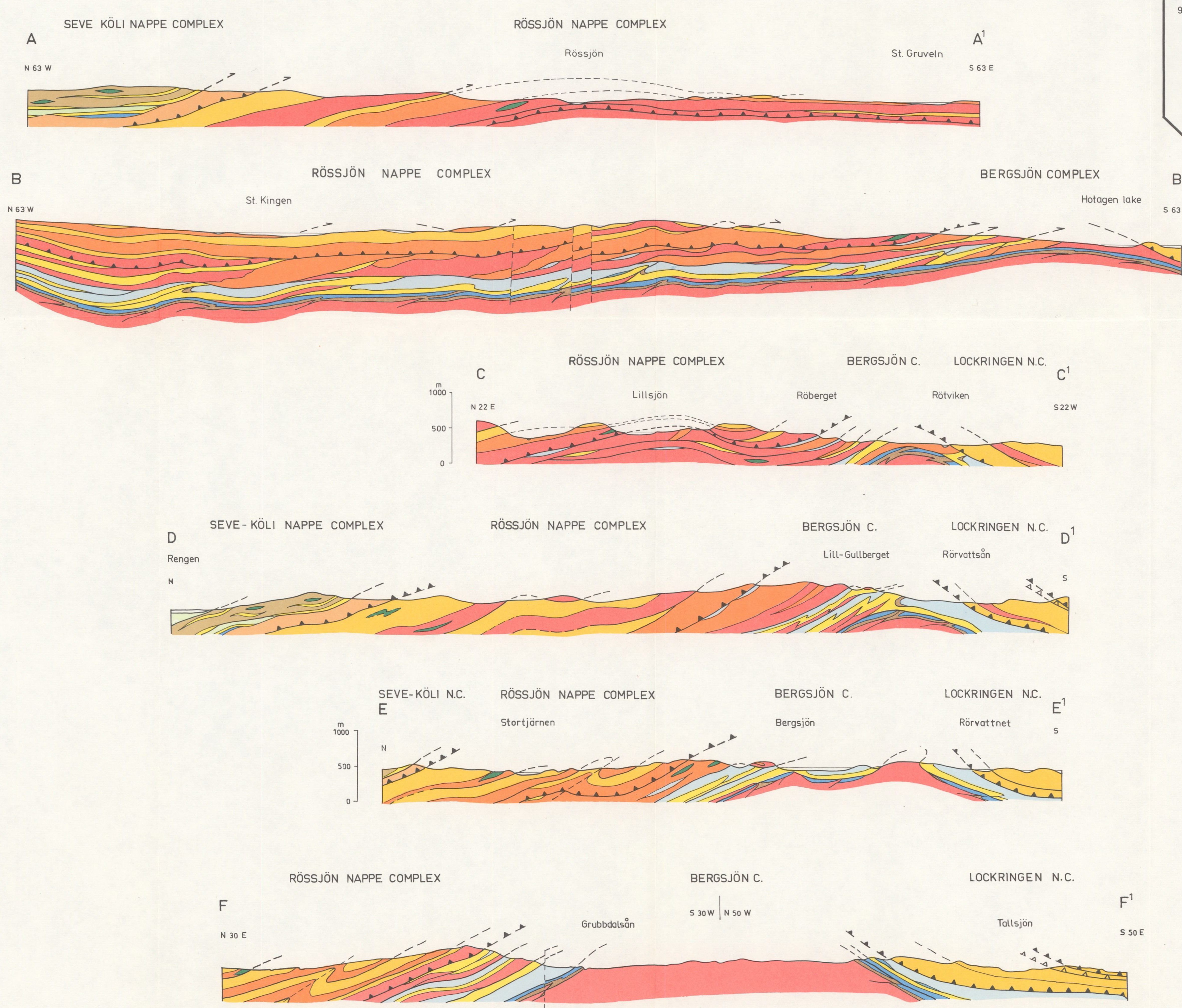
RÖSSJÖN AND LOCKRINGEN NAPPE COMPLEXES

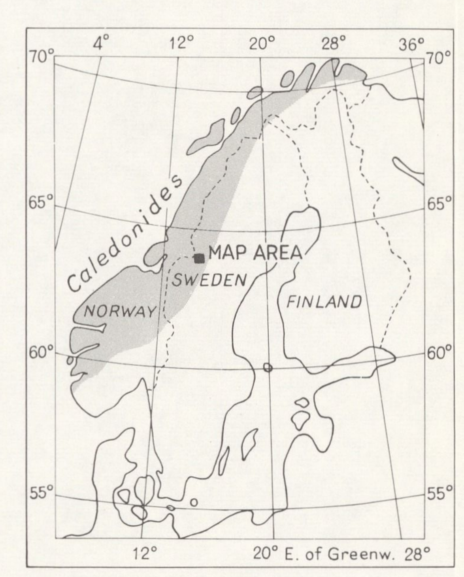
- Meta-arkose
- Greenstone
- Porphyry
- Granite
- Mylonite

BERGSJÖN COMPLEX

- Greywacke
- Limestone
- Alum shale
- Quartzite, quartzitic micro-conglomerate
- Dolerite
- Porphyry
- Granite

- Bedding
- Main cleavage
- Fold axis
- Lineation
- Fault
- Minor thrust, allochthon
- Major thrust, allochthon
- Thrust, parautochthon
- Rock exposures





ENCLOSURE I

SEVE – KÖLI NAPPE COMPLEX

TECTONIC UNITS (this work)	Seve – Köli Nappe Complex (Rengen – Valsjön)	Seve – Köli Nappe Complex (S of Lockringen)
Tectonic position	allochthonous	allochthonous
Correlation (other authors)	Seve – Köli Nappe Complex (ZACHRISSON, 1973)	Seve – Köli Nappe Complex (ZACHRISSON, 1973)
Metamorphic facies (main phase)	epidote – amphibolite facies	epidote – amphibolite facies
Sediments: LOWER PALEOZOIC (ORDOVICIAN, CAMBRIAN); EOCAMBRIAN (VARANGIAN)	Uncertain age Rengen – Valsjön Greenschist Metatuffite Quartzphyllite Quartzite Dolomitic marble Mica-schist	Uncertain age S of Lockringen Greenschist and Meta-arkoses
Basement: DIABASES in the sediment	X	X
Basement: DIABASES only in the basement		
Basement: PORPHYRY		
Basement: GRANITE		
Thickness of the tectonic units	The top is not outcropping in the map area	The top is not outcropping in the map area
Morphology	Dip slopes and little walls	Dip slopes and little walls
Exposure	Poorly exposed	Poorly exposed

METAMORPHISM and DEFORMATION

deformation		zone	metamorphism
Gentle open folding	F_4	chlorite zone	
		chlorite zone	
Production of crenulated microfolds (axial planes dipping N-NW).	F_3	chlorite zone	Cataclasis in lower or sub-greenschist facies conditions. Local chloritization of garnet, biotite.
		chlorite zone	
Essentially post-crystalline deformations resulting in a crenulation cleavage (S_2).	F_2	biotite zone	Recrystallization of quartz, muscovite and biotite. Cataclasis in upper greenschist facies conditions.
		garnet zone	Continued growth of garnet. Appearence of small inclusion-free new garnets.
Formation of a slaty cleavage (S_1).	F_1	garnet zone	Growth of garnet and hornblende porphyroblasts.

Overthrusting of Seve over Rössjön and Lockringen.

LOCKRINGEN NAPPE COMPLEX

TECTONIC UNITS (this work)	LOCKRINGEN III	LOCKRINGEN II	LOCKRINGEN I
Tectonic position	allochthonous	allochthonous	allochthonous
Correlation (other authors)	Särv Nappe (STRÖMBERG)	Granite – Mylonite Nappe (ASKLUND, 1960)	Granite – Mylonite Nappe (ASKLUND, 1960)
Metamorphic facies (main phase)	greenschist facies: biotite	greenschist facies: chlorite | biotite	epidote-amphibolite facies
Sediments	Meta-arkoses	Meta-arkoses	Meta-arkoses
Basement: DIABASES in the sediment	X		
Basement: DIABASES only in the basement		X	
Basement: PORPHYRY		X	
Basement: GRANITE		X	
Thickness of the tectonic units	10 meters	500 – 800 meters	500 – 800 meters
Morphology	Hilly to mountainous	Hilly to mountainous	Hilly to mountainous
Exposure	Fairly well exposed	Fairly well exposed	Fairly well exposed

deformation		zone	metamorphism
Gentle open folding	F_3	chlorite zone	Strong cataclastic processes in lower greenschist facies conditions. Local chloritization of garnet, biotite. Growth of muscovite, chlorite.
Formation of crenulation cleavage or fracture cleavage(S_2). Asymmetrical folding. Subvertical axial planes.	F_2	chlorite zone	(as above)
Formation of slaty cleavage (S_1). subparallel to the sedimentary bedding, and lineation(L_1).	F_1	chlorite, biotite or garnet zone	Growth of garnet in Lockringen I, of hornblende in the lower part of Lockringen II, of biotite in Lockringen III.
?		chlorite, biotite or garnet zone	?

RÖSSJÖN NAPPE COMPLEX

TECTONIC UNITS (this work)	RÖSSJÖN IV	RÖSSJÖN III	RÖSSJÖN II	RÖSSJÖN I
Tectonic position	allochthonous	allochthonous	allochthonous	allochthonous
Correlation (other authors)	Granite – Mylonite Nappe (ASKLUND, 1960)	Granite – Mylonite Nappe (ASKLUND, 1960)	Granite – Mylonite Nappe (ASKLUND, 1960)	Granite – Mylonite Nappe (ASKLUND, 1960)
Metamorphic facies (main phase)	greenschist facies: biotite	greenschist facies: biotite	greenschist facies: chlorite	greenschist facies: chlorite
Sediments	Meta-arkoses	Meta-arkoses	Meta-arkoses	Meta-arkoses
Basement: DIABASES in the sediment	(X ?)			
Basement: DIABASES only in the basement	X	X	X	X
Basement: PORPHYRY	X	X	X	X
Basement: GRANITE	X	X	X	X
Thickness of the tectonic units	300 – 500 meters	200 – 500 meters	50 – 400 meters	0 – 200 meters
Morphology	Dip slopes (to the N) or cliffs (to the S)	Dip slopes (to the N) or cliffs (to the S)	Dip slopes (to the N) or cliffs (to the S)	Dip slopes (to the N) or cliffs (to the S)
Exposure	Fairly well exposed	Fairly well exposed	Fairly well exposed	Fairly well exposed

deformation		zone	metamorphism
Gentle open folding. Subvertical faulting, also affecting the thrust planes.	F_3	chlorite zone	Important cataclasis processes (protomylonites, mylonites and ultramylonites) in greenschist facies conditions. Growth of muscovite, epidote, quartz, chlorite. Local chloritization of biotite.
Formation of a crenulation cleavage (S_2) or fracture cleavage (S_2). Subvertical axial planes dipping to the NW.	F_2	chlorite zone	(as above)
Formation of a subhorizontal slaty cleavage (S_1), subparallel to the sedimentary bedding (S_0). Main lineation (L_1 : N 60 W).	F_1	chlorite or biotite zone	Growth of biotite (Rössjön III-IV). Albitization of basic plagioclases (Rössjön I-IV).
?		chlorite or biotite zone	?

Overthrusting of Seve, Lockringen and Rössjön over the Bergsjön.

BERGSJÖN COMPLEX

TECTONIC UNITS (this work)	BERGSJÖN III	BERGSJÖN II	BERGSJÖN I
Tectonic position	parautochthonous	parautochthonous	autochthonous
Correlation (other authors)	Olden Nappe (ASKLUND, 1960)	Olden Nappe (ASKLUND, 1960)	Olden Nappe (ASKLUND, 1960)
Metamorphic facies (main phase)	very low grade	very low grade	very low grade
Sediments	Greywackes Limestone Alum shales Quartzite and Shales (tectonically reduced)	Greywackes Limestone Alum shales Quartzite and Shales (tectonically reduced)	Limestone Alum shales
Basement: DIABASES	X	not observed	X
Basement: PORPHYRY	X		Dikes of porphyry
Basement: GRANITE	X	X (rare)	X
Thickness of the tectonic units	400 – 700 meters	Sediments: 50-100 meters	Sediments: 10-15 meters
Morphology	Cliffs	Valley	Valley
Exposure	Fairly well exposed (except contacts)	Fairly well exposed (except contacts)	Fairly well exposed (except contacts)

deformation		zone	metamorphism
Formation of major open folds : Olden antiform. Subvertical faulting, also affecting the thrust planes.	F_2	maximum chlorite zone	
Asymmetrical folding with production of a fracture (crenulation) cleavage (S_1) Jämtlandian decollement.	F_1	maximum chlorite zone	Strong cataclastic processes in lower greenschist facies conditions. Local growth of muscovite, chlorite, epidote, actinolite.
?			?

Synopsis of the main geological features of the Hotagen area.

PRISKLASS G

Distribueras genom

Liber Kartor

162 89 VÄLLINGBY

Växjö 1980 C Davidsons Boktryckeri AB

Printed in Sweden.

ISBN 91-7158-162-6