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ROBERT LILLJEQUIST

CALEDONIAN GEOLOGY OF THE LAISVALL AREA, SOUTHERN NORRBOTTEN, SWEDISH LAPLAND

WITH 1 PLATE

STOCKHOLM 1973

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ABSTRACT

The geology of the Laisvall area, located within the eastern border zone of the Caledonian Mountain Range, is presented, supported by evidence from more than 1 000 drill-holes. On a Pre-Cambrian basement (syenites and granites) a succession of late Pre-Cambrian, Cambrian and (?) Ordovician rocks were deposited. During Caledonian deformation large-scale thrusting took place with the emplacement of nappes. The lowermost nappe units are composed mainly of highly brecciated and mylonitized Pre-Cambrian and late Pre-Cambrian rocks, overridden by schists and quartzites belonging to the so-called Seve-Köli Nappe Complex. The autochthonous sedimentary rocks are very well preserved in the central part of the study area (around the Laisvall Mine) having been subjected to minor faulting while in the north-western parts of the area they are folded, contorted and broken up into an imbricate structure, involved with slices of the basement. Folds trending c. N–S and WNW interfere, but their relative age-relationship is uncertain. These folds dominate the geometry of the uppermost nappe unit, the Yraf Nappe Complex, superimposing an early isoclinal folding and the thrusting. The last tectonic phase in the area was brittle and resulted in faults and joints. Dominating joint sets are developed in c. N30°E and N60°W, while others, less pronounced, strike c. N30°W, N–S and E–W. It is suggested that the joints were formed late in the history of the Caledonides. The morphology of the area is mainly inherited from the rock structures and has been accentuated during the glacial erosion in the Pleistocene.

I. INTRODUCTION

The Laisvall area is situated at the eastern border of the Swedish Caledonides, just south of the Arctic Circle and between Long. 16° and 18°E (Fig. 1). The area investigated includes the westernmost parts of the Pre-Cambrian of the Baltic Shield, the overlying late Pre-Cambrian, Cambrian and possibly Ordovician sediments, and the parautochthonous and allochthonous rock units thrust over these sediments.

The present paper outlines the structural pattern of the Laisvall area. A geological map in the scale of 1:50 000 is presented (Pl. 1) based on detailed field work by the author and geological maps in different scales produced since 1931 by geologists of the Boliden Company.

The first geological investigation in the Laisvall area started in 1931 after the discovery of glacial boulders rich in galena. After an interruption, the investigations were taken up again in 1938 and then many new localities with ore boulders were found. The boulders originated from an autochthonous late Pre-Cambrian or Cambrian sandstone succession which overlies the Pre-Cambrian bedrock. One year later, ore was drilled on both sides and underneath Lake Stor-Laisan and since then prospecting work and geological mapping has continued in order to increase the known ore reserves and to decipher the origin of the ore-bodies.

Within the map-area more than 1 000 drill-holes have been made, going through more than 120 000 m of rock. The Laisvall area can thus be regarded as one of the best known areas along the eastern border of the Caledonides.

The topography is dominated by Lake Stor-Laisan (424 m a.s.l.) transversing the area N–S as far as Hällbacken in the north, where the course swings to E–W. The Laisvall area is rather rich in lakes and streams, the drainage pattern mainly trending NW. This trend dominates the whole eastern border of the Scandinavian Caledonides as well as the Pre-Cambrian shield to the east. The

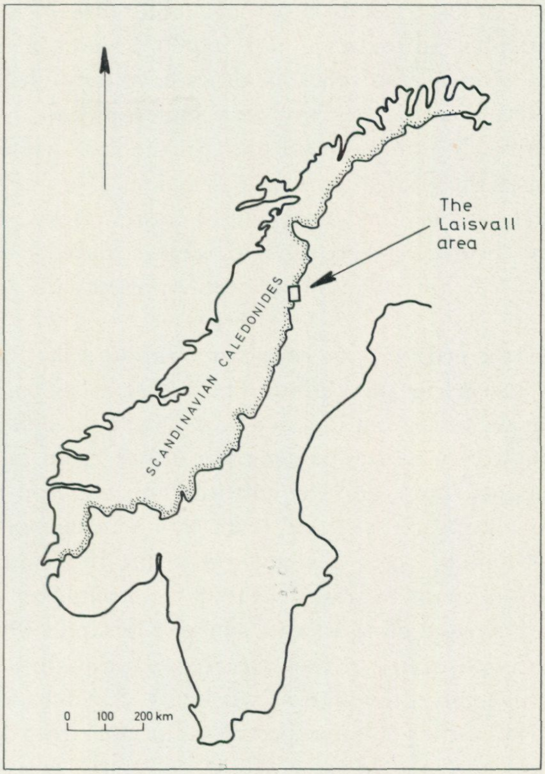


Fig. 1. Geographical location of the Laisvall area.

major part of the area is covered by woods and bogs. To the west of Lake Stor-Laisan some mountains rise just above the timber-line, which reaches c. 600 m a.s.l. Winter in Laisvall lasts from late September to late May, reducing the field season to 3–4 months each year.

The term late Pre-Cambrian is used throughout this paper instead of such names as Eocambrian, Infracambrian, Varegian etc., as was suggested by the Subcommission on Pre-Cambrian Stratigraphy of the International Union of Geological Sciences in 1969.

The geological map (Pl. 1) has been compiled from material available in the archive of the Boliden Company (E. Dahlström 1931, F. Kautsky 1938–1944, E. Ljungner 1939–1947, E. Grip 1939, N. Marklund 1944–1953, H. Zweifel 1958–1961, L. A. Barkey 1961, and L. Carlsson 1966–1970), together with complementary geological mapping by the author in 1964, 1965 and 1967. The area surveyed is c. 920 km². The map was originally drawn from vertical air photographs, taken in 1938, in the scale of 1:20 000. The information from this map has been transferred to newly available, official topographic maps (mainly 25 H Arjeplog) in the scale of 1:50 000. Several of the old names of mountains, lakes, streams and other localities have been changed on the new map, which is used as a basis for this text. Outcrops and drill-sites are indicated rather completely in the central parts of the area while in the northern and southern parts the recording is less complete. The region north of the E-W trending part of Lake Stor-Laisan almost entirely lacks outcrops. It should be noted that no distinction between greywackes and the underlying shales has been made in this area; the colour here represents the dominating rock-type.

The geology of the central parts of the area (around the Laisvall Mine) has been completely revised by the author. The earlier maps compiled by Ljungner and covering the areas east of Lake Stor-Laisan have been of great help. The fault and the thrust at Kramaviken are drawn from maps produced by Barkey (1964, unpubl. rep.), and the imbricate structure on the eastern slope of the mountain Niepsurt, west of Lake Stor-Laisan, was interpreted by Marklund (1954, unpubl. rep.). The geology of the area south-west of Stuor-Jutas is copied from maps by Zweifel (1958 b, unpubl. rep.) and the region further north-east is based on Marklund's map (Marklund 1948, unpubl. rep.).

I have had no opportunity to visit the area Gautojaure-Björnide; the geology presented is mainly drawn from works by Zweifel (1958 a and 1959, unpubl. rep.). The geological interpretation of the areas around Sounger, around Vuolle-Bieljaure and to the north of Vejejaure (areas north of Gautojaure-Björnide) are based on vertical air photographs.

The geology south of Stainak–Gardevare–Korsträsk has been compiled by Carlson based on earlier maps by Kautsky and Marklund and revised with the assistance of flight electro-magnetic anomaly maps.

ACKNOWLEDGEMENTS

The present investigation was suggested by Dr. Erland Grip of the Boliden Company and was carried out as a post-graduate thesis at the University of Lund under the supervision of Professor Sven Hjelmqvist. The geologists of the Prospecting Department of the Boliden Company have all been most helpful. In particular, I would like to acknowledge Dr. Hans Zweifel and Dr. Hans Helfrich for their interest and constructive critisism and Dr. Leif Carlson for our close co-operation. Mr. Martin Burvall assisted me in the mine and came with many useful suggestions. Dr. Ove Stephansson offered his time critically reading the paper and discussing it fruitfully. Many improvements to the paper are also due to Dr. Sven Laufeld. The English language has been corrected by Dr. David Gee who also suggested valuable improvements. The drawings and diagrams have been produced by the drawing section of the Prospecting Department of Boliden and I am much appreciative of Barbro Lindström's skilled work. Finally, I wish to express my gratitude to the management of the Boliden Company for permission to publish this paper.

II. OUTLINE OF LAISVALL GEOLOGY

The broad outline of the geology of the Laisvall area is fairly simple. On a Pre-Cambrian basement a succession of sedimentary rocks was deposited. In the western parts of the area these autochthonous sediments are covered by nappes which were thrust from the west over the sediments. All the rock units generally dip at a low angle to the west.

The Pre-Cambrian basement is composed of so called "Sorsele Granite", a well-differentiated intrusive suite with both acid and basic members, the former dominant. On this basement lies a sedimentary breccia passing transitionally into an overlying arkose which in turn is followed by an arenaceous shale or siltstone. The autochthonous sequence continues with a 40 m thick formation of quartzitic sandstone divided into a lower, a middle, and an upper member. The upper sandstone member passes upwards into a shale conglomerate, about half a meter thick, which has been taken as the boundary between the late Pre-Cambrian (Eocambrian) and the Cambrian. This sedimentary succession is referred to as the Laisvall Formation (Fig. 2). It is overlain by shale and siltstone of the Siltstone Formation and by dark graphitic shale of the Alum Shale Formation which passes upwards into the Greywacke Formation.

The autochthonous sediments are overthrust by parautochthonous and allochthonous units. The more locally derived nappes (referred to as the Kaskajaure Nappe Complex) are chiefly composed of rocks derived from the Pre-Cambrian basement and from the late Pre-Cambrian sparagmites and quartzites. A metamorphic allochthonous complex (the Yraf Nappe Complex) forms the uppermost tectonic unit within the area, and is mainly built up of quartzites and mica-schists which, towards the underlying thrust-plane, are strongly sheared and mylonitized.

III. STRATIGRAPHY AND LITHOLOGY

1. AUTOCHTHON

1.1 THE PRE-CAMBRIAN BASEMENT

The Pre-Cambrian basement, the "Sorsele Granite", in the Laisvall area has been treated as a late Karelian intrusive suite (Ödman 1957). Isotope age determinations have yielded an age of 1625 ± 45 m.y. (Welin 1970). The differentiated rock-suite includes hornblenditic granites, granite porphyries, gabbros, syenites and monzonites together with associated dikes. No detailed investigation of the Pre-Cambrian rocks in the area has been made.

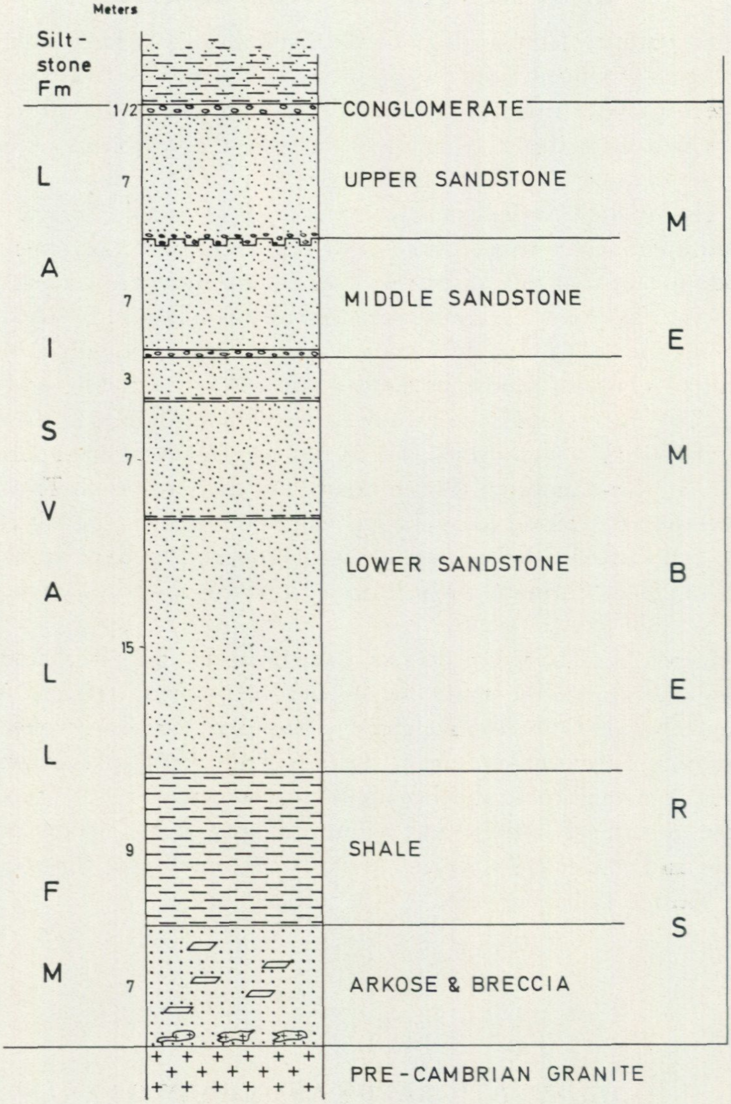


Fig. 2. Stratigraphical scheme for the Laisvall Formation.

The surface of the Pre-Cambrian basement is fairly flat but presedimentary hillocks have been discovered under the autochthonous sediments. The topography of the basement has been thoroughly discussed by Ljungner (1943, 1950) and by Carlson (1970, unpubl. rep.).

1.2 THE LAISVALL FORMATION

1.2.1 Introduction

The Laisvall Formation is to be seen partly in the lower part of Kautsky-malmen (including the Kautsky ramp) and partly in the entrance ramp of the Laisvall Mine. The autochthonous sedimentary succession overlying the granite basement has been previously referred to as the Laisberg Series (Kulling 1955).

1.2.2 The basal arkose member

The "Sorsele Granite" is overlain by an erosion breccia which is followed by an arkose. Inclusions of granite are common in the arkose and, locally, in the upper part, a conglomerate resembling a tillite has been found (Grip 1950). In its upper parts the arkose often is intercalated with shaly horizons and can pass upwards into an arkose-banded shale. The arkose and the sedimentary breccia vary very much in thickness in different parts of the area mapped. In the central parts they can reach a total thickness of 14 m but may also be lacking. In the Lulle-Naddok area the basement is covered by about 10 m of erosion breccia, conglomerate and an arkosic sandstone and at Valvo, east of the narrow lake system Maiva-Jutis, 8 m of arkose rest upon the Pre-Cambrian rocks. At the southern end of Lake Maiva the arkose is followed by 3 m of arkosic sandstones (Zweifel 1958 b, unpubl. rep.) which, like all the arkosic sandstones east of the Laisvall Mine, are younger than the arkoses to the west of Lake Stor-Laisan, being probably deposited simultaneously with the so-called "lower shales" or maybe even with the lower sandstone member, thus reflecting the edge of an advancing sea during late Pre-Cambrian times (Barkey 1964, unpubl. rep.). Within the area around Björnide, the arkose has not been found in outcrop but has been penetrated in drillholes and seen in local erratics.

The arkose in Ackerselet (in the south) is generally c. 10 m thick but can occasionally reach 17 m. South of Dellikälven the arkose thins considerably. The basal sediments in the Björnliden area (south-east of Ackerselet) are petrographically unlike the arkose in the central Laisvall area as they contain beds of polymict conglomerate.

1.2.3 The shale member

The arkose is generally followed by green and red shales and siltstones, up to 17 m thick (called "the lower shales"). This stratigraphical unit has not been described from the northern regions (around Björnide). In the southern regions (Luspevare-Björnliden) the arkose is followed by c. 10 m of shales and siltstones overlain by 25 m of siltstones with shaly fragments and shales corresponding to the lower sandstone member in the Laisvall Mine area.

1.2.4 The sandstone members

In the central parts of the Laisvall area sandstones were deposited above the "lower shales". Three members are distinguished.

1.2.5 The lower sandstone member

The lower sandstone member is a white, well-sorted sandstone with a thickness of 15–30 m. It is partly recrystallized. The more pure sandstone sequences are generally more quartzitic compared with sections with shaly sandstones where the primary structures are better preserved. The grain-size is usually about 1,3 mm and the quartz grains are well sorted with subordinate microcline, sericite and kaolinite. The feldspar is often somewhat weathered.

The sandstone layers are interbedded with thin horizons of green shales, especially in the lower part of the sequence. In the mining area there occur two particularly persistent shaly beds at c. 15 m and 22 m above the base of this sandstone member. Both are used as natural roofs in the rooms between the pillars in the mine. Primary structures such as load casts, slump and ripple marks are often well preserved in the shaly horizons.

East and south of the village of Laisvall ("Laisvalls by" on the map) the lower sandstone member is partly or completely replaced by siltstones and shales. In the Björnide area, in the north, the white lower sandstone is c. 25 m thick and, as is the case in the area around the mine, layers of green shales appear. Up to several meters of grey shale are here also found within the sandstone. In the imbricated western parts of the Gautojaure-Björnide area the sandstones are completely converted to quartzites.

1.2.6 The middle sandstone member

The middle sandstone member is easily distinguishable from the lower sandstone member by its darker colour and lack of feldspar. The darker colour is due to the presence of graphite in the matrix. The thickness of the middle sandstone member varies between 2 and 12 m within the central parts of the area; most commonly it is 8 m. The average grain size is c. 0.1–0.5 mm. The basal 1–5 dm of the middle sandstone member is conglomeratic with pebbles (c. 5 mm in diameter) of quartz and quartzite.

The same pebble conglomerate horizon can be followed southwards down to Dellikälven and further south and can be used as a marker horizon. The middle sandstone member thins out rapidly towards the south and the conglomerate is underlain by vividly coloured shales. No lower sandstone member can be distinguished. Sandstones of the same lithology as the middle dark sandstone member in the central parts of the Laisvall area are lacking in the Gautojaure-Björnide area, where a grey, rather coarse quartzite follows above the white, lower sandstone.

1.2.7 The upper sandstone member

The upper sandstone member, in the area around the mine, is also initiated by a conglomerate of about the same character as the conglomerate in the base of the middle sandstone member, though somewhat coarser. This upper member of the sandstone sequence is more coarse-grained than the underlying sandstones (0.1–3 mm) and is characterized by a rapid lateral change in grain-size. The rock is almost entirely made up of quartz. Cross-bedding, indicating transport from the west and south-west is very common along with other sedimentary structures usually occurring in shallow-water environments. The colour of the sandstone is greyish to white while subordinate interbedded shales are greenish grey. In the central parts of the Laisvall area the upper sandstone member is very persistent, varying between 4 and 11 m in thickness. A profile along the south-western shore of Lake Stor-Laisan reveals that the upper sandstone increases in thickness southwards, but the conglomerate found between the two upper members of the sandstone sequence disappears and passes laterally into sandstones and locally even further into more shaly horizons. According to Kautsky (1940) a light grey, coarse sandstone with quartz grains of varying size follows above a white sandstone in the Gauto-jaure-Björnide area in the north. This coarse sandstone unit is often conglo-meratic with pebbles of dark grey fine-grained quartzite. Upwards, there follows a similar grey, but fine-grained, sandstone with translucent grains of quartz, mostly appearing as brilliant black dots in the rock. Still higher up in the sequence a conglomerate occurs which is stratigraphically corresponding to the "shale conglomerate" of the central Laisvall area.

1.2.8 The conglomerate member

The upper sandstone member grades upwards into a conglomerate member, 0.3–2 m thick, with elongated pebbles of dark shale. This conglomerate, generally referred to as the "shale conglomerate" is supposed to initiate the Cambrian succession according to Kautsky (1945). In a comment to a lecture in the Geological Society of Sweden by Føyn, Kulling (1967) mentioned some fragmentary fossils encountered at the top of the conglomerate reminiscent of a trace fossil found in the late Pre-Cambrian Australian Ediacara Fauna, viz. *Spriggia annulata*.

The conglomerate with shale pebbles can be found both in the northern and southern parts of the area, and serves as an excellent marker horizon.

1.3 THE SILTSTONE FORMATION

The Laisvall Formation is followed by a sequence of siltstones, shales and marls, c. 40 m thick in the central parts of the Laisvall area. The Siltstone Formation is exposed in the entrance ramp of the mine. In the upper part of

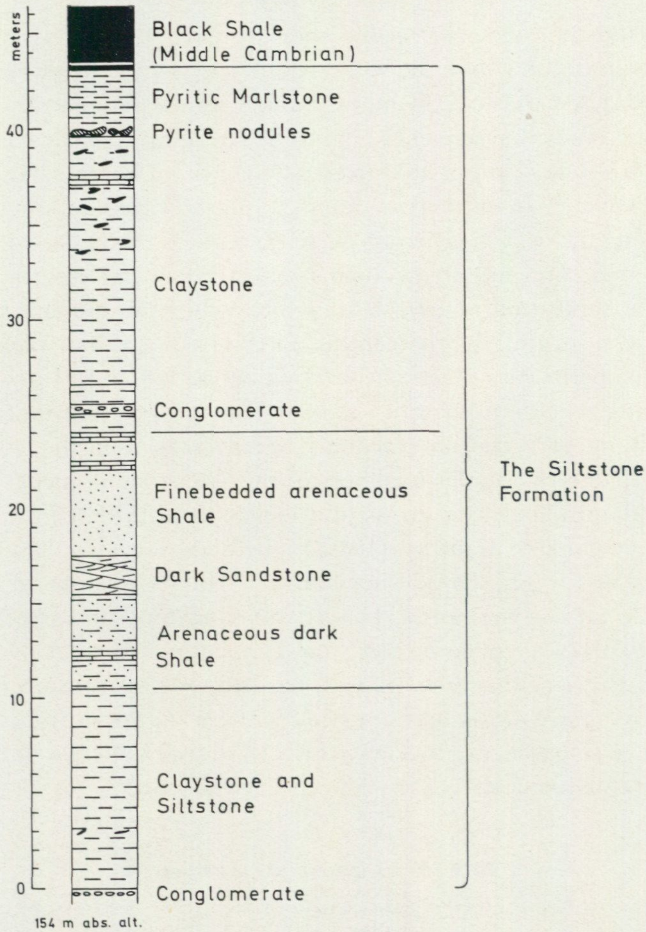


Fig. 3. The Siltstone Formation. Based on borehole No. 279. From Marklund (1948).

these argillaceous sediments lenses of limestone occur, which yield Lower Cambrian fossils. These strata are overlain by Middle Cambrian alum shales (Kautsky 1945).

A section through the Siltstone Formation (as seen in dh No. 279) was described by Marklund (1952) and is illustrated here in Fig. 3. No details of the argillaceous sediments above the shale conglomerate are given from areas outside the central parts of the study area.

No fossils have been found in the sediments below the Siltstone Formation, except the doubtful fragmentary fossil mentioned above, so the precise age of the sandstone members of the Laisvall Formation cannot be established.

In the Vassbo area (in the southern part of the Swedish Caledonides) corresponding shales and mineralized sandstones are Early Cambrian in age (Tegengren 1962).

1.4 THE ALUM SHALE FORMATION

Black bituminous shales (alum shales) c. 50 m thick overlie the uppermost member of the Laisvall Formation. The lower contact to the siltstone member is sharp, whilst the upper parts are invariably disturbed by the overriding nappes. Within the area around the mine the thickness reaches 50 m and, south of the mountain Pieljekaise in the north, 54 m (Ljungner 1950). Southwards, towards Dellikälven, the black shales are more arenaceous and often intercalated with sandy shales and light quartzites. South of Dellikälven it appears that the Alum Shale Formation is lacking. Here dark sandy shales and greywackes occur in a monotonous sequence measuring more than 300 m, and with thin calcareous horizons in the higher parts of the succession.

The black shales are at least in part Middle Cambrian in age (Kautsky 1945).

1.5 THE GREYWACKE FORMATION

In the northern parts of the map-area, much of the terrain is covered by sandy shales and greywackes, called by Kautsky "the grey, ugly sandstone" and by Marklund "the Greywacke or the Ringsele Series". Kautsky assumed a Middle Cambrian age while Marklund placed the Ringsele Series in the Eocambrian. Zweifel (1959, unpubl. rep.) observed that the greywackes are stratigraphically younger than the black shales and that the latter successively pass into greywackes.

Sediments of very similar character occur in the County of Jämtland where they are called "greywackes of Föllinge-Holmsjö facies". These are of Ordovician age and it is likely that the greywackes of the Laisvall area are of approximately the same age. However, until determinable fossils are found this problem cannot be finally resolved.

In the northern parts of the map (Pl. 1) the Greywacke Formation is seen to occupy extensive areas. It has not been possible to differentiate the sediments belonging to the Greywacke Formation from the underlying shales in this badly exposed area of extreme tectonic disturbance. Greywackes of similar type are also encountered in the lower part of the parautochthon.

2. PARAUTOCHTHON AND ALLOCHTHON

2.1 INTRODUCTION

The autochthonous sediments in the Laisvall area are covered by overthrust rock units. Previous nomenclature of these tectonic units is given in Table 1.

TABLE 1

THE SUBDIVISION OF THE NAPPE UNITS OF THE LAISVALL AREA ACCORDING TO KAUTSKY, MARKLUND, AND LILLJEQUIST

Kautsky 1940	Marklund 1959	Lilljequist (this paper)
Yraf Complex Metamorphic quartzites, sparagmites and mica schists.	*Yraf Complex* Diaphthoritic schists *Chlorite-sericite-schist Complex* Blastophyllonites	*Yraf Nappe Complex* Metamorphic rocks, mainly mica-quartzites, mica schists, and gneisses. In the lower parts of the nappe complex, strongly sheared chlorite-sericite schists or phyllonites.
Kaskajaure Complex A northerly quartzitic facies and a southerly sparagmitic facies.	*Kaskajaure Complex* Cataclastic Crystalline Rocks	*The Kaskajaure Nappe Complex* Cataclastic to mylonitized rocks derived from the Pre-Cambrian basement, arkoses, sparagmites, conglomerates, and banded quartzites.
Gautojaure Complex Tectonically disturbed series of quartzites-schists.	*Parautochthonous Nappe* Sheared slates	*The Parautochthonous Complex* Brecciated quartzites and sheared slates and greywackes. Slices of short-transported sedimentary rocks corresponding to the autochthonous sediments.
Flat-lying autochthonous sediments Pre-Cambrian	Lais-series Crystalline basement	Autochthonous sediments Pre-Cambrian basement

In this paper the schemes of Kautsky and Marklund are slightly modified to include the following tectonic units:

a) The Yraf Nappe Complex.

Meta-sediments, chiefly mica-schists, mica-quartzites, gneisses, and subordinate amphibolites form the Yraf Nappe Complex. Its lower part has been strongly sheared and retrogressed, being converted to phyllonites during thrusting. The Yraf Nappe Complex presumably has been transported from the central parts of the Caledonides.

b) The Kaskajaure Nappe Complex.

The main part of the Kaskajaure Nappe Complex is composed of cataclastic or mylonitized rocks composed of crystalline basement and late Pre-Cambrian (?) sediments including arkose, sparagmite, conglomerate, and shaly quartzite. Similarity of these lithologies with those in the autochthon and parautochthon suggests a shorter transport distance than that required for the Yraf Nappe Complex.

c) The Parautochthonous Complex.

Included in the Parautochthonous Complex are those minor units of highly brecciated quartzites, greywackes, and wedges of sedimentary rocks derived tectonically from the autochthonous formations. It is not always possible to make a sharp distinction between the parautochthonous thrust-sheets and the Kaskajaure Nappe Complex. The rock-masses in the latter have been transported further from the west.

The Gautojaure Complex, as described by Kautsky, is not treated here as a separate unit. Within the Gautojaure-Björnide area there exists a different tectonic style in that the sediments, dominated by shales and greywackes, are strongly folded in association with basement imbrication. Wedges of quartzites, granites and sparagmites compose ridges surrounded by strongly sheared and attenuated black shales and greywackes.

2.2 THE PARAUTOCHTHONOUS COMPLEX

The Parautochthonous Complex includes short-transported nappes or slices of rocks from the sedimentary formations above the Pre-Cambrian basement. The Parautochthonous Complex is best exemplified by the nappe sheets at Luspevare. The stratigraphy and the imbricate structure of this quartzite-shale nappe was studied by Marklund (1956, unpubl. rep.). From two drill-holes (Nos. 49 and 55) through the nappe in Luspevare the following stratigraphic scheme has been constructed. (See p. 16.)

Upper blue-grey quartzite sequence	0.6 m	Quartzite, coarse-grained and blue-grey with shale pebbles.
	2.9 m	Quartzite, fine- to coarse-grained.
	0.7 m	Quartz-pebble conglomerate.
Upper light quartzite sequence	2.5 m	Quartzite with thin horizons of green shales.
	3.5 m	Quartzite, white and massive.
Middle quartzite sequence	2.0 m	Quartzite, medium-grained and micaceous. Greenish grey colour.
	0.2 m	Quartz conglomerate.
Lower quartzite sequence	2.3 m	Shaly siltstone with layers of quartzite. Greenish yellow.
	0.5 m	Quartzite, green with fragments.
	7.4 m	Quartzite, medium-grained. Layers of green siltstone, max. 40 cm thick.
Lower shale and arkose sequence	2.0 m	Quartzite, dark and micaceous.
	2.8 m	Siltstone, dark and fine-bedded.
	3.6 m	Quartzite, dark and with coarse fragments.
	0.8 m	Siltstone, dark and fine-bedded.
	2.4 m	Quartzite, dark and micaceous.
	3.2 m	Sedimentary breccia with boulders of granite.
	9.6 m	Siltstone.
	1.4 m	Arkose with thin layers of dark micaceous siltstone.

The upper quartzite sequences correspond to the upper and middle sandstone members of the central Laisvall area. The sediments under the quartz conglomerate can be correlated with the lower part of the Laisvall Formation up to and including the lower sandstone member. It is thought possible that the sediments which form the Luspevare nappe have been derived from the Niepsurt area on the west side of Lake Stor-Laisan. Two sections through the nappe are given in Fig. 4.

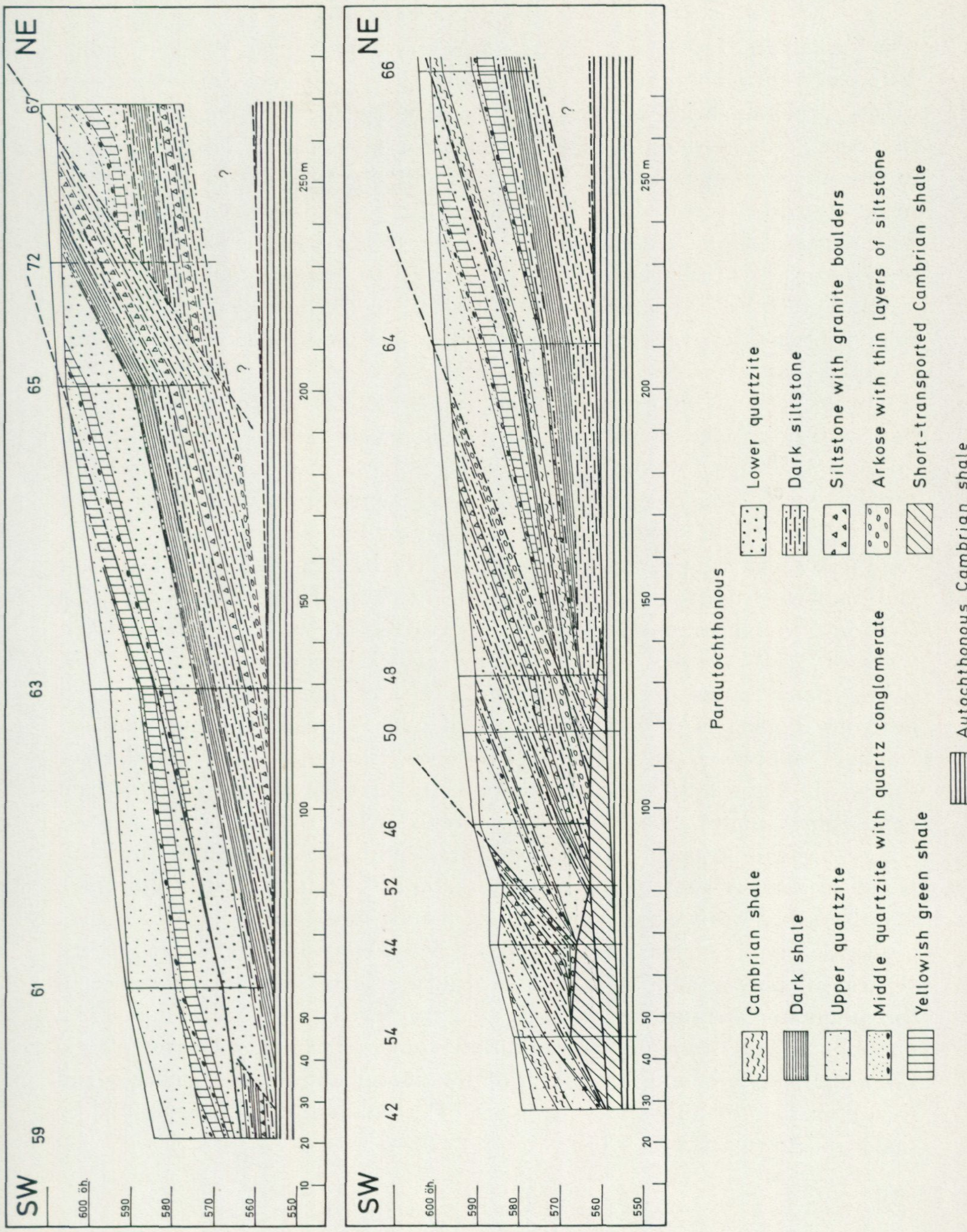


Fig. 4. Profiles through the parautochthon at Luspevare. From Marklund 1956 (unpublished report).

2.3 THE KASKAJAURE NAPPE COMPLEX

The Kaskajaure Nappe Complex embraces very different rock types, including both basement (gabbro, syenite, granite, porphyry) and rocks of sedimentary origin, probably being of late Pre-Cambrian age (sparagmite, arkose and quartzite). All are more or less brecciated or mylonitized. Two main rock groups were distinguished by Kautsky (1940), the boundary between them being placed between the eastern border of Lake Gautojaure via Långsjön to Saivatj, east of the mine. South-west of this line the Kaskajaure Nappe Complex mainly consists of cataclastic Pre-Cambrian rocks, coarse conglomerates and red and green banded sparagmites. North-east of the line, well-bedded green or grey (often calcareous) quartzites dominate. The inhomogeneous Kaskajaure Complex has a variable thickness. To the west of Lake Stor-Laisan, Pre-Cambrian syenites and granites occur at the bottom of the complex, followed by a sparagmite sedimentary unit. The mountain Garbmadak (north of Kramaviken) is built up of 60 m of a very coarse polymict conglomerate (probably formed under glacial conditions) within which a sandy primary horizon occurs dipping c. 50°NE. It is underlain by c. 150 m of gabbro. To the north, approaching the Naddok Mountains, the Kaskajaure rocks thin out (see Pl. 1 profile GH), and in some areas they are completely lacking (Pl. 1 profile AB), a thin horizon of parautochthonous and locally derived greywackes remaining between the Yraf Nappe Complex and the autochthonous sediments. To the west of Bajeb Rabna and Vuoleb Rabna, a sheet of cataclastic basement rocks outcrops dipping N70°W/15°SW. East of Lake Stor-Laisan the Kaskajaure Complex appears as N40°W elongated slabs, surrounded by sheared black shales (Marklund 1952). The rocks in these slabs consist of red syenite, or light red porphyry almost always overlain by greenish arkose.

The protruding heights of Krappesvare (south of Gautojaure), Niepsurt (south of Kramaviken), Sounger (up in the north), Didnok (east of Björnide), and the area north-west of Vejejaure are mainly made up of rocks belonging to the Kaskajaure Nappe Complex, which is rather easily distinguished on the vertical air photographs by a lack of regular structures. In the precipice of the mountain Niepsurt, to the west of Lake Stor-Laisan, Marklund (1953, unpubl. rep.) has distinguished four different units, separated by thrust-planes. Upon the autochthonous sediments follow parautochthonous quartzites and shales, overlain by a threefold repetition of Pre-Cambrian rocks separated by shales and greywackes.

2.4 THE YRAF NAPPE COMPLEX

Above the Kaskajaure Nappe Complex lie allochthonous rocks of a completely different appearance, constituting the Yraf Nappe Complex and corresponding to what is elsewhere called "the Seve-Köli Nappe Complex". Within the Yraf Nappe Complex micaceous quartzites and garnet mica-schists dominate. The name of the metamorphic nappe derives from Lake Yraf, north-west of Lake Gautojaure, and was introduced by Kautsky. Parts of the Yraf Nappe Complex have reached a high metamorphic grade; gneisses and amphibolites are found in the higher levels and in the western parts of the area microcline porphyroblasts appear.

The rocks of the Yraf Nappe Complex cover extensive areas west of Lake Stor-Laisan in addition to a belt stretching from Laisvall Village northwards towards Hällbacken-Gruttor (east of Lake Stor-Laisan) and the north-eastern parts of the map-sheet, around Lake Issmejaure.

The lowermost part of the nappe complex (generally between 20 and 60 m) consists of highly sheared chlorite- sericite-schists with thin, folded veins of quartz. Pseudomorphs after garnet and relict biotite flakes indicate that the rocks have been extensively retrogressed. The competent quartzitic horizons have been mylonitized while the less competent shales have been contorted, giving the rocks a gnarled appearance. This intensively tectonized lower part of the Yraf Nappe Complex has suffered most from the thrust movements.

The contact of the Yraf Nappe Complex with the underlying rock units is relatively flat and dips gently westwards.

Marklund (1950) divided the Yraf Nappe Complex to the west of Lake Stor-Laisan into three sub-units, in descending order:

a) 50 m of feldspar-porphyroblastic schists and gneisses, including Caledonian granites
b) 25 m metamorphic quartzites
c) 100–150 m of diaphthoretic mica-schists, passing upwards into veined gneisses with microcline porphyroblasts.

Drill-hole No. 480 (west of the Naddok Mountains, Pl. 1), represents a typical section through the Yraf Nappe Complex within the Laisvall area. 10 m of intensely mylonitized chlorite phyllonites are overlain by more than 117 m of mica-laminated, feldspar-rich quartzites alternating with mica-schists.

It is generally impossible to distinguish between what is primary sedimentary layering and secondary foliation in the schists and gneisses. Rarely, early isoclinal folds with axial plane schistosity have been observed. It is, however, outside the scope of this paper to describe the intricate petrographic, stratigraphic, and tectonic history of the metamorphic nappe.

3. THE ORE BODIES

The Laisvall ore bodies are chiefly situated in the lower and upper sandstone members of the Laisvall Formation. Mining operations have followed the ore from the eastern side of Lake Stor-Laisan, south-westwards under the lake, to Kramaviken on the western side. The mine extends 6500 m underground at a depth of 80 to 170 m (Fig. 5). The mineral association is galena, sphalerite, fluorite, barite, calcite, and pyrite. The total quantity of ore at Laisvall today is 53 million tons of 4.1 % Pb at a cut-off grade of 2 % Pb and a recovery of 100 % (mined ore and present ore reserves). Hitherto the ore has been mined

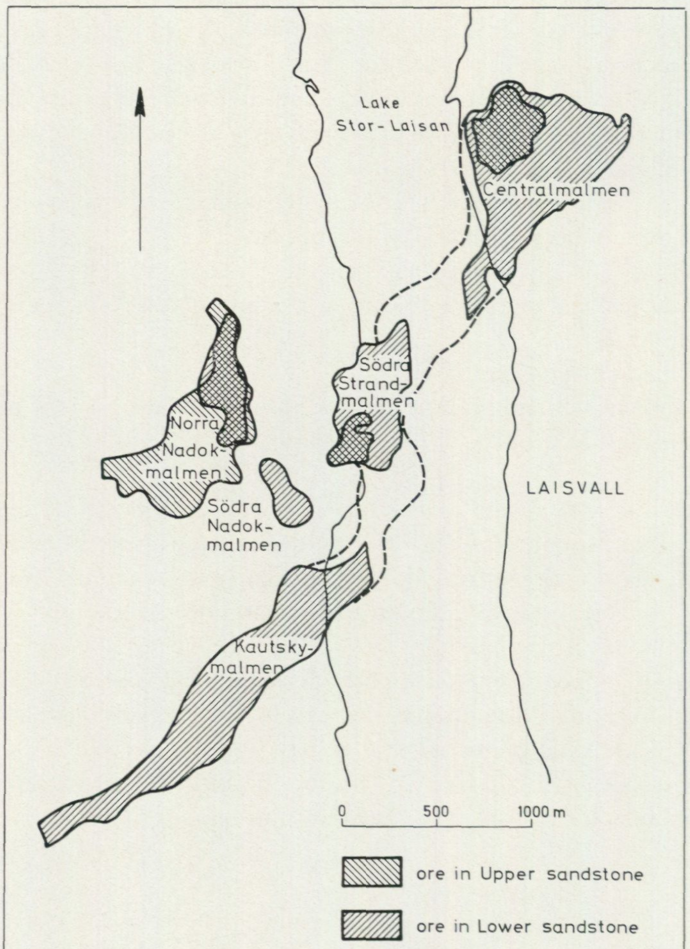


Fig. 5. Location of ore bodies at Laisvall.

mainly from the lower sandstone member, but large quantities of galena and sphalerite of economic importance occur also in the upper sandstone member, e.g. in the Nadok ore body. Subordinate mineralizations occur in the middle sandstone member and in the basal arkose. At Lake Maiva (east of the Laisvall Mine) a minor deposit of galena occurs in the basal arkosic sandstone.

IV. TECTONICS

1. INTRODUCTION

When this investigation started, in the spring of 1964, the intention was to map and analyse joints, faults and other observable planar structures within the Laisvall Mine, in connection with an investigation of the rock mechanics. Thus a complete inventory was made of all the joints and faults in the mine as it existed then. In order to find out whether the joint system was constant on a local or regional scale, a larger area around the mine was also investigated. Finally, it was found necessary to map and re-map a more extensive area, and to collect measurements of the orientation of s-planes, fold axes and lineations to be able to interpret the relationship of the joint system to the phases of deformation that have influenced the rocks.

Below follows an account of earlier hypotheses of the tectonics of the Laisvall area and then a description of the regional and morphologically conspicuous structural trends. In a later section the tectonic character of each of the major rock units is presented.

2. EARLIER INVESTIGATIONS OF THE STRUCTURE

The Laisvall area has been affected by both thrusting and folding. Ljungner (1940) suggested that the lower nappe complex (Kaskajaure) had been upthrusted from the SW, while the overlying Yraf Nappe Complex had its roots to the NW. This conclusion he based on the orientation of small-scale folds and glide planes underneath the thrust-sheets. Marklund (1954, unpubl. rep.) supported the idea that the Kaskajaure Nappe Complex had come to rest before the Yraf Nappe moved from the west. Around Gavasjaure (further westwards, outside the Laisvall area) and in the gorge of Grama Jukku he noted that the Yraf rocks rest discordantly on top of steeply dipping sheets of syenite, belonging to the Kaskajaure Nappe Complex, and stated that the boundary between the two nappe units was not planar. Ljungner (1950) suggested that a flexure caused by the load pressure of the nappes on the basement moved like a wave in front of the advancing nappes.

Two different fold systems have been recognized in the Laisvall area by earlier investigators. Thus Kautsky (1940) reported NNE-trending open folds in the autochthonous rocks from the area to the east of Lake Stor-Laisan. Folds of the same orientation have been described from the hillock Valvo (Marklund 1948, unpubl. rep.) and from the area between Laisvall Mine and Storbergsudden (Kautsky 1939, unpubl. rep.).

No folds have been reported from the Kaskajaure Nappe Complex, but Marklund (1947, unpubl. rep.) suggested that the sparagmitic rocks in the Garbmadak Mountain have been compressed perpendicular to their strike in N40°E. He also showed that two fold systems are developed in the Yraf Nappe Complex, one trending N55°W and the other in a direction perpendicular to this. The NW-trending folds are especially well developed northwestwards from the mine, where, according to Marklund, the thrust planes also have been folded.

In the Gautojaure-Björnide area in the north, hills of quartzites, sparagmites, and Pre-Cambrian granites rise from a lower terrain of mainly shales and greywackes. Two structural directions are easily visible from the map, one trending about N-S (Björnide, Bieljaure) and the other NE to E-W (Gautojaure, Vejejaure and Långsjön).

Kautsky (1940) interpreted the tectonics of the Gautojaure-Björnide area as resulting from culmination of two interfering anticlines, trending NNE and E-W. He supposed that the anticlines were formed at about the same time. One of the E-W striking anticlines occurs in the Krappesvare ridge, the other in the Buodak-Korpberget ridge (northwest of V. Sveggejaure). Between Krappesvare and the Buodak-Korpberget ridge is a syncline. The E-W trending structure of Krappesvare can be followed eastwards to Gardjaure-Rabnajaure and further towards Långudden. The southern limbs of the anticlines dip somewhat steeper than their northern limbs. Kautsky was of the opinion that the Gautojaure-Björnide area can be regarded as an area of intensively folded autochthonous rocks. In many places, extremely brecciated Pre-Cambrian basement appears, generally as westerly dipping plates, which have been thrust up into the contorted shales.

The present geological picture of the northern Gautojaure-Björnide area is mainly based on the work of Zweifel (1958 a, unpubl. rep.). According to him, shales and greywackes dominate, while quartzites only occur in some zones. The area is strongly imbricated with upthrusted slabs of quartzites and cataclastic rocks belonging to the Kaskajaure Nappe Complex (probably rooted here) and the basement. The shales and greywackes, being more incompetent, have been folded during the deformation. In the northernmost part of the area the imbricate structure plays a subordinate role and plastic folding seems to dominate, even in the quartzites.

The fold axes have a varying orientation. Around Lake Gautojaure they trend N40°E to N80°E, plunging 15°SW at the western end of the lake and 50°SW at the eastern end.

Along the line Dammsjön-Långsjön, the fold axes plunge W and NW, and at Poudak, they plunge NE. The late Pre-Cambrian sediments and the rocks of the Kaskajaure Nappe Complex within the Gautojaure-Björnide area are not only the result of a culmination, the deformation also being the result of upthrusting of the more rigid rocks into the shales and greywackes. The quartzites and shales can be followed northwards up to the boundary of the Peljekajse National Park where they disappear under the Yraf Nappe Complex.

The Gautojaure-Björnide area has been affected by the following tectonic sequence, according to Zweifel (1958 a, unpubl. rep.):

a) Thrusting – forming the Kaskajaure Nappe Complex.
b) Thrusting – forming the Yraf Nappe Complex.
c) In connection with or shortly after these, thrust movements of smaller scale took place within the sandstones (quartzites) creating several repetitions within this formation.
d) Folding on E-W axes.
e) Folding on SW-NE axes.
f) The folding under e) is transformed into a phase of rupture in which an imbricate structure is formed. The sandstones become more tectonized and recrystallized and are thrust into the overlying shales and greywackes.

3. TECTONIC CHARACTER OF THE AUTOCHTHON

Except for joints and faults, the Pre-Cambrian basement has not been studied in detail. Its deformation has earlier been treated by Ljungner (1950). The topography of the basement surface has been studied in detail by Carlson (1970, unpubl. rep.).

The autochthonous sediments in the central parts of the Laisvall area are largely undisturbed, and in the vicinity of the mine the sediments are dipping 2–4°W (see profiles, Pl. 1). The mine itself offers the best opportunities for structural observations within the authochthonous sediments; in the field continuous outcrops are not very accessible.

Within the sandstone sequence in the mine, six minor thrusts have been encountered. In the southern part of Södra Strandmalmen (Fig. 5) a thrust-plane occurs striking N30°W with a westerly dip of 22°. The relative movement does not exceed 20 cm and is accompanied by minor brecciation. A similar thrust has been observed close by, orientated N60°E/21°SE. Still another thrust in the same area was inaccessible at the time of the present investigation but is reported to strike N14°W with a dip of 15°W.

Grip (1954) reported a more prominent thrust plane cutting the tunnel under Lake Stor-Laisan, striking N14°–20°W. The adit to Norra Nadokmalmen goes through a thrust plane dipping 10–15°W and striking N-S. The amount

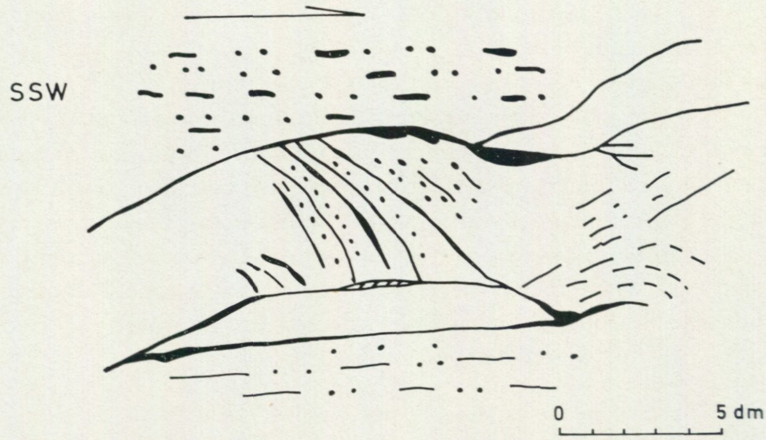


Fig. 6. Small thrust in Kautskymalmen. Black = galena mineralization. Above and beneath the thrust-zone the mineralization follows the sub-horizontal layering.

of movement is estimated at some few meters. In the north-eastern parts of Kautskymalmen, another minor thrust occurs in the sandstone sequence, striking N70°W and dipping 15°SW (Fig. 6).

Assymetrical drag-folds, caused by slipping or gliding in the more argillaceous bands, have been found in some sandstones within Kautskymalmen. The fold axes trend between N-S and N20°W with a gentle plunge towards the south (Fig. 7). Small tension joints appear in the closures, filled by secondary galena and calcite.

The arkose and the sandstone members in the central parts do not generally show any signs of deformation, but around the village of Jutis the bedding

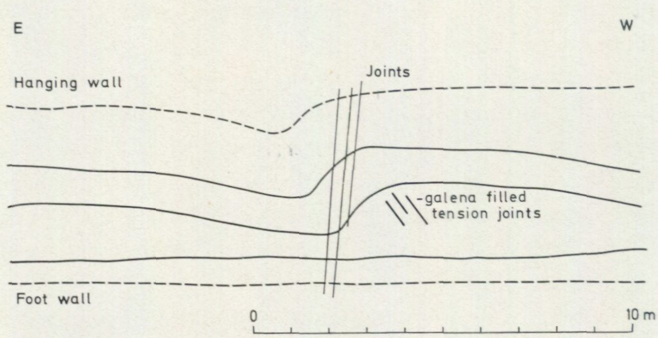


Fig. 7. Asymmetrical intrafolial fold (drag fold) in the lower sandstone member. From Kautskymalmen.

planes dip 20–50°NW or W, and are locally brecciated and strongly quartz veined. It is quite possible that the sandstones here are parautochthonous. A syncline trending N20°E has been reported from the same area by Marklund.

The Siltstone and Alum shale Formations are usually very badly exposed as their soft character has favoured rapid erosion and development of a vegetation cover. The Middle Cambrian alum shales on both sides of Kramaviken are strongly sheared and disturbed, showing small-scale folds trending N20°W. On the western slope of the mountain Assjatj (Aistjakk), from where Kautsky (1945) described an Early Cambrian fauna, the shales are highly contorted with small-scale folds mainly trending NE and WNW.

4. TECTONIC CHARACTER OF THE PARAUTOCHTHONOUS COMPLEX

In between the autochthonous sediments and the Kaskajaure Nappe Complex there often occur slabs of highly brecciated and contorted quartzites and greywackes. These rocks are here treated as parautochthonous and can be studied in the eastern slope of Delleknäs-Niepsurt-Geddak, on the east side of Garbmadak, north of Naddok-Buodatj, south-east and east of Såvvovare, east of Björnberget, and in the Gardevare-Luspevare-Björnliden area in the south-east. Where the underlying rocks are to be seen, these consist of strongly sheared shales, which also occur between the quartzite slabs. Most of the quartzites as well as the slip surfaces underneath the thrust-sheet dip SW, W and S (Fig. 8a).

From sections based on drill-holes at Luspevare (Marklund 1956, unpubl. rep.), it can be shown that the parautochthon here is made up of N-S striking thrust-sheets dipping westwards, forming a typical imbricate structure. From the sections (Fig. 4) it can be seen how the quartzites are "squeezed" out of the shales; they thin out towards the base of the nappe. Marklund suggested that this mechanism of separation ("squeezing") plays an important role in forming the more massive quartzitic nappes which occur further southwards along the eastern Caledonian border. At the base of the section the Cambrian shales are often repeated, very short-transported parautochthonous shale sequences overlying the autochthonous shales.

On the east side of Björnberget, steeply dipping parautochthonous sediments (quartzites and shales) are present underneath the cataclastic rocks of the Kaskajaure Nappe Complex. East of the Rabna lakes a S-dipping massive, cataclastic quartzite rests on highly contorted shales. At these localities, small folds in the quartzites are present which trend N60–70°W. The few bedding planes that have been possible to measure within the parautochthonous rocks tend to fall along a great circle indicating a WNW fold axis.

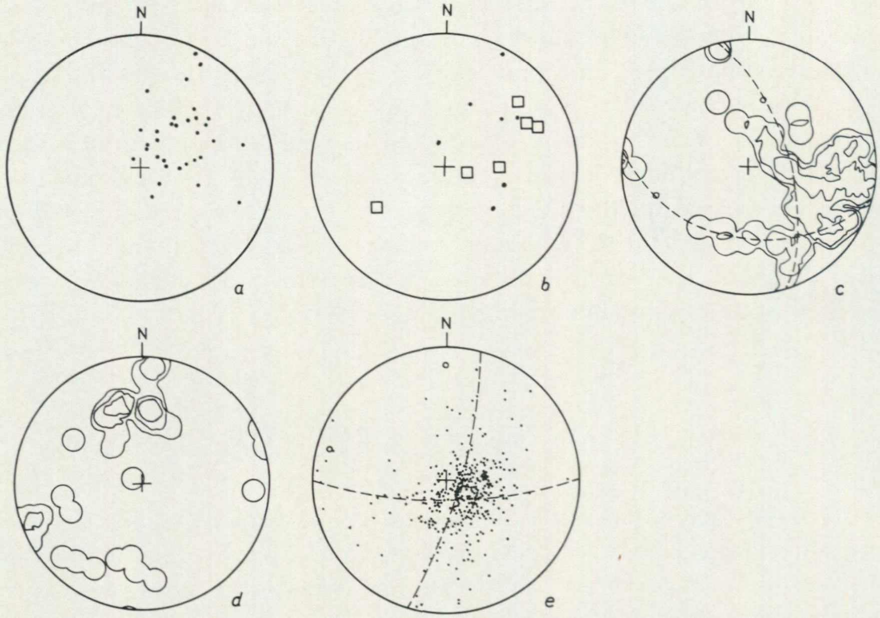


Fig. 8. Equal area, lower hemisphere projection. a) Poles to bedding planes from parautochthonous quartzites at Björnberget-Såvvovare. b) Secondary foliations associated with the Kaskajaure Nappe Complex at Niepsurt and Såvvovare. Dots = poles to rock contact surfaces; squares = poles to major glide planes. c) Poles to s-planes. 73 readings from Märkströmmen. Circles = deduced fold axes. Contours, 5, 3 and 1 %. d) 48 foliation intersections (β diagram) from Märkströmmen. Contours, 11, 5 and 1 %. e) Poles to s-planes from the whole of the Yraf Nappe Complex. 342 readings. The deduced fold axes (circles) dip 12° towards N and 10° towards N75°W.

5. TECTONIC CHARACTER OF THE KASKAJAURE NAPPE COMPLEX

As mentioned above, the Kaskajaure Nappe Complex is composed of cataclastic to mylonitic rocks derived from the Pre-Cambrian basement or late Pre-Cambrian sparagmites, conglomerates, and quartzites. Except for joints very few other measurable structures are present. A few measurements of the surfaces in contact with underlying rocks and some measurements of major slide planes are shown in Fig. 8b.

On the east side of Märkströmmen (a stream gorge where rocks are excellently exposed) at Gautojaure there is an alternating sequence of contorted black Cambrian shales and brecciated late Pre-Cambrian (?) sparagmites. The area was found suitable for registration of fold axes and s-planes. Altogether 73 s-planes have been measured and their poles are plotted on a π-diagram (Fig. 8c). Two great circles appear, whose normals are nearly at right angles to each other. They indicate two fold axes, one plunging N10°E/45°N, and the other S73°W/35°W. The majority of the s-planes dip moderately to steeply

W and NW. A nearly identical result can be observed on a β-diagram (Fig. 8d), where 48 intersections are plotted. The data from the structures at Märkströmmen agree well with the result of the investigations by Kautsky, Ljungner and Zweifel in the Gautojaure-Björnide area, where both the Kaskajaure Nappe Complex and the autochthonous sediments have been affected by later folding. As shown above, the two fold directions occur both on a regional and on a local scale.

6. TECTONIC CHARACTER OF THE YRAF NAPPE COMPLEX

The s-surfaces measured within the Yraf Nappe Complex include those probably caused by tectonic shearing and some also reflecting primary bedding. Along the foliation, segregations of newly formed microcline and bands of quartz often appear.

Mesoscopic folds and lineations have been observed and measured from the Yraf Nappe Complex. The net of observation points has been distributed as regularly as possible. Observations from each sub-area have been plotted separately and later the data from several small areas have been combined into larger homogeneous regions.

Altogether 342 s-surfaces have been measured from the Yraf Nappe Complex. Their orientation and the distribution of their poles are shown in Fig. 8e. From the diagram it is obvious that most of the s-poles are concentrated within the south-eastern quadrant of the circle, that is, they dip rather gently towards the NW, N and W. Moreover, there is a weak tendency of the s-poles to be gathered along two great circles, the poles of which indicate two fold axes. Steep-dipping s-surfaces are exceptional. The two prominent fold axes are approximately oriented at right angles to each other and plunge 12°N, and N75°W/10°W.

Mesoscopic folds are seldom met with in the field; altogether only 29 such folds have been observed. The directions of the fold axes have been plotted on a strike frequency diagram together with lineations (Fig. 9). Mainly two di-

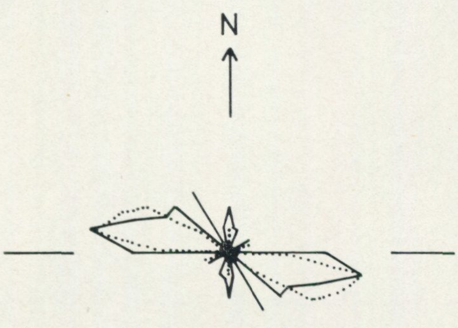


Fig. 9. Strike frequency diagram of 29 measured fold axes (continuous line) and 20 readings of lineations (dashes) within the Yraf Nappe Complex.

rections dominate, namely E-W and NNE-SSW. The lineations strike in the same directions as the fold axes.

At a few localities it has been possible to observe the existence of early formed isoclinal folds lying in between the foliation planes of the metamorphic rocks. Scarcity of observations does not permit a detailed description of these.

Summing up, we have demonstrated two directions of open folds within the Yraf Nappe Complex. E-W folding dominates in the north towards Nadok-Hällbacken. It also influences the Gautojaure-Björnide area. N-S folds dominate at Lulle-Naddok, at Luspevare, and at the eastern border of the Yraf Nappe Complex, to the west of the Jutis lakes. In general, these folds are asymmetrical and overturned towards the E. On the mountain Alle-Naddok, the eastern precipice reveals a major flexure which probably is responsible for the formation of the valley now occupied by Lake Stor-Laisan.

7. LINEAMENTS AND MAJOR FEATURES

Morphologically conspicuous lines or lineaments have been studied on vertical air photographs in the scale of 1:20 000. Above the timberline, joint patterns are distinguishable as fine, thin lines, while valleys, lakes, streams, and precipices are more difficult to interpret as to their origin. However, all lineaments have been marked with a pencil on the photographs and their directions have been measured and compiled in a strike frequency diagram (Fig. 10). As seen from the diagram, most of the lineaments strike between N30–50°W with a less pronounced group around N20°E. In addition, several weak

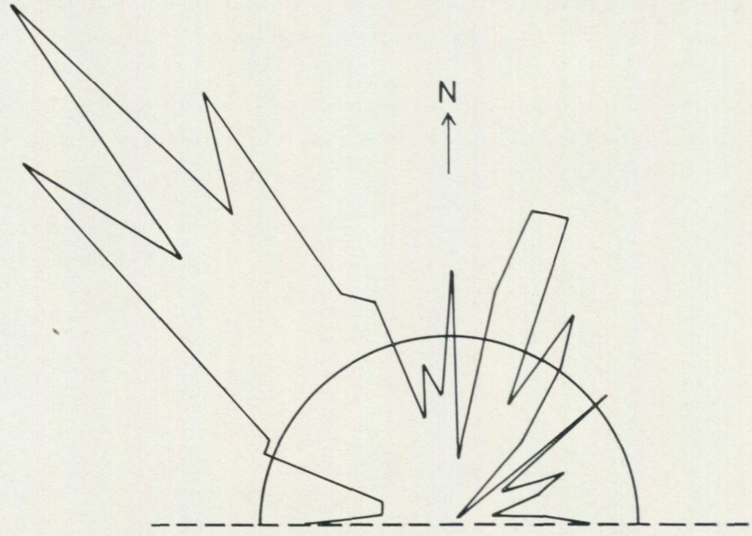


Fig. 10. Lineaments from the Laisvall area. 409 readings ± 5°, from vertical air photographs. The arc represents 10 observations.

maxima can be distinguished in the directions N-S, E-W, and ENE-WSW. Especially pronounced are the N-S trending directions of Lake Stor-Laisan, the lake system Maiva-Jutis, and the ridges between them. On a regional scale this direction diverges from the general pattern.

In the northern parts of the area, E-W trending features dominate.

Rudberg (1954) thoroughly studied the morphology of Västerbotten County, and explained the pronounced NW-trending features of the eastern parts of the mountain range and of the eastern border as a result of glacial erosion, little influenced by rock structure.

8. FAULTS

The fault tectonics of the Caledonian border were treated by Kautsky (1938, unpubl. rep.) who studied the area from Laisvall and northwards. In the area of Laisvall-Jutas there exist faults striking NNW, while the areas further north are dominated by faults striking NW and E-W. Kautsky presumed that the faults were connected in some way with the lead mineralizations and that they were post-Caledonian in age.

The only fault zone that has been available for studies during the present investigation, was that going through Centralmalmen in the mine, which strikes NNE and dips moderately SE. The fault planes have slickensides indicating reverse movement amounting to 20 cm. This fault zone is most probably the continuation of the fault running NNE from the south-eastern parts of Kramaviken.

Several of the faults striking N-S to NNE (generally revealed through drill-hole profiles) are listric reverse faults, the fracture surfaces being concave upwards. This has been shown both in the area to the west of Kautskymalmen (Barkey 1964, unpubl. rep.) and in the Gautosjö-Björnide area. The westernmost flanks are thrust towards the E.

Recently it has been shown that several of the normal faults in the sandstone members are older than the Middle Cambrian alum shales (Carlson 1970, unpubl. rep.). Within a graben at Lulle-Naddok the Lower Cambrian siltstones reach between 30 and 50 m while the siltstones outside only are between 10 and 30 m. This indicates that the graben was formed before the thrust movements occurred. The graben is striking NE, and the south-eastern fault zone is about 80 m wide with an amount of displacement of c. 10 m. Minor faults striking E-W and NW are also proven from the area around Lulle-Naddok.

In the Maiva area (east of the Laisvall Mine) a group of faults run in a N-NE direction, forming a graben in which the sandstone members of the Laisvall Formation are preserved. Faults striking NW also occur. Zweifel (1958, unpubl. rep.) assumed that the faults at Maiva were younger than the mineralization but probably initiated in Pre-Cambrian time.

A normal fault with displacement of 60 m is located north-east of Såvvovare and several other NW-trending faults have been constructed from vertical air photographs, in the area east of Lake Stor-Laisan.

9. JOINTS

9.1 THE PRE-CAMBRIAN BASEMENT

The autochthonous Pre-Cambrian basement within the Laisvall area is strongly fractured. The joint planes are often covered with epidote, chlorite, and iron oxides. Joints filled with fluorite, calcite, pyrite, and chalcopyrite have rarely been observed. The field observation localities are shown in Fig. 11. There appears to be a good agreement between the different localities and the following sets of joints have been discerned (Loc. 1–4 in Fig. 11; Loc. 1 is shown in Fig. 12a).

PC 1) N10–50°W, dipping moderately towards SW.

This set of joints shows slickensides indicating thrust movements from the SW. However, no signs of differential movement can be seen. Both calcite and fluorite have been observed coating the joint planes.

PC 2) N16–38°W, subvertical.

Predominantly joints dipping steeply towards the NE. A coating of calcite and fluorite has been noticed.

PC 3) N20–65°E, subvertical.

Horizontal slickensides and a thin coating of calcite are often seen on the joint surfaces.

PC 4) N-S, subvertical.

It is not certain whether or not these joints form a separate set.

PC 5) N76°W, vertical.

This fifth set can only be recognized in the Kautskymalmen adit.

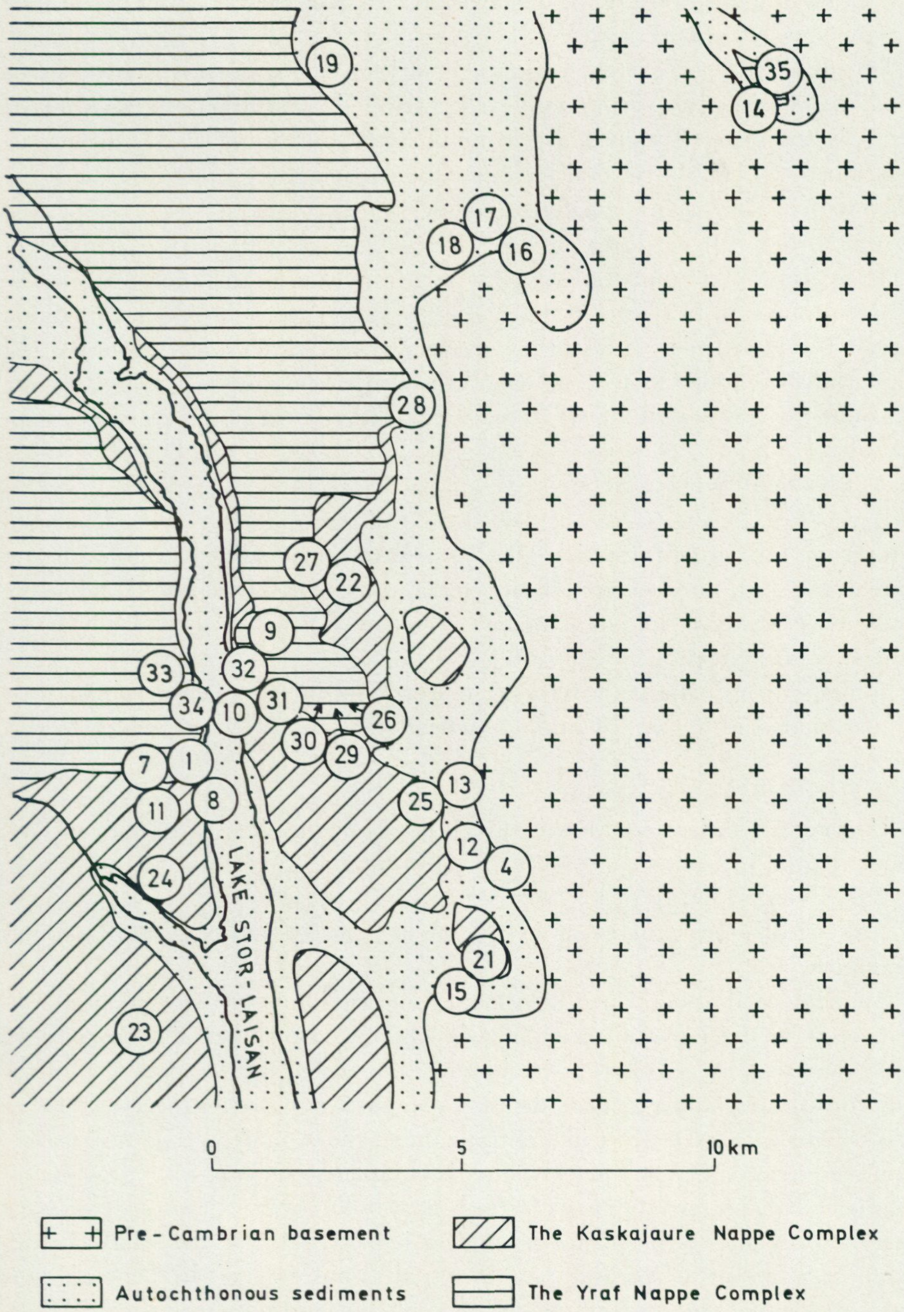
Fig. 11. Sketch-map showing the localities of the joint measurements. Localities No. 3 and 20 fall south of the map Fig. 11, No. 2 to the east. No. 14, 20 and 35 fall outside the map Plate 1.

Localities within the Pre-Cambrian granite: 1. Kautskymalmen drift (Fig. 12a), 2. Jutavare, 3. Dellekjokk-Ackerselet. 4. Såvvovare.

Localities within the autochthonous sediments: 7. The ramp to Kautskymalmen (arkose, Fig. 12b), 8. The Kautskymalmen shaft (the shale member, Fig. 12c), 9. Centralmalmen (Fig. 12d), 10. Södra Strandmalmen (Fig. 12e), 11. Kautskymalmen, 12. Såvvovare, 13. NW of Saivatj, 14. Laisovare, 15. Assjatj, 16. Valvo, 17. L. Jaulak, 18. SW of L. Jaulak, 19. Stor-Jutas, 20. Luspevare.

Localities within the Kaskajaure Nappe Complex: 21. Assjatj, 22. Björnberget, 23. Niepsurt, 24. Garbmadak, 25. Såvvovare.

Localities within the Yraf Nappe Complex: 26. N of Tjålmåk, 27. Björnberget, 28. W of Stour-Jutas, 29. Along the Loholm-Såvvovare road, 30. On the road Laisvall to Aisjaure, 31. Along the road between Laisvall Mine and Laisvall, 32. The entrance ramp to the mine, 33. Lulle-Naddok, 34. The ventilation shaft to Södra Strandmalmen, 35. Laisovare.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25
11
8
12
4
24
LAKE STOR-LAISAN
21
15
23
0
5
10km
Pre-Cambrian basement
Autochthonous sediments
The Kaskajaure Nappe Complex
The Yraf Nappe Complex

Fig. 11.

9.2 THE AUTOCHTHONOUS SEDIMENTS

A summary of the joint system in the autochthonous sediments gives the following set of joints (most of the observations are from the sandstone members):

A 1) N30–50°E, subvertical.

Except locality 17, this set of joints is lacking in the north-eastern part of the Laisvall area. It is exceptionally well developed in the arkose in the Kautsky ramp in the mine. Within Södra Strandmalmen horizontal slickensides have been observed. Within several localities the space between the joint planes is filled with calcite, galena, sphalerite, and pyrite.

A 2) N20–35°W, vertical.

These joints commonly have a great length (master joints) and often appear as open fractures. In Centralmalmen, in the mine, some joints with this direction show slickensides with sinistral movement traces. This set of joints is not represented in Södra Strandmalmen and is also lacking in the arkose. Outside the mine the NNW-striking set of joints is lacking in the north-eastern part of the area.

A 3) N60–70°W, vertical.

Except for localities No. 12, 14 and 15 these joints are well developed within the sandstone formation. The joint surfaces are generally smooth and planar and lack all evidence of movement. Calcite is often found filling the open space between the joint planes.

A 4) N–S, vertical.

Joints with this direction have been seen only in the Centralmalmen part of the mine and at loc. 14 and 15, where they appear with uneven, rough surfaces.

A 5) E–W, vertical to subvertical.

Uneven, rough joints with this direction occur only in Centralmalmen and at loc. 15 and 16.

A 6) ENE–WNW, vertical.

This set of joints only exists in loc. 13, 19, and 20 and is generally poorly developed.

As mentioned above, most information on the joints in the autochthonous sediments of the Laisvall area has been obtained from the mine (Figures 12 b–e). The scarcity of outcrops in the field and the relatively small size of the outcrops do not allow a more detailed comparison between the localities. In Kautskymalmen as well as in Centralmalmen the A 1, A 2, and A 4 sets of joints dominate. The A 2 set of joints is completely lacking in Södra Strandmalmen. The discrepancy between these nearby localities can not be explained satisfactorily and, bearing this in mind, it is inadvisable to deal with the differences between the separate field localities in more detail. It is enough here to conclude that one or all of the sets of joints of Centralmalmen occur in most of the other localities studied.

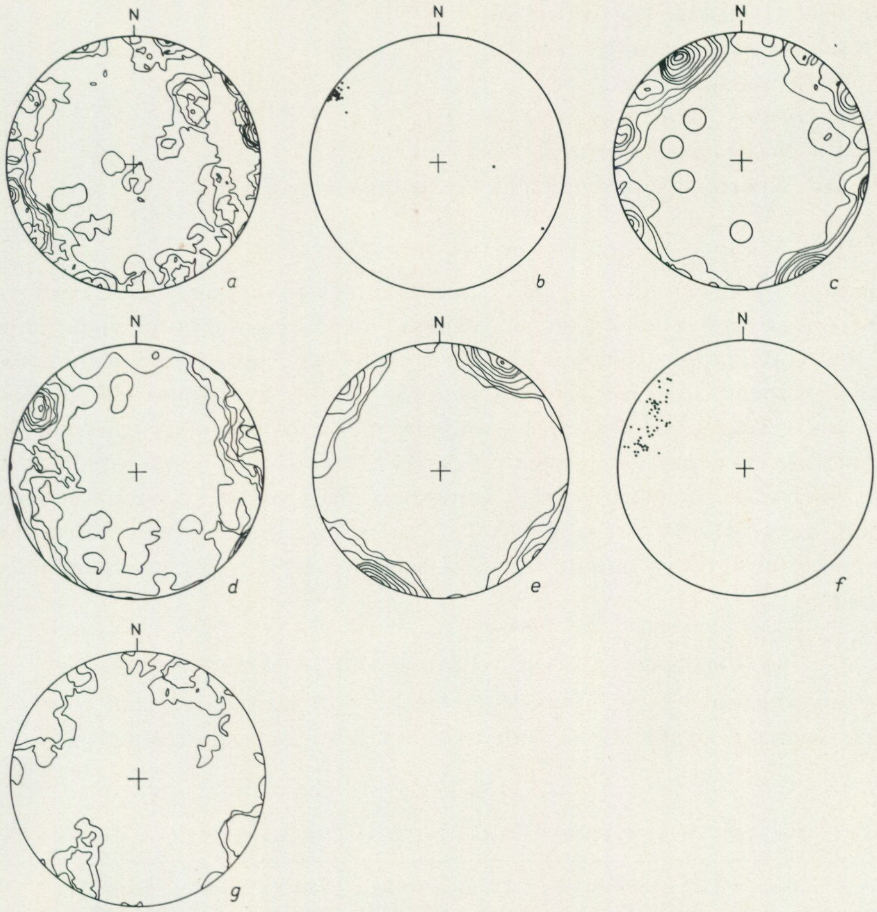

Fig. 12. Equal area, lower hemisphere projection of poles to joint planes. a) 239 readings from the granite below Kautskymalmen. Contours, 6, 5, 4, 3, 2 and 1 %. b) 23 readings from the arkose member in Kautskymalmen. c) 189 readings from the shale member above Kautskymalmen. Contours, 21 to 1 %. d) 369 readings from the sandstone of Centralmalmen. Contours, 8 to 1 %. e) 402 readings from the lower sandstone member in Södra Strandmalmen. Contours, 18 to 1 %. f) 50 readings of galena-filled small joints from the lower sandstone member, Centralmalmen. g) 125 readings from major joints within the Yraf Nappe Complex, Contours, 3 and 1 %.

9.3 THE KASKAJAURE NAPPE COMPLEX AND THE PARAUTOCHTHONOUS COMPLEX

These highly brecciated and mylonitized rocks underlying the Yraf Nappe Complex are usually poor in consistent and planar joints. A consequence of this is that the joint system is not as clearly defined as in the other rock units. The following joint systems can be described in order of decreasing frequency:

K 1) NNE-striking subvertical joints
K 2) ENE-striking subvertical joints
K 3) N–S-striking joints
K 4) NNW-striking subvertical joints
K 5) NW-striking subvertical joints
K 6) NW-striking joints with a moderate dip towards SW.

9.4 THE YRAF NAPPE COMPLEX

The joint frequency of the Yraf Nappe Complex is very varying; in general, the rocks are rather densely intersected by joints. A diagram of the major joints of the Yraf Nappe Complex has been compiled (Fig. 12g) indicating two almost perpendicular sets of joints striking N20–40°E and N45–70°W. Both sets are vertical to subvertical. By studying the individual diagrams from different field localities it is obvious that these two sets of joints occur at all sites with the exception of the ventilation shaft to Södra Strandmalmen, where a set of joints striking NNW is present at the expense of the NW-striking joints. Joints striking E-W, N-S, and N80°E occur rarely at a few localities.

9.5 SUMMARY OF THE JOINT SYSTEM OF THE LAISVALL AREA

The investigation of the joints from the Laisvall area shows that 5 sets of joints dominate (Table 2), all with a vertical to subvertical orientation.

TABLE 2

PRINCIPAL VERTICAL OR NEAR VERTICAL JOINT SETS OF THE LAISVALL AREA

The Yraf Nappe Complex	The Kaskajaure Nappe Complex	The Autochthonous sediments	The Pre-Cambrian basement	Joint plane morphology
N20-65°E	N10-45°E	N30-50°E	N20-65°E	Sinistral movement Calcite filling
N30-70°W	N30-70°W	N60-70°W	N75°W	Calcite filling
(N20°W)	NNW	N20-35°W	N15-40°W	Sinistral movement
(N-S)	(N-S)	N-S	N-S	Rough
(E-W)		E-W		Rough

( ) indicates that the joint set is poorly represented within the rock unit.

The joints orientated N-S and E-W are few and generally show rough irregular surfaces. This may be an indication that these have been developed very late in the structural history of the area. The sets of joints striking NE and NW are dominant within all rock formations and within most localities. The NE-striking joints often show signs of horizontal slickensides indicative of sinistral movement along the fractures. As no indication of actual movement can be observed it is thought that the slickensides appeared after the joints formed due to minor block movements. This conclusion is supported by the fact that many joint planes in Södra Strandmalmen are coated with minerals on which the slickensides occur. Sinistral movements are also indicated by slickensides on the joint planes striking N20–30°W in the mine. As these joints are not ubiquitous they might be connected with faulting. In Centralmalmen NNW-striking joints seem to be concentrated around a N-S orientated fault zone.

Joints striking NW-WNW and NNE-NE are in many cases filled with ore minerals but most commonly with calcite. In Kautskymalmen calcite-filled fractures striking N40°E have been observed with about 20 cm thick calcite layers.

It has not been possible to establish any age relationship between the joint planes of different orientation.

The deviation within each set of joints is rather pronounced; it is less within the autochthonous sediments than within the other rock units. Moseley & Ahmed (1967) have showed that joints of the same set can diverge as much as 15° from the mean within coarser sandstones. Within more pelitic sediments the deviation is generally not as high.

In the northern part of Centralmalmen a limited area exhibits plenty of galena-filled small joints (up to 20 cm in length). Within four smaller sub-areas 50 measurements of these small joints have been made (Fig. 12f). The dispersion from the mean of these 50 observations is found to be as much as 22°. The galena-filled joints which are regarded as tension joints, are striking NNE. Similar tension joints with the same orientation have been found in the flexures of the folds in Kautskymalmen (Fig. 7). At the entrance ramp, rocks belonging to the lowermost part of the Yraf Nappe are intersected by quartz-filled tension joints striking between N-S and N20°E, and identical joints have been seen at Garbmadak striking N20°E. All these small tension joints were most probably formed through stretching during the thrust movements.

Within the lowermost nappes and within the Pre-Cambrian basement, planes dipping moderately towards SW have been noticed. They often show well developed slickensides.

V. SUMMARY AND DISCUSSION

The autochthonous sedimentary rocks of the central parts of the Laisvall area lie relatively undisturbed on a weathered Pre-Cambrian basement. In general, only the uppermost Cambrian shales have been strongly affected by the thrust movements. Small scale thrusting occurs within the sandstones of the Laisvall

Formation in the mine. The thrust-planes dip westwards and occasionally to the SW and SE.

Within the sandstones, five "drag folds" with N-NNE fold axes have been observed (in Kautskymalmen). Folds with the same axis orientation have also been found outside the mining area, namely at Valvo and in the area between the Laisvall Mine and Storbergsudden (further north).

The bedding planes within the parautochthonous quartzites generally dip SW or W and the few fold axes found all plunge N60°W. The same direction appears in Fig. 8a, where the poles to the bedding planes from the Björnberget-Såvvovare area are plotted. Only one bedding plane has been found in the Kaskajaure Nappe Complex, and it strikes N60°W and dips NE.

The Yraf Nappe Complex overlies the other rock units (see profiles Pl. 1) with most of the schistosity surfaces dipping at low to moderate angles NW and W (Fig. 8e). Two fold axis orientations are ubiquitous, trending c. N-S and WNW. Both groups of folds are open and asymmetric, the former often overturned towards E. Isoclinal folds with axial surface schistosity have rarely been observed.

In the northern part of the map-area (Gautojaure-Björnide) the NNE and E-W foliation orientations are highly pronounced. Fold axial surfaces, thrusts and small-scale folds all follow these directions. Locally, when the two main fold directions interfere, NW and NE trending folds have been developed. The NNE trending fold axes plunge moderately to the N, while E-W axes are plunging W. The folds have been described as isoclinal by both Ljungner and Kautsky.

Ljungner (1945, unpubl. rep.) was of the opinion that the Kaskajaure Nappe Complex was thrust from the SW before the thrusting of the Yraf Nappe Complex took place (thrust from NW), an opinion shared by both Marklund and Kautsky. Marklund drew attention to the fact that the Yraf Nappe Complex rests discordantly upon steeply inclined sheets of Pre-Cambrian rocks (at Kraptbäcken and near Gavasjaure). He also described a series of elongated flat slabs of Pre-Cambrian rocks (including sparagmites) immersed in a mass of brecciated shales underneath the Yraf rocks, and with a marked N40°W strike orientation.

In his scheme for the sequence of tectonic events in the Gautojaure-Björnide area, Zweifel (1958, unpubl. rep.) placed the thrusting of the Kaskajaure Nappe Complex prior to the thrusting of the Yraf Nappe Complex. Thus it appears that Kautsky, Ljungner, Marklund, and Zweifel all were convinced that the Kaskajaure Nappe Complex is a separate thrust unit which was thrust over the autochthonous sediments earlier than the Yraf Nappe Complex.

In the case of the late folds, their opinions differ. Ljungner regarded the WNW-oriented folds as the youngest, while Zweifel thought the NNE-oriented folds were later. Kautsky and Marklund were of the opinion that they originated simultaneously.

The question of the relative age of the different folding phases has indeed been very controversial. Lindström (1958) gave an excellent review of earlier ideas concerning tectonic events within the Caledonides.

During the last decade several interesting papers have been published dealing with areas within the northern parts of the Norwegian Caledonides not far from Laisvall, particularly in the metamorphic nappes (e.g. Rutland 1959, Hollingworth, Wells and Bradshaw 1960, Gustavsson 1966, and Henley 1970). They have generally agreed on the following sequence of deformation in the northern Caledonides. An earlier plastic deformation resulted in recumbent isoclinal folds, which was accompanied or followed by flattening, stretching, and movements towards the ESE and SE. A later, less plastic deformation produced open folds on N-S and E-W axes. Finally non-plastic deformation resulted in faults and joints.

Within the Laisvall area evidence of an early deformational phase is restricted to the occasional isoclinal folds within the Yraf Nappe Complex and perhaps to the steeply inclined sheets of better preserved rocks within the Kaskajaure Nappe Complex. The same main deformational events must have influenced both the interior and the border of the Caledonian geosyncline, at least in as nearby areas as Laisvall and the regions of the papers cited above. Thus, during the first phase most of the thrusting took place which in the peripheral parts resulted in an imbrication structure within the more locally derived thrust-sheets beneath the main nappe. The origin of these deformations can be sought in both the mechanism of plate tectonics and gravity tectonics.

The thrust movements within the Laisvall area took place from the W to WNW which is revealed by slickensides on bedding surfaces in the pelitic layers within the sandstone members in the mine and in the chlorite schists at the entrance ramp. The folding within the lower sandstone member in Kautskymalmen took place during the thrust movements, when sliding along the more pelitic layers caused drag folds in the more competent psammitic banks. Also these folds indicate a movement from the W or WNW.

No convincing evidences have been found indicating that the Kaskajaure Nappe complex moved from the SW to its present position earlier than the Yraf Nappe Complex was thrust from the W-WNW. The NW-trending structures within the highly brecciated rocks underneath the Yraf Nappe Complex are presumably related to the first plastic folding phase, antedating the climax of the thrusting.

The age relationship between the second-phase open folds within the Yraf Nappe Complex striking N-S to NNE and those open folds trending perpendicular (transverse) to the mountain range is still not established. Ghosh & Ramberg (1968) have performed buckling experiments with intersecting fold patterns. They stress the fact that orthogonal relationship of two fold-trends must not be taken as a criterion for synchronous deformation. A large angle between the two sets of folds indicates two periods of deformation but can also be developed in connection with vertical movement of rocks under the action of gravity (Ramberg 1967).

Joints within the Laisvall area are post-crystalline and formed after the thrusting and the plastic deformation were completed. They transverse all rock types and all structures within the area and have usually subvertical orientation.

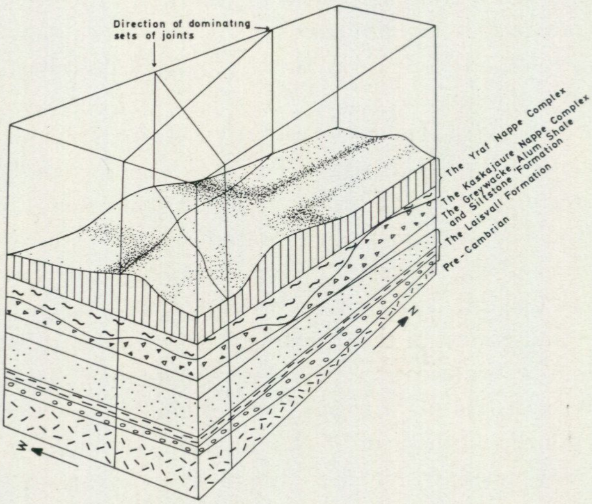

Fig. 13. Schematic block diagram of the central part of the Laisvall area.

Table 2 gives a summary of the principal subvertical to vertical sets of joints in the area investigated, and Fig. 13 and Fig. 14 show the relationships between the dominating joint directions, the fold axes of the late open folds, and the direction of the thrust movement.

Joints striking NNE-NE and NW-WNW are dominant within all the different rock units. They are more or less perpendicular to each other. A striking phenomenon is that the NNE-NE striking set of joints is approximately parallel with the trend of the Caledonian mountain range. A third set of joints strikes NNW and two minor sets can be distinguished around N-S and E-W.

In order to be able to give an explanation of the genesis of the principal joints occurring in the Laisvall area it is of importance to know whether they are of local or regional significance.

The occurrence of joints have been rather sparsely reported in the published literature on the Caledonides. Vogt (1927) treated the joint system of the

Sulitelma area in considerable detail, and presented a material based on his own and P. J. Holmqvist's observations. The joints are all more or less vertical and very rarely have slickensides been detected. Sets of joints striking N60°W and N30°E predominate, accompanied by less prominent sets striking N30°W and N-S. Within the whole area studied (200 sq. Km), the joint orientations maintain the same directions through different rock types and structures, and are independent of folds and schistosity planes.

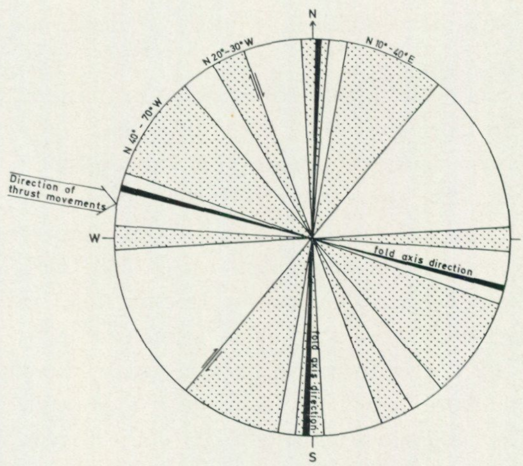

Fig. 14. Diagram showing the spatial relationship of the principal joint sets, the dominating fold directions and the directon of the thrust movement.

North of Balvattnet, Lindström (1961) has measured joints whose orientations broadly agree with the joint systems of Laisvall and Sulitelma. The sets of joints strike N30°E, N45–65°W, N20°W, and N10°E. All joints cut through all other structures and have strongly influenced the present topography of the area.

Gustavson & Grønhaug (1960) mention vertical sets of joints striking N30°E, N60°W, and N20°W within the northwestern parts of the Børgefjell area. The same directions of joints can be followed several tens of kilometers both southwards and northwards.

Joints striking c. N25°E predominate in the southeastern corner of the Salangen map unit, Troms (Lund 1965). At right angles to these joints occur transverse joints striking N65°W. Furthermore joints striking N15°W and N85°E are reported.

From the Vassbo Mine, Tegengren (1962) has described joints intersecting the Cambrian sandstones, striking N35°E, N15°W, and N75°W. The last-mentioned set predominates.

As is the case of Laisvall, all the areas quoted have joints more or less parallel and transverse to the trend of the Caledonides. Thus we can establish a set of joints striking parallel to the Caledonides (c. N30°E) and another transverse and at right angles to the former (c. N60°W). A third ubiquitous set of joints strikes NNW. The other reported joint directions seem to be of a more local character. Vogt came to the conclusion that the joint system of the Sulitelma region is a result of stresses which acted during the last folding phase of the Caledonides. According to Lindström (1961), the joints were generated as a result of a stress acting very late in the structural history of the area.

It is difficult to relate the formation of the principal joint directions to the deformation pattern caused by the major Caledonian events (compare Fig. 13 and 14). As the joints cut through all other existing structures, I agree with Lindström (1961) that the joints were formed after the tectogenesis, in Mesozoic and/or Tertiary times, when the Caledonides were subject to upheaval and drifting away from the American continent and Greenland. The whole Baltic shield is strongly fractured and the fracture lines in Finland seem to favor NW-SE, NE-SW directions, and to a lesser extent N-S and E-W directions (Mikkola 1971). The same lines appear on a map showing the distribution of earthquakes in Finland during the last centuries (Penttilä 1963). According to Mikkola (op. cit.) movements seem to have taken place since early Pre-Cambrian times along the same lines.

If the above assumptions are reasonable, the joints in the Laisvall area (as well as the principal joints of the northern Caledonides) appeared in Mesozoic or Tertiary times along fracture lines that have been active since the Pre-Cambrian and which still seem to be active.

Most of the reversed faults in the Laisvall area seem to be connected with the thrust movements. But we also have evidence for faulting in Cambrian times, affecting the sediments below the alum shales, and forming a graben tectonics. Several of the faults which have not been possible to date were probably formed in Cenozoic time when the Caledonides were last uplifted.

The morphology of the Laisvall area is the result of both the structure of the bedrock (thrust zones, folds, fault zones, and joints) and the glacial erosion in the Pleistocene. The morphologic map shows mainly NW-striking lineaments (Fig. 10) which probably have been sculptured out from fracture zones, which were deepened and smoothened during the Quaternary glacial erosion.

The direction N20°E is also conspicuous in the landscape (Fig. 10), and is likewise thought to have its origin in fracture zones.

Lake Stor-Laisan and the lake system Maiva-Jutis follow a N-S trending course. The eastern slope of the mountain Lulle-Naddok shows an asymmetrical flexure-shaped fold with a steep eastern limb. This suggests that the origin of the N-S direction of these lakes is to be found in the fold structure of the Yraf Nappe Complex. The valley of Lake Stor-Laisan was probably first formed in a fold flexure and later the erosion worked through the overthrusted units. The WNW to E-W trending features are mainly due to the transverse fold system.

Summing up the tectonics, the investigation of the Laisvall area gives the following results:

1. An early phase of isoclinal folding was closely followed by thrust movements from the W or WNW. Within the northern parts of the area (Gautojaure-Björnide) the Cambrian and late Pre-Cambrian sediments were folded and thrust along with slices of Pre-Cambrian basement into a complicated imbricate structure, while the sediments in the central parts of the area rest more or less undisturbed on the basement. The last plastic deformation of the area created open folds on NNE and WNW axes. It has not been possible to determine their relative age.

2. It is uncertain how or when the joints were formed in the Laisvall area. A suggestion is put forward that the dominating sets (N30°E and N60W)) appeared in Mesozoic or Tertiary times along fracture lines that have been active since Pre-Cambrian and still are active.

3. The morphology of the area is mainly inherited from the rock structures (folds and fracture zones) which have been accentuated by glacial erosion.

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NGU = Norges Geologiske Undersøkelse

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LEGEND
Mica schist
Mica quartzite
Gneiss
Phyllonite
YRAF NAPPE COMPLEX (ALLOCHTHON)
Cataclastic sparagmite and conglomerate
Cataclastic basement rocks
KASKAJAURE NAPPE COMPLEX (ALLOCHTHON / PARAUTOCHTHON)
Quartzite
Shale
PARAUTOCHTHONOUS COMPLEX
Greywacke
Shale
GREYWACKE FORMATION
Black shale
Grey shale
Siltstone
ALUM SHALE FORMATION AND SILTSTONE FORMATION
Conglomerate
Sandstone
Shale
Arkose
LAISVALL FORMATION
AUTOCHTHON
Granite
Syenite
Gabbro
PRE-CAMBRIAN BASEMENT
Geological boundary
Inferred geological boundary
Fault
Inferred fault
Thrust
Inferred thrust
Lineament
S-surface orientation
Fold axis
Drill-hole
Ore contour (>2% Pb)
GEOLOGICAL MAP
OF THE LAISVALL AREA
Southern Norrbotten,
Swedish Lappland
Robert Lilljequist
Scale 1:50 000
0
5 km
Horizontal Scale 1:40000
Vertical Scale 1:20000
600 m
500 m
400 m
Lulle-Naddok
Lake Stor-Laisan
Bjönberget
Garbmadak
Alle-Naddak
The Laisvall area
0
200km
Vuolle-Bietjaure
Suonger
V. Sveggejaure
Vejejaure
Buodak
Didnok
Björnide
Issmejaure
Gautojaure
Långsjön
Dammsjön
Hällbacken
Gruttur
Märkströmmen
Kroppesvare
Jutis
V. Jutis-sjön
Jaulak
Valve
Bajeb Rabna
Gardjaure
Vuoleb Rabna
Långudden
Stuor-Jutas
Buodatj
Kramosjön
Alle-Naddok
Storbergs-udden
Björnberget
St. Nammats
Dbh 480
Lulle-Naddok
Laisvall Mine
Laisvall
Dbh 279
Gramajokku
Såvvavare
Saivatj
Tjålmåk
Garbmadak
Geddak
Stor-Laisan
Laisvalls by
Assjatj
Aisjaure
Niepsurt
Muorkenåive
Hålmyran
Båtsjaur
Korsträsk
Gardevare
Stainak
Luspevare
Skorvtjörn
Dellikriås
Björnliden
Remtliden
Haukobolltjärn
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