SVERIGES GEOLOGISKA UNDERSÖKNING

SER C NR 609 AVHANDLINGAR OCH UPPSATSER ÅRSBOK 60 NR 9

PETER PADGET

The geology and mineralization of the Radnejaure area, Norrbotten county, Sweden

ÖVERSIKT: BERGGRUNDEN OCH MINERALISERING INOM RADNEJAUREOMRÅDET, NORRBOTTENS LÄN

WITH 2 PLATES

STOCKHOLM 1966

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ABSTRACT

The paper deals with the geology and mineralization of an area of PreCambrian rocks situated about 20 km east of Arjeplog, N. Sweden (map sheet Stensund 25 I) and arises out of an ore-prospecting campaign conducted by the Ore Investigation Department (Malmbyrån) of the Geological Survey of Sweden in the years 1957—1963. The bed-rock is frequently moraine-covered and forested but routine geological mapping in conjunction with ground geophysical surveying enable a geological map and profiles to be constructed (Plates 1—2). Greenstones of andesitic basalt composition and leptites of dacite-rhyolite composition occupy the central part of the area and together with their sedimentary derivatives constitute a major 'supracrustal' fragment in the prevailing granite terrain. The rocks may be grouped into 6 main formations the distribution and mutual relations of which are evident from the map (Plate 1) and profiles (Plate 2). Intrusive rocks of gabbroic and diabasic character also occur. Granites of late or post-kinematic age and moderately potassic in chemical composition enclose the layered rocks. A marked zone of pegmatite intrusion shows a zonal relationship to the granites in the eastern part of the area. The metamorphic and metasomatic features of the supracrustal rocks, particularly in the vicinity of the granites, are described as are features of tectonic interest such as pre-granite folds (Jäknatjavelk anticline, Ballek syncline) and associated minor structures. Post-granitic faulting is represented by the Svannvik-Plättvik Fault System and the Ballek-Sademåive-Lulepotten zone of movement. Brief descriptions are also given of known copper mineralizations in the area and the methods used to locate them.

Introduction

The village of Radnejaure is situated 20 km east of Arjeplog in the southern part of Norrbotten county, northern Sweden. The area under consideration is about 350 km² in size and lies mainly to the north, east and south-east of this village. The terrain is a typical one for northern Sweden (fig. 1), with forested, ice-smoothed hills and slopes interspersed with lakes and bogs. A few roads exist facilitating access to most parts of the area.

Fig. 1. General view of the area looking NW across Gubblijaure towards Soggovare. P. P. Photo 1962.

Geological studies were begun in 1958 in connection with prospecting for copper ores. Investigations have continued up to the time of writing (January 1964) and form part of the ore prospecting programme of the Geological Survey of Sweden. Apart from geological mapping, extensive programmes of boulder (i. e. float) tracing, geophysical surveying (ground measurements only) and diamond drilling have been carried out as well as a little geochemical prospecting. The geological results of these investigations are given in the present paper and accompanying map (Pl. 1). It must be emphasized, however, that many uncertainties still exist regarding the geology of parts of the area, often largely due to lack of exposures and reliance on indirect geophysical methods. Revisions may therefore be necessary in the future when new exposures are available (e. g. roadcuts, diamond-drilling etc.). It should also be remembered that more intensive studies have been made where mineralization is known or expected to exist. This leads to a certain unevenness in the geological description: granites, for instance, are not discussed in any great detail whilst structural and stratigraphic aspects receive more attention. Mineralizations known to date are considered in their geological context only: detailed descriptions and strictly economic aspects are reserved for treatment in the future when drilling and sampling are more complete.

The scope of the paper is shown by the Table of Contents.

Previous to the present investigation no detailed mapping had been carried out. Knowledge of the area, however, was conveniently summarized on manuscript maps in the archives of the Geological Survey of Sweden, Stockholm. These maps also served as a basis for the drawing of the regional map of the county of Norrbotten by Ödman (1957). In his studies of the Arvidsjaur porphyries Grip (1935, 1946) included some observations from the area, notably the sequence of beds on the hill Radnekvare (1946, fig. 2). He also indicated the existence of folding on NNE-trending axes to the east of Arjeplog (1946, fig. 1): synclines were apparently postulated on the existence of zones of acidic rocks, the latter being considered stratigraphically younger than more basic-intermediate types.

In the present investigation mapping has been carried out on aerial photographs at a scale of approximately 1:20 000. On the basis of these a topographic map was drawn and used as a base for the geological map. Good quality photographs became available from 1960 and these allowed a photogeological interpretation to be made. Information obtained in this way, mainly jointing, has been taken into consideration when drawing the geological map of the area.

Acknowledgements

The results, both scientific and economic, achieved in the Radnejaure area are the result of active cooperation between the various sections and individuals of the Survey's Ore Investigation Department (Malmbyrån). The author wishes to thank all who have taken part in the work and in particular the prospectors whose discoveries of mineralized blocks first attracted attention to the area and were a constant source of inspiration.

Supracrustal rocks

So-called supracrustal rocks occupy most of the central parts of the area. They fall into two main groups — dark, basic to semibasic types collectively called greenstones, and light coloured, acidic types of leptitic character. Conglomerate, mica-schist and even one thin limestone also occur but are quantitatively minor elements. Field mapping, aided by a judicious use of geophysical data (magnetic, electrical), indicates the existence of several distinct formations. These are:

6. Radnekvare Acid Group
5. Main Greenstone Group
4. Laddok Leptite
3. Nimtekjaure Greenstone
2. Nimtekjaure Leptite
1. Jäknatjavelk Group

All the above are older in age than the granites of the area but no trace of an older, basal granite-gneiss complex can be found. The granite emplacement has, unfortunately, often caused recrystallization so that the primary character of the supracrustal rocks is obscure. Acidic rocks affected in this way are referred to as leptite though the term is not favoured.

1. Jäknatjavelk Group

The oldest rocks are to be found in the vicinity of the hill Jäknatjavelk in the eastern part of the area, south-east of Gubblijaure. They here occupy the core of the Jäknatjavelk anticline and are heavily granitized. It is, however, possible to distinguish and map over short distances greenstones and leptites reminiscent of those occurring in higher stratigraphic formations. Thus some of the greenstones are of andesitic-basaltic composition and often show plagioclase laths of primary, porphyritic character. They are interpreted as lavas. The leptite is fairly fine-grained and usually contains sericite of secondary origin. A fine compositional banding is sometimes seen, as for example, in exposures in the old river course, east of lake Gubblijaure and has been taken as an indication of the primary bedding. A chemical analysis (No. 2942, Table 1) of this rock shows it to be close to granite in composition but with perhaps a little too much iron. The presence of a fine-grained pigment may explain this. The rock may well be an arkosic sediment.

A conglomerate (K7) is exposed in the steep NE-facing slope of Jäknatjavelk over a distance of 25 m. It is here 10 m thick and contains large and small pebbles of both leptite and greenstone (fig. 2). There are no 'foreign' pebbles such as granite to indicate a major stratigraphic hiatus and it is interpreted as being the product of local erosion. It passes upwards into more even-grained leptite.

Rocks lying between recognizable supracrustals are largely gneisses, granite or pegmatite and transitional zones occur. The sharp boundaries shown on the map are therefore somewhat idealized and subjective.

TABLE 1. *Analysis of leptite from the Radnejaure area*

	wt %		
SiO_2	72.75		
TiO_2	0.46		
Al_2O_3	13.34		
Fe_2O_3	1.92		
FeO	1.95		
MnO	0.05	al	42.1
MgO	0.38	fm	19.7
CaO	1.12	c	6.5
Na_2O	3.76	alk	31.7
K_2O	3.51	si	391.9
$H_2O < 110°$	0.06	k	0.38
$H_2O > 110°$	0.66	mg	0.15
P_2O_5	0.05	qz	165.1
BaO	0.04		
CO_2	0.02		
S	0.04		
F	0.01		
	100.12		

Analysis (no. 2942) of leptite sample (27/662) from exposure near old river bed 1.8 km east of Svannvik (Gubblijaure). Analyst: A. Aaremäe, Geological Survey, Sweden.

2. Nimtekjaure Leptite

The first formation of more continuous extent occurs north of the lake Nimtekjaure in the east part of the area. It is of leptitic character and consists largely of quartz, feldspar and some mica. It is known from a few exposures and indirectly from magnetic surveys. In its main outcrop north of the lake the strike is ENE and the dip moderate to the SSE. It is about 600 m thick. The relationship to the underlying Jäknatjavelk Group is obscured by granite and granite-gneiss. The upper contact, however, with the greenstones can be easily followed on magnetic maps of the area. Towards the WSW there is evidence from a study of blocks that it becomes more micaceous and structural considerations indicate that it must turn sharply northwards as shown on the map, plate 1. It is probably represented here by more variegated rocks including conglomerate (K8) between lakes Tjålmak and Gubblijaure (fig. 3). Exposures, however, are very poor and to judge from blocks granitization is extensive, the formation losing its identity as a result.

In thin section a typical sample consists almost exclusively of quartz, a small but consistent amount of biotite, a little titanite and often a little epidote or

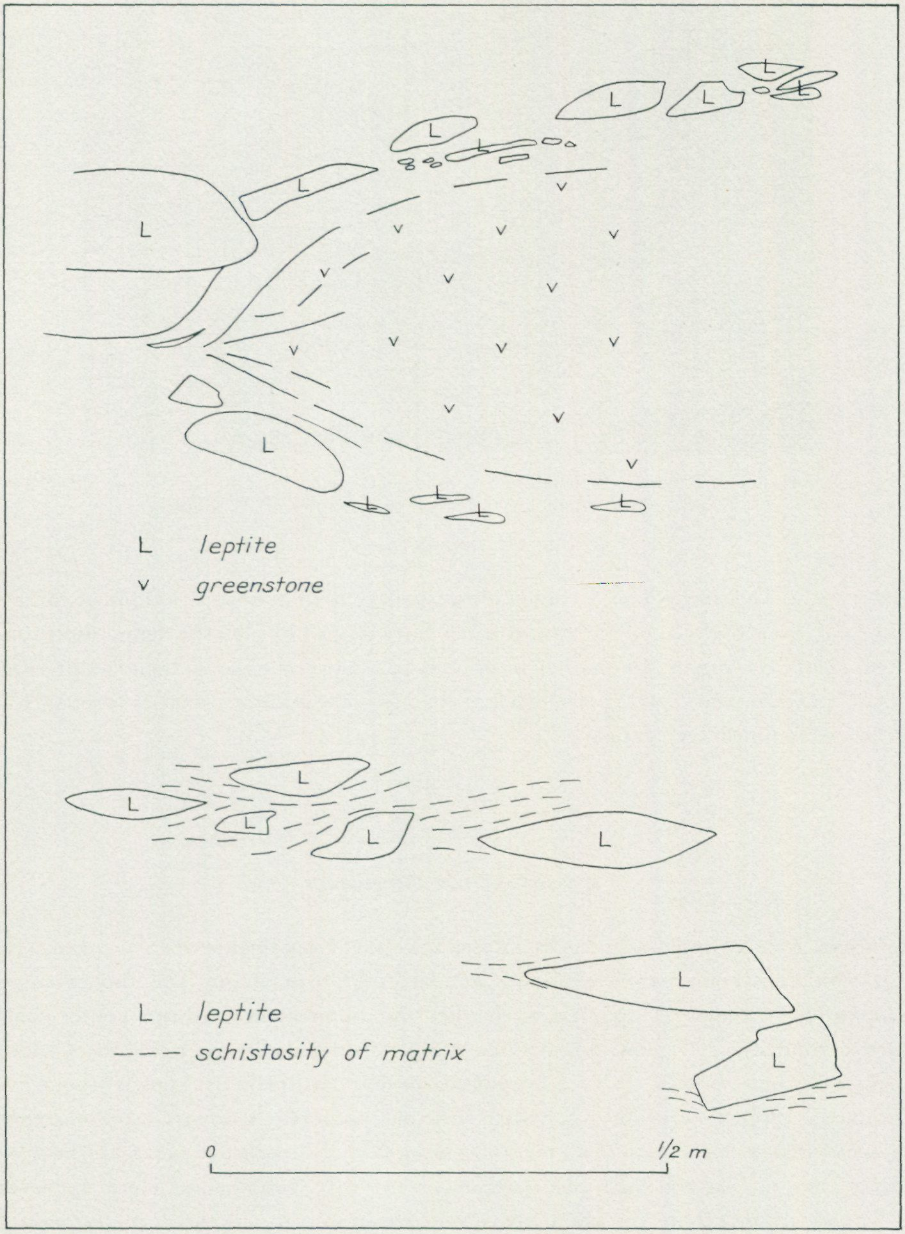

Fig. 2. Sketches of conglomerate K7, exposed ENE of the hill Jäknatjavelk in the eastern part of the map area.

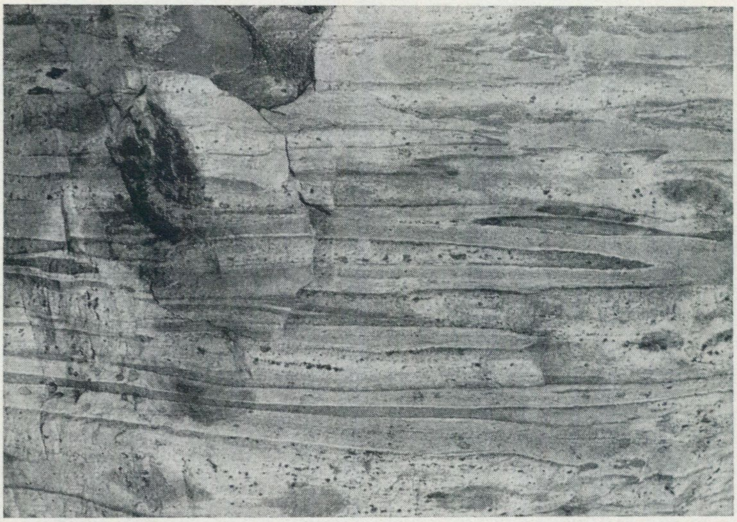

Fig. 3. Elongated and flattened pebbles in conglomerate K8, 2.8 km east of the hill Björkberget. Note zoned character of the pebbles. P. P. Photo.

clinozoisite. The plagioclase is commonly oligoclase with abundant twinning. Muscovite and microline are common and often have a porphyroblastic habit indicating their secondary origin. In some outcrops slightly more micaceous laminae alternate with mica-free ones giving the rock a banded appearance. This is probably a primary, sedimentary feature.

3. Nimtekjaure Greenstone

A broad zone of semi-basic rocks crosses the lake Nimtekjaure in a northeasterly direction. It is known from exposures and drilling north of the lake and extensive geophysical surveys. It apparently overlies the Nimtekjaure Leptite conformably in the Nimtekjaure region. Southwards it is conformably overlain by the Laddok Leptite Group, judging from a magnetic survey, but little is known about the formation proper owing to a complete lack of exposures. Structural considerations indicate that a continuation of the formation is to be expected in the vicinity of Stora Laxsjön (eastern end) and northwards towards Gubblijaure. Here, however, extensive granitization has taken place and the rocks are in the form of biotitic and dioritic gneisses.

In typical outcrops north of the lake Nimtekjaure both massive and schistose types of basaltic andesites occur. These consist of andesinic feldspar, hornblende, biotite and titanite and obviously extensive recrystallization has taken place.

There is no primary pyroxene and the porphyritic feldspars are heavily saussuritized. No chemical analyses exist but the rocks clearly resemble those of the Main Greenstone Group described below.

4. Laddok Leptite

This broad curving zone of leptitic rocks occurs in the southern part of the area. Exposures are far from abundant, particularly in the wide, open valley occupied by the lakes Laddok and Plättik. Blocks, many of local origin, are, however, numerous and geophysical surveying indicates the presence of rocks with very weak magnetism. The contact with the greenstones of the Main Greenstone Group (see below) to the west and north-west seems to be invariably sharp and can be mapped with a high degree of uncertainty. The contact with the greenstones of the Nimtekjaure zone is entirely constructed from geophysical data (magnetic survey) and the study of local blocks. It seems to be fairly sharp south-west of Tjålmak, a lake not to be confused with another lake with the same name near Stora Laxsjön. South-west of the lake Lilla Laxsjön the formation is thought to interdigitate with micaceous leptites and mica-hornblende schists which in turn pass over into greenstones belonging to the lower part of the Main Greenstone Group. On the hill S. Nimtekvare in the south-east of the area, zones of greenstone occur in a granite milieu. Their position suggests they are lateral equivalents of the Laddok Leptite in an easterly direction.

The dominant rock type is a medium to fine-grained leptite which in certain places shows a distinct compositional banding. Generally the rocks have undergone recrystallization and on Tjäurevare have almost granitic grain size. No conglomeratic horizons are known but it is possible that some of the leptites represent banded arkoses. Further elucidation of the stratigraphy of the component beds is impossible due to lack of exposures, metamorphism and granitic and pegmatitic emplacement.

5. Main Greenstone Group

This is located centrally in the supracrustal area and has a NNE trend. South of the lake Gubblijaure a few exposures show the dips of certain compositional boundaries to be consistently to the WNW or W at angles varying from 50 to 80 degrees. The base of this unit is therefore considered to lie towards the east and younger beds towards the west. At its greatest width the Group has a thickness of at least 6 000 metres and may be subdivided into 3 units as follows:

a. A series of *alternating porphyritic and non-porphyritic andesitic basalts*, occasionally amygdaloidal. These are seen in several exposures in the Björkberget area where, unfortunately, metamorphism is considerable and exposures too few to allow detailed mapping. To the north of the lake Gubblijaure, however, and in particular north of Store Soggovarre, more continuous exposures can be studied. Here a variety of dark, basaltic rocks occur, some with long feldspar laths scattered through the rock, others with cm large feldspars more closely packed and equidimensional. These clearly alternate with each other and vary in thickness but can be mapped to some extent confirming the general strike and dip. The lower part of the unit is characterized by more schistose greenstones, known largely from studies of local blocks in the Stora Laxsjön area. In the strike direction towards the NNE they seem to pass into more massive greenstones whilst to the SW they most likely interdigitate with micaceous and quartz-mica schists. No exposures exist to demonstrate this but it is a likely interpretation from the geophysical data available. The relationships are shown crudely on the map of the area.

b. Massive, compositionally *homogeneous basaltic andesites* are exposed on the hill N. Kåivåive and extend southwards towards Lul. Radnejaure and northwards to Soggovarre. Porphyritic plagioclase is common and in some varieties the form is markedly lath-like (fig. 4) showing a tendency to dimensional orientation. This may indicate flow but it was not possible to detect any constant orientation useful for measuring strike and dip of individual beds and horizons. Nor was it found

Fig. 4. Basaltic andesite with well developed plagioclase laths. Exposure at roadside 1.6 km WSW of the hill Ballek. Photo G. Nilsson.

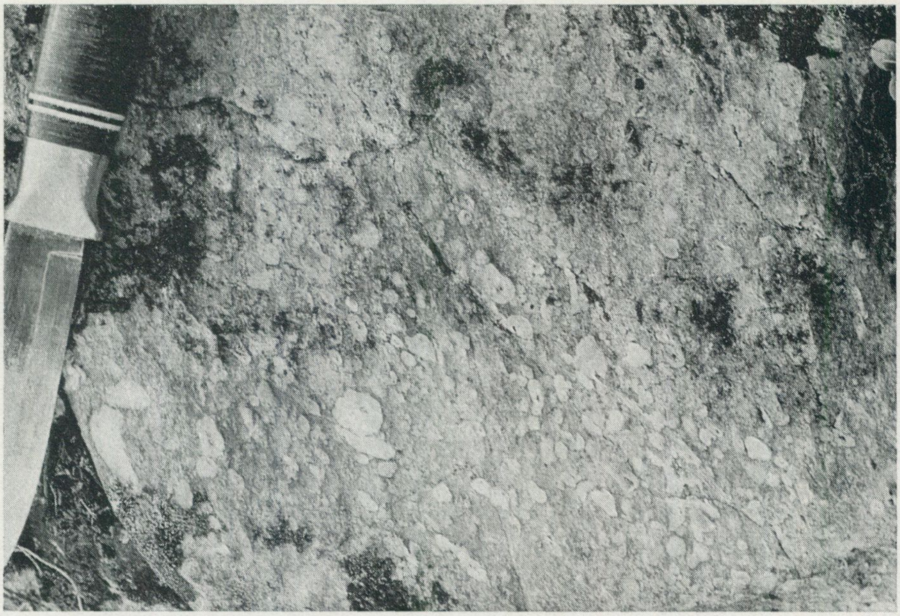

Fig. 5. Quartzose amygdules in andesitic basalt 150 m west of Gubblijaure and 400 m SSE of Mockajaure. Block of local origin. P. P. Photo 1965.

Fig. 6. Andesitic basalt with alternating amygdaloidal and plagioclase-rich layers. Note marked parallel orientation of the plagioclase laths (dark in picture). P. P. Photo 1965.

possible to effect a further subdivision of the unit as a whole owing to the prevailing petrographic homogeneity. Indeed thought has been given to the possibility that the rocks are in reality part of an intrusive but there is nothing in the contact relations to support this.

c. *Amygdaloidal greenstones,* with or without plagioclase laths, are characteristic of the uppermost unit (figs. 5, 6). They lie towards the west end of Gubblijaure and extend SSW towards the lake Nuostajaurats. They have a composition between that of basalt and andesite. See analysis No 2948, table 2. Schistosity is well developed in this part of the area and no mappable primary features could be found.

The continuation of the Group as a whole to the north and north-east is very poorly known, largely due to an almost complete lack of exposures. Thus south of the lake Östra Ribbraur only the Habakvare hill gives any idea of the nature of the geology. Here both greenstones and leptite are found and it must be assumed that the latter is an intercalation in the former as shown on the map. Further north, granite most likely becomes of increasing importance but the exact course and nature of the contact is difficult to predict. Perhaps aeromagnetic surveying would throw some light on the problem. In the Ballek region the strike is clearly northwesterly and the greenstones are clearly cut off by the granite. Certain narrow zones of greenstone in the granite itself may well belong stratigraphically to the Group. A further feature of interest in this region is the occurrence of zones of acidic supracrustals apparently interbedded with greenstones (north and NE of Ballek). In other words leptitic rocks, which include some conglomerate are the lateral equivalents of some of the greenstones. The limits of the leptitic zones are known in some detail thanks to detailed magnetic surveying. The conglomerate, known only from blocks, contains a mixture of light-coloured leptitic and darker greenstone pebbles. Of special interest for the structural interpretation is a narrow zone of leptite exposed about 700 m NNE of Ballek. It is interpreted as a sedimentary unit intercalated with greenstones. A similar type of rock is known to occur 2.5 km ESE of Ballek and though in contact with greenstone at one point its width and distribution are unknown. These occurrences together with that reported from Habakvare are interpreted as lateral equivalents or facies variants of the Main Greenstone Group.

Another occurrence of greenstone which may belong stratigraphically to the Group crosses the lake Lulepotten in a NE direction. Drilling shows it to include both porphyritic and non-porphyritic types as well as amygdaloidal greenstone and greenschist. Analysis of a typical sample south of the lake is given in Table 2, No 2967.

To the south and SSW the Group as a whole is in sharp contact with granite.

The petrographic characters of the greenstones have been studied largely in thin

TABLE 2. *Analyses of andesitic basalts from the Radnejaure area*

Anal. no.	2967				2948			
Sample no.	Bh 61201				27/668			
	wt %	cation %			wt %	cation %		
SiO_2	56.84	53.72			48.96	47.41		
TiO_2	0.95	0.68			1.92	1.39		
Al_2O_3	19.07	21.21	Or	12.50	17.63	20.10	Or	20.10
Fe_2O_3	3.45	2.44	Ab	42.25	5.83	4.24	Ab	22.65
FeO	3.24	2.55	An	25.65	6.14	4.94	An	34.58
MnO	0.12	0.11	Q	7.39	0.21	0.17	Q	5.41
MgO	1.35	1.93			3.72	5.40		
CaO	6.04	6.13	Mt	3.66	9.42	9.76	Mt	6.36
BaO	—	—	Ilm	1.36	0.02	—	Ilm	2.78
Na_2O	4.61	8.45	Wo	1.06	2.43	4.53	Wo	4.72
K_2O	2.07	2.50	En	3.86	1.41	1.74	En	10.80
P_2O_5	0.32	0.28	Fs	1.52	0.37	0.29	Fs	3.20
H_2O >110°C	0.95		Ap	0.75	1.78		Ap	0.77
H_2O <110°C	0.15				0.04			
F	0.05				0.09			
CO_2	0.82				0.08			
S	0.01	—			0.02	—		
	100.04	100.00			100.07	99.97		
-for F, S	0.03				0.04			
	100.01				100.03			
al	36.3				26.7			
fm	24.1				39.1			
c	21.0				25.9			
alk	18.6				8.3			
si	183.7				125.8			
k	0.23				0.28			
mg	0.27				0.36			
ti	2.3				3.7			
p	0.4				0.5			
qz	+9.3				−7.4			
suite index δ	3.2 = weak Pacific				2.5 = average Pacific			

Anal. 2967 drill-hole about 1.2 km SE 'Brändudden', south of Lulepotten.
Anal. 2948 exposure 1.0 km SW Store Soggovare.
Analyst: A. Aaremäe, Geological Survey, Stockholm.

sections aided by a few chemical analyses. Thus the microscopic examination shows remarkable homogeneity as regards mineral composition.

The primary porphyritic feldspar is a plagioclase of andesinic composition though rather variable within this range. Saussuritization is common and possibly due to later metamorphism. The matrix, however, seems to be completely recrystallized consisting of common hornblende with poikiloblastic habit, biotite, epidote clinozoisite together with small amounts of quartz, andesinic plagioclase and titanite. No primary pyroxene has been seen to date.

In order to get a better idea of the chemical character of these rocks opportunity was taken to collect suitable material, i. e. material macroscopically representative for rocks of a given locality, devoid of leaching and metasomatism and with a minimum of tectonic deformation. Some metamorphism was, however, discernible in thin sections of the samples.

TABLE 3. *Trace element concentrations in selected intermediate-basic rocks*

Sample no.	Rock type	Locality	V	Cr	Co	Ni	Cu	Zn	Pb	Ag	Mo
27/41	Andesite basalt: porphyritic ± amygdules. 5c.	St. Soggovare	145	85	25	45	230	130	160	<3	8
27/161	„	„	165	85	25	45	140	75	<10	<3	<5
27/162	„	„	160	65	30	50	80	90	<10	<3	<5
27/385	„	„	120	65	30	55	20	190	<10	<3	<5
27/307	Andesite-basalt: porphyritic. 5b.	N. Kåivåive	150	85	30	55	80	100	<10	<3	<5
27/308	„	„	110	70	40	60	30	100	<10	<3	<5
27/309	„	„	150	60	30	65	45	100	<10	<3	<5
27/310	„	„	145	85	30	50	90	170	<10	<3	<5
27/311	„	„	120	55	25	50	80	190	<10	<3	<5
27/14	Uralite-type gabbro	St. Soggovare	135	75	45	90	55	170	<10	<3	<5
27/323	„	N. Kåivåive	160	55	30	50	20	180	<10	<3	<5
27/326	Basic dyke	„	130	75	35	65	220	140	<10	<3	<5

Analyst: H. Roosaar. Geochemical Laboratory, Geological Survey, Stockholm.

The analyses confirm the mineralogical estimation of the rock composition showing them to be andesites and basaltic andesites (cf. Nockolds, 1954, Table 6 analyses 2—4) with small amounts of normative quartz. They show the relatively high alumina and low potash characteristic for rocks of this type. Calculation of the suite index (sigma) as suggested by Rittman (1962, p. 110) shows clearly that both are calc-alkaline or Pacific in character. Obviously the analyses are too few in number to allow one to say much about the volcanic suite as a whole or the petrographic province to which it belongs. This is an attractive problem for future research. However, the existence of more acid volcanics (rhyodacites and dacites) in the area encourages comparison with basalt-andesite-rhyolite provinces such at that in the NW of the U. S. A. (Cascade Mountains). These rocks are typically calcalkaline and continental rather than oceanic.

Spectrographic analyses of a number of samples taken from the N. Kåivåive (stratigraphic unit 5b) and Stora Soggovare (stratigraphic unit 5c) areas are given in Table 3. Samples 27/161 and 27/162 are taken from the same exposure and virtually the same material as silicate analysis 2948. In general they have similar trace element abundances with a Co: Ni ratio of 1:2. Copper is somewhat variable. The abundances are also normal for rocks of similar character (Turekian and Wedepohl, 1961).

6. Radnekvare Acid Group

The rocks of this group are located entirely in the west part of the area where they occupy a broad zone striking NNE. Exposures are, however, few but it is possible to draw the limits with the assistance of geophysical data. The easterly contact with the uppermost unit (5c) of the Main Greenstone Group is sharp. A narrow zone (K2) of conglomerate south of the eastern tip of the lake Mockajaure contains greenstone fragments and cross-bedding (fig. 7) indicates that younger

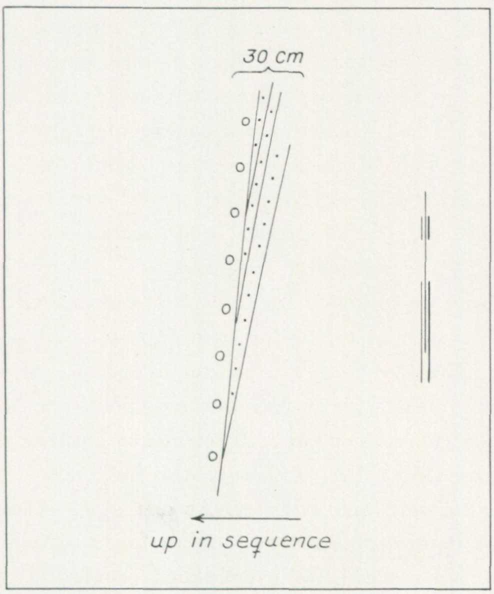

Fig. 7. Discordance in conglomerate 600 m west of Gubblijaure.

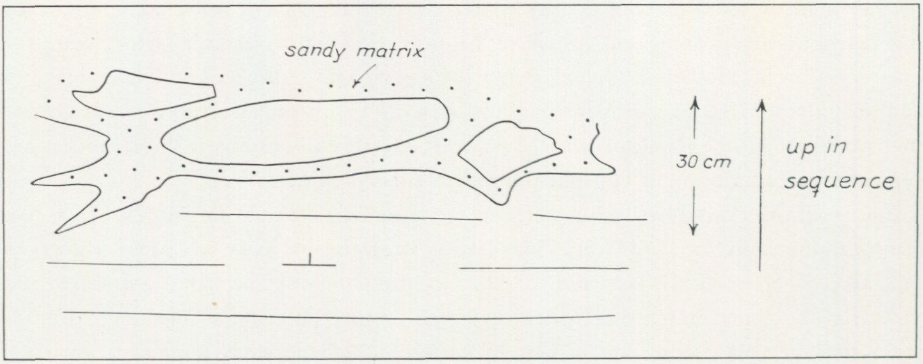

Fig. 8. Contemporaneous erosion of pelitic schist, the fragments 'cemented' by a sandy matrix.

beds occur in a westerly direction. Penecontemporaneous erosion features in sediments a short distance west of the lake Jopajaurats indicate the same thing (fig. 8). Southwards, in the region of Radnejaure village, the contact is not exposed but in the extreme southwest corner of the map area a succession can be followed on the hill St. Radnekvare. The exposures are mentioned by Grip (1946) in his comprehensive review of the Arvidsjaur district. The succession is as follows:

iv. quartz porphyries of the Arvidsjaur type (Grip, 1935): massive and homogeneous:

iii. tuffites with both a fragmental and banded character, gas cavities common: known only from blocks of local origin:

ii. quartz porphyries of the Arvidsjaur type, massive:

i. 'leptites' occasionally weakly banded and acid to sub-acid in composition (acid plagioclase, a little potash feldspar, muscovite, biotite, epidote and titanite). Most are too fine-grained for satisfactory determination of the minerals and require chemical analysis for further elucidation of the petrography.

A profile over the hill St. Radnekvare has previously been published by Grip (1946, p. 11). He reports the presence of keratophyric formations as well as a thick liparite. Unfortunately, the line of profile is not shown on his maps. It possibly lies outside the limits of the present investigation.

This succession cannot be followed for any great distance to the NNE. The porphyries, for example, persist as far as the lake Jopajaurats but fail to reach Lulepotten (Mockajaure). There is instead a greater abundance of leptitic schists with conglomeratic horizons, often with an abundance of porphyry pebbles. Lime-bearing leptitic schists are also common to judge from blocks and the rock then resembles a calciferous sandstone. Under the microscope the fragments are distinctly angular and mainly consist of quartz and feldspar. At one place (Sademåive) a bed, one metre thick, of limestone is exposed. There is thus fairly convincing proof that this portion of the acidic zone is essentially composed of clastics of arkosic type and some chemical sediments.

Of particular interest are the conglomerates since with their help it is possible to measure with greater certainty the strike and dip of the beds and in one case the direction of 'younging'. The nature of the pebbles also gives us some idea of the sedimentary milieu and provenance of the material. The conglomerates are numbered K 1—6 on the map, to which reference may be made.

K 1, occurring immediately NW of the lake Jopajaurats, is full of pebbles of typical Arvidsjaur Porphyry type, mostly angular and with an arkosic matrix.

K 2, a few hundred metres west of Gubblijaure, consists of pebbly horizons in an arkosic matrix. Study of cross-bedding indicates that the beds 'young' towards the west.

K 3 is unfortunately, known only from blocks but these have been traced to a point near the south shore of Lulepotten. Further west, i. e. against the direction of ice transport, they are absent. At the suspected source of origin nearly all visible blocks are conglomeratic and there can be little doubt that the horizon occurs here. In some blocks fragments of head size are present in certain layers. Normally they are smaller and usually rounded to some extent. They consist almost entirely of pale grey liparites, to use Grip's (1946) terminology, and porphyries with characteristic blue quartzes. It is evident that coarse-grained horizons alternate with finer ones and indicate fluctuating conditions of sedimentation.

K 4, exposed on the south slope of the hill Sademåive, is about 5 m thick and includes a variety of fragmental material of both basic and acidic character. The pebbles are both rounded and angular and it is no problem to recognize types occurring in exposures of the vicinity, e. g. greenschists and porphyritic greenstones, leptitic schists. There has evidently been little grading or sorting of material.

K 5, to the north of K 4, contains pebbles of two types, namely, dark porphyritic greenstones and pale grey 'liparites' with flow banding. The latter are up to 0.5 m in length and broken along the banding and joints at right angles to it. The matrix is a mixed gravel with abundant greenstone fragments. The greenstone pebbles can be easily matched with those of the central zone but the liparitic fragments are more readily comparable with the rocks of Stora Radnekvare to the south.

K 6 is known from one exposure only, namely close to a narrow lake, 1.5 km north of K 4. It also consists of a mixture of greenstone pebbles, commonly porphyritic, and lighter coloured leptitic fragments. It appears to be some distance inside the greenstones of the Main Greenstone Group but may be genetically related to the other conglomerates of the Radnekvare-Lulepotten zone.

From the above it may be concluded that the conglomerates are local and do not persist for great distances along the strike. The material is illsorted, often angular and probably deposited rapidly in restricted basins. Most of the material is local in origin and there is a marked lack of debris foreign to the rock types prevailing in the area. No granite pebbles occur.

Conclusion

In the foregoing, an attempt has been made to identify and describe the various supracrustal formations. Emphasis has been placed on establishing the order of succession, their mutual relationships and general petrographic and chemical characters. It is evident that individual formations vary in thickness and to some extent interdigitate with each other. The succession established therefore has only local value and extrapolation to other areas is not recommended.

The greenstones are interpreted as extrusive lavas of basalt-andesite composition. Subdivision into individual beds is, however, impossible: 'slaggy tops', for example, may exist in the amygdaloidal portion (5 c) of the Main Greenstone Group but are difficult to recognize owing to the prevailing schistosity. Occasional wedging on a small scale has been seen (fig. 9). A remarkable feature is the great thickness and relative homogeneity of the Main Greenstone Group, particularly south of Gubblijaure. This may indicate approach to a major centre of volcanic activity which persisted for a significant period of time. Northwards the group is more variegated and some of the schistose greenstones may be sediments. The intercalation of leptitic rocks has already been noted.

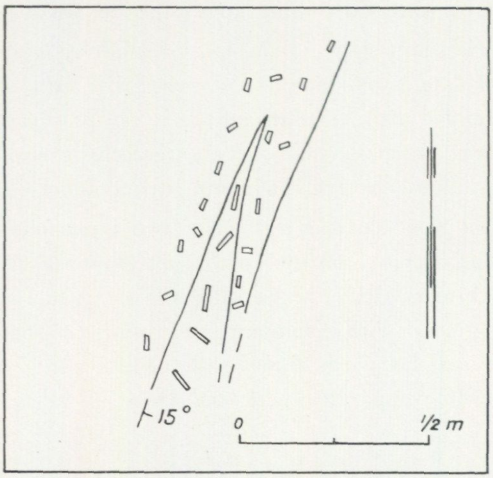

Fig. 9. Narrow wedge of porphyritic andesite with long plagioclase laths (2—3 cm long). Exposure 2.2 km SE of Ballek. Length of wedge about 0.4 m. From field sketch.

The primary nature of the acidic rocks is often difficult to establish. Thus those in the east part of the area — the Nimtekjaure and Laddok Leptites are definitely layered formations but with only an occasional conglomerate. Chemical sediments are almost totally lacking. The texture is crystalloblastic and sure proof of a clastic origin is difficult to find. However, in mineral and chemical composition they most closely correspond to arkose or volcanic arenite. As such they are comparable, for example, with members of the Tuffite Formation in the Ledfat area, Västerbotten (Offerberg, 1959). The precise status and significance of the leptitic rocks is, of course, an old problem in both Sweden and Finland. (For recent views see Simonen, 1960 and Edelman, 1960). Nor is the Radnejaure area with its relatively sparse exposures the place to settle the matter definitely one way or the other. For the purpose of the present paper it is important to realize that the leptitic rocks occur as formational units and help to delineate the major structural features of the area.

Acid intrusives, represented by the porphyries, are only known to exist as part of the Radnekvare Group. These rocks increase in thickness to the SSW outside the map area and it is possible that a centre of acid volcanism existed in that direction. The Group also contains recognizable clastic sediments such as arkosic quartzites in which the grains have close affinities with the acidic volcanics. Chemical sedimentation is limited to the carbonate cement in calciferous sandstones and to one thin (1 m) horizon of limestone. Conglomerates are more numerous, the material being both acidic (sometimes recognizably volcanic), and basic including porphyritic greenstones. There is thus close petrographic affinity with the volcanic rocks and the provenance of the clastic material is local. Normal orthoquartzites, shales and ironstones are absent. This is taken to indicate limited chemical and mechanical differentiation, the sediments probably accumulating in depressions in a predominantly volcanic terrain.

Gabbroic rocks

Intrusive rocks of gabbroic composition occur at several places in the area. For descriptive purposes they may be divided into two groups one fine to medium grained with a uralitic appearance in hand specimens; the other a more normal gabbroic type with a grain size and texture characteristic of metagabbros. The largest and most conspicuous body belonging to the first group occurs on the NE-facing slope of Stora and Lilla Soggovare and extends NNW to Ballek. An apparently identical body occurs to the south of Gubblijaure and is possibly connected with the Soggovare body in the manner shown on the map of the area. In the field both bodies are massive and homogeneous and the rock is studded with hornblende individuals 1—3 mm in diameter giving it a uralitic appearance. In thin section, laths of andesinic plagioclase, slightly saussuritized, are ophitically or subophitically arranged. Hornblende occupies the interstices and commonly has darker, more pleochroic rims. It is invariably anhedral and no eightsided individuals or pyroxene relics have been observed. Other minerals present in small quantities include quartz, epidote-clinozoisite, titanite and opaque minerals such as magnetite and hematite. In some sections the hornblende seems to have grown porphyroblastically at the expense of the plagioclase laths. It is therefore to some extent secon-

TABLE 4. *Analysis of uralite-type gabbro from the Radnejaure area*

		wt %	cation %			
SiO_2		48.42	46.11			
TiO_2		0.80	0.57			
Al_2O_3		14.96	16.74	Or	6.55	55.70
Fe_2O_3		6.24	4.46	Ab	17.45	
FeO		4.68	3.71	An	29.85	
MnO		0.23	0.17	Q	1.85	
MgO		8.34	11.94			
CaO		11.02	11.25	Mt	6.69	44.28
Na_2O		1.88	3.49	Ilm	1.14	
K_2O		1.10	1.31	Wo	9.80	
P_2O_5		0.25	0.23	En	23.88	
H_2O	> 110°C	1.70		Fs	2.16	
H_2O	< 110°C	0.12		Ap	0.61	
F		0.09				
CO_2		0.12				
S		0.03				
		99.98	99.98			
-O for F, S		0.05				
		99.93				
al		19.9				
fm		47.8				
c		26.5				
alk		5.8				
si		109.2				
k		0.30				
mg		0.59				
ti		1.4				
p		0.3				
qz		—14.0				

Uralite-type gabbro, exposure 700 m SE Stora Soggovare summit. Sample no. 27/761. Analyst: A. Aaremäe. Analysis no. 2968.

dary and the rock is called meta-gabbro. A chemical analysis was carried out on a representative sample taken from an exposure on Stora Soggovare. It has a typical basic composition (Table 4) except perhaps for the presence of a little normative quartz.

No attempt has been made to carry out a systematic petrographic study of the gabbro but a few field observations are of interest. Thus the southwest boundary of the Soggovare body with the andesitic basalts is sharp and fairly accurately mapped due to the presence of numerous exposures. At one place on Stora Soggovare the adjacent rock is a porphyritic andesite which appears to be much harder than normal. This may be a baking effect of the gabbro. The east and NE boundary is poorly known due to lack of exposures. A curious wedge or apophysis pointing northwards occurs, however, close to the stream about 1.2 km NE of Stora Soggovare. It seems to be partly involved in folding of the beds which is known to be present in this region. The actual contact of this wedge with the andesitic basalts is not seen but can be drawn with a fair degree of accuracy. Towards the east it seems to be discordant. The gabbro, though massive in its typical development is clearly schistose along its margins. This is particularly well seen south of Gubblijaure. The regional metamorphism probably post-dated its intrusion. Blocks close to one of the small 'satellite' bodies SW of Stora Soggovare show quartz and chalcopyrite veining in connection with shearing of the rock.

The second group is represented by several relatively small bodies with a gabbroic appearance. These are almost invariably somewhat altered due to regional metamorphism and no primary pyroxene is known to exist, its place being taken by secondary hornblende. North of Ballek two elongate bodies are known to occur from exposures and from magnetic surveys carried out in the area. Blocks in the neighbourhood show them to be affected by the enclosing granite which is obviously of later age. About 600 m north of the lake Nuostajaurats a small elongate body occurs. In the S. Kåivåive area an elongate body, much tectonized, forms a distinct ridge in the topography. A narrow body is found on the west side of the prominent peninsula which juts out into the lake Tjålmak. It is cut and partly altered by pegmatite veins. A few other bodies are postulated from the concentration of gabbro blocks in scree.

From the above it is clear that all the gabbros seem to pre-date regional metamorphism and granite-pegmatite activity. They are associated with the more basic rocks and are also commonly aligned concordant with the strike of the latter.

Structure

Several features of structural interest have emerged from the present investigations. These include observations on minor-folding, lineation and schistosity in individual exposures. Mapping and a judicious use of geophysical data have enabled larger folds to be deduced, in particular the Jäknatjavelk anticline and Ballek syncline. A photogeological study revealed the presence of marked jointing in some parts of the area. Several important faults have been detected by electrical methods, in particular the Svannvik-Plättik system. These features are considered in more detail below.

Jäknatjavelk anticline

The eastern part of the area is dominated by an anticline, the Jäknatjavelk anticline (Plate 2), named after prominent high ground with this name to the SE of Gubblijaure. As may be seen from the map the main fold axis plunges SW at angles varying from 25 to 30 degrees. Exposures are, however, rare in this direction and no detailed mapping of the fold is possible. The evidence suggests, that gneissification of the leptitic and greenstone formations of the hinge zone is extensive. Towards the north-east, in the direction of the core of the fold, gneissification becomes more and more significant and the fold less symmetrical. A steeper westerly limb becomes apparent and this may be overturned to the north-west in the area ESE of the eastern end of Gubblijaure. Exposures are more frequent here and measurements of lineation and minor folding confirm the plunge of the main structure. The associated *ac* and *bc* joints are normally well developed and often have topographic expression. For this reason they are readily detected by photogeological methods of interpretation. Typical profiles across the anticline are shown in Plate 2.

A further feature of interest is the folded character of part of the Nimtekjaure Leptite on the SE flank of the anticline. In the field two parallel zones of leptite trending ENE are known to occur. These have been connected in the form of a drag-fold plunging WSW parallel with the main axis of the main anticline. This seems a reasonable construction to make on general structural grounds and in the absence of evidence (exposures, geophysical data) to the contrary. Greenstones are also involved in this structure and these are strongly schistose (?axial plane schistosity) and have well developed lineation. Mineralization is also known to occur in the WSW continuation of the axial plane. The only other explanation is that two distinct leptite zones exist.

Ballek Syncline

This is the name given to a major fold in the west part of the area essentially complementary to the Jäknatjavelk anticline described above. Its general form is indicated by the rocks of the Radnekvare Group which have a NNE trend, widening out to the SSW in the direction of regional plunge. The rocks of this zone therefore occupy the core of a fold whose axis, when projected NNE passes through the hill Ballek, hence the name. Details of the folding are best seen on Sademåive where the contact between acid rocks of the Radnekvare Group and more basic rocks of the Main Greenstone Group is known in some detail from exposures and geophysical surveying. The fold is obviously a complicated one and can only be explained by postulating the existence of several lesser folds on the main structure (See map of area and profile, Pl. 1). The anticlines thus represent local reversals of curvature, a not uncommon phenomena in folded beds (cf Turner and Verhoogen, 1960, fig. 113b). Within the Radnekvare Group no distinctive marker horizons can be mapped in sufficient detail to confirm the nature of the folding but the connection shown on the map between conglomerates K 1 and K 3 is relevant in this respect. Volcanic rocks such as the porphyries are restricted to the SSW and therefore lie higher up in the succession. Dips are vertical or westerly except in one case, the conglomerate K 3, where it is probably to the east. This means that the westerly limb is inverted in the manner shown in the profile, Plate 1.

The synclinal structure is also emphasized by the strike of the andesitic basalts north of Gubblijaure. South of the lake they trend NNE but assume a progressively more NW direction northwards towards Ballek, i. e. in the direction of the fold axis. The latter probably passes through the hill Ballek in the extreme north of the area. The westerly limb of the syncline cannot, however, be followed out in detail owing to the presence of granite. Greenstones occurring in the granite are, however, interpreted as relict portions of the Main Greenstone Group.

East and north-east of Ballek minor-folding can be seen at several places. The fold style is conveniently displayed by a 1 m thick layer of leptite interlayered with andesitic basalts (figs. 10, 11). This example and other folds in the vicinity (figs. 12, 13) are interpreted as drag features on the main syncline, apparently congruent

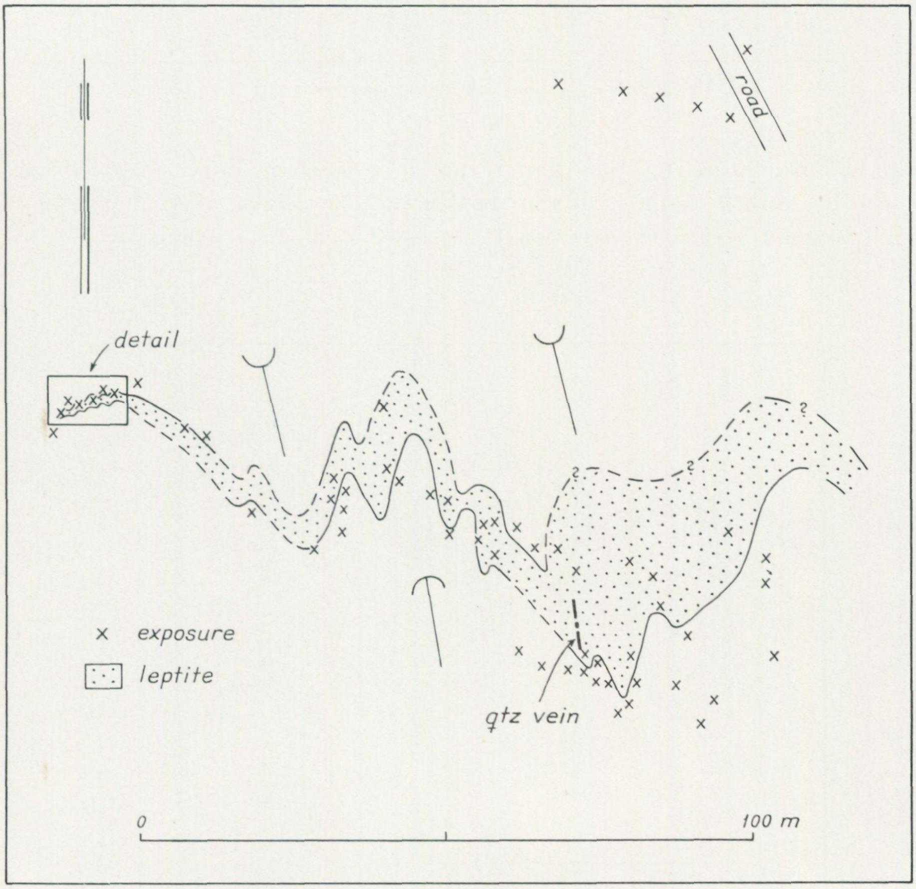

Fig. 10. Folded leptitic bed in greenstone (unornamented). Exposure 700 m NNE of the hill Ballek in the northwest part of the area.

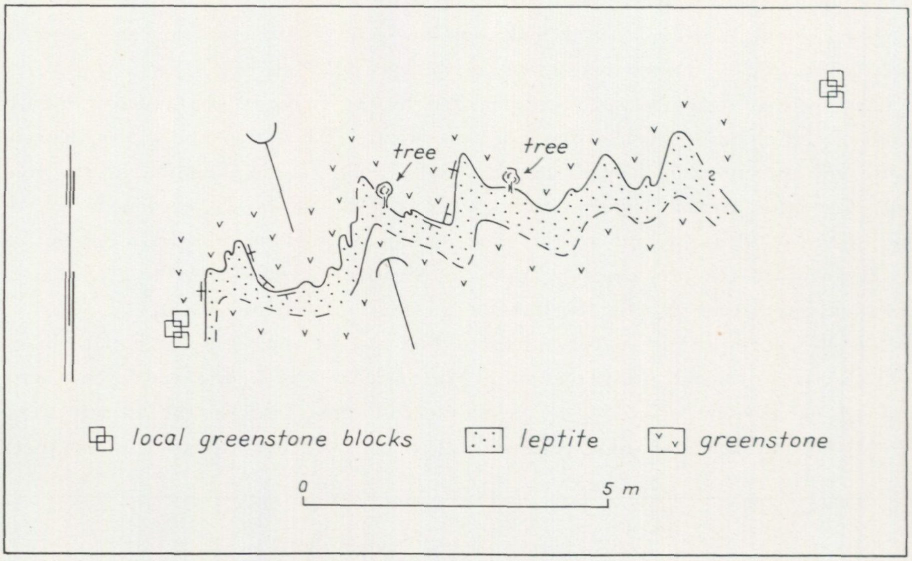

Fig. 11. Detailed drawing of leptite bed shown in fig. 10.

with the main structure. Their axes plunge in a southerly rather than SSW direction due perhaps to the local resistant effect of the massive, uralite-type gabbro. The lesser folds commonly have a well developed axial plane schistosity.

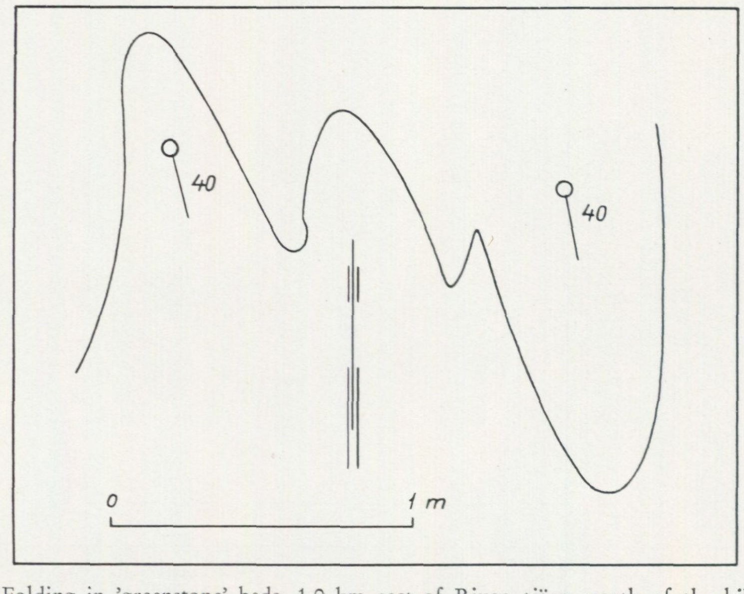

Fig. 12. Folding in 'greenstone' beds, 1.0 km east of Riugo tjärn, north of the hill Ballek.

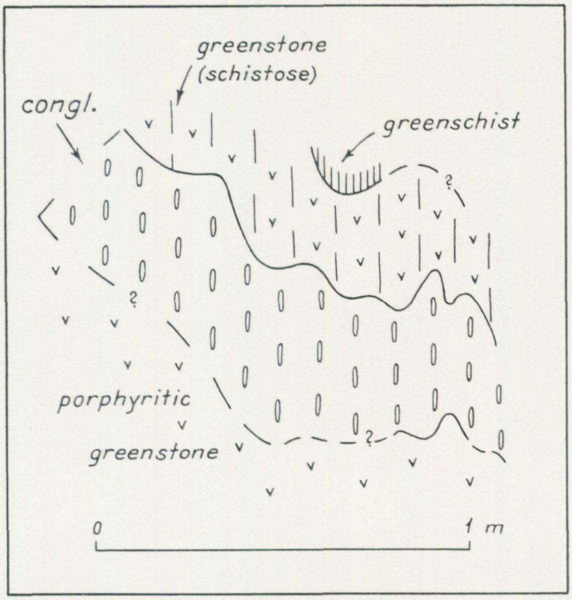

Fig. 13. Cross-section through folded beds, at right angles to the fold-axis. Note axial plane schistosity and elongation of pebbles in same plane. Exposure 700 m east of Riugo tjärn.

Strong schistosity affects many rocks involved in the Ballek syncline. This is particularly pronounced in the Sademåive-Lulepotten area where it may be merely a severe form of axial plane schistosity associated with the folding. However, there is also granulation, mylonitization and even local brecciation of the more brittle leptitic rocks suggesting rupture or shearing (fig. 14). This even affects some of the adjacent granite and granitic veins in the supracrustal formations and is therefore to some extent later than both the granite and folding (fig. 16). The zone most affected by these manifestations of mechanical movement is shown by a fault on the map of the area. (Plate 1).

The existence of this syncline was first postulated by Grip (1946, pp. 10—11) though he gave no name to it. He considered the acidic rocks to be stratigraphically younger than the basic ones from extensive studies in southern Norrbotten and hence the wedge-like form of the Radnekvare Group was most conveniently explained as a syncline (fig. 15 alternative 1). In the present investigations no *a priori* assumptions have been made regarding the stratigraphy and the existence of a syncline has been deduced from other evidence. It is therefore gratifying to be able to confirm Grip's interpretation. However, it is conceivable that the observed relationships of the acidic and basic rocks have another explanation.

Their interdigitation on Sademåive may be merely primary facies change and not due to folding (fig. 15 alternative 2). Certain andesitic basalts of, say, the

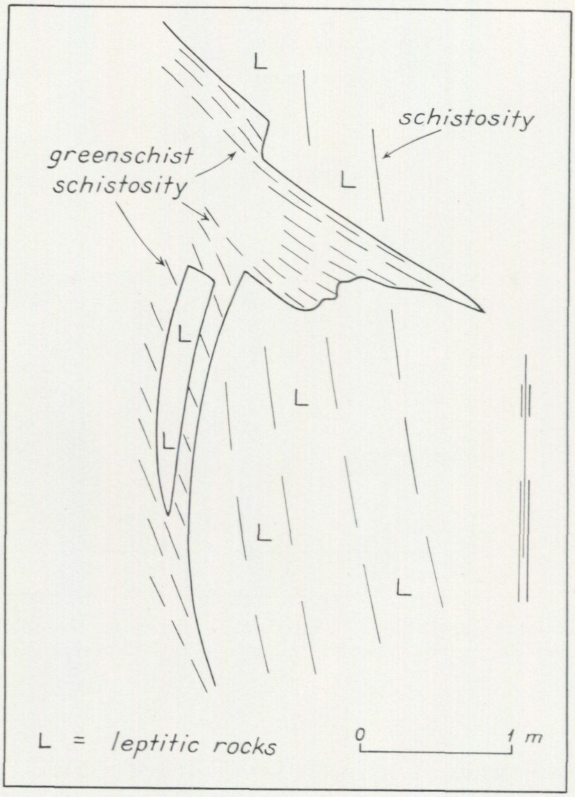

Fig. 14. Brecciation of leptite. Sademåive, 600 m north of the eastern end of Mockajaure.

Ballek area are therefore the time equivalents of certain acidic rocks (leptitic schists) to the SSW. The existence of both greenstone (andesitic basalt) and leptite fragments in the conglomerates (K 5) is perhaps more readily explained in this way. Furthermore, progressively younger beds occur to the west and the stratigraphic succession is hereby expanded with greenstones forming the youngest members. The beds, therefore, form part of the western limb of the Jäknatjavelk anticline. Such an explanation is attractive in many ways and was, in fact, used as a working hypothesis during a certain period of the investigations. But more extended work to the north, NE and W has convinced the author that a major syncline is the best explanation for the observed rock distribution and lesser structural elements. A critical feature is, of course, the postulated westerly, inverted limb of the Ballek syncline. There are, unfortunately, no exposures which enable the direction of younging of the beds of this limb to be determined. At the present stage of our knowledge, then, a synclinal structure seems to offer the best explanation of the observed facts.

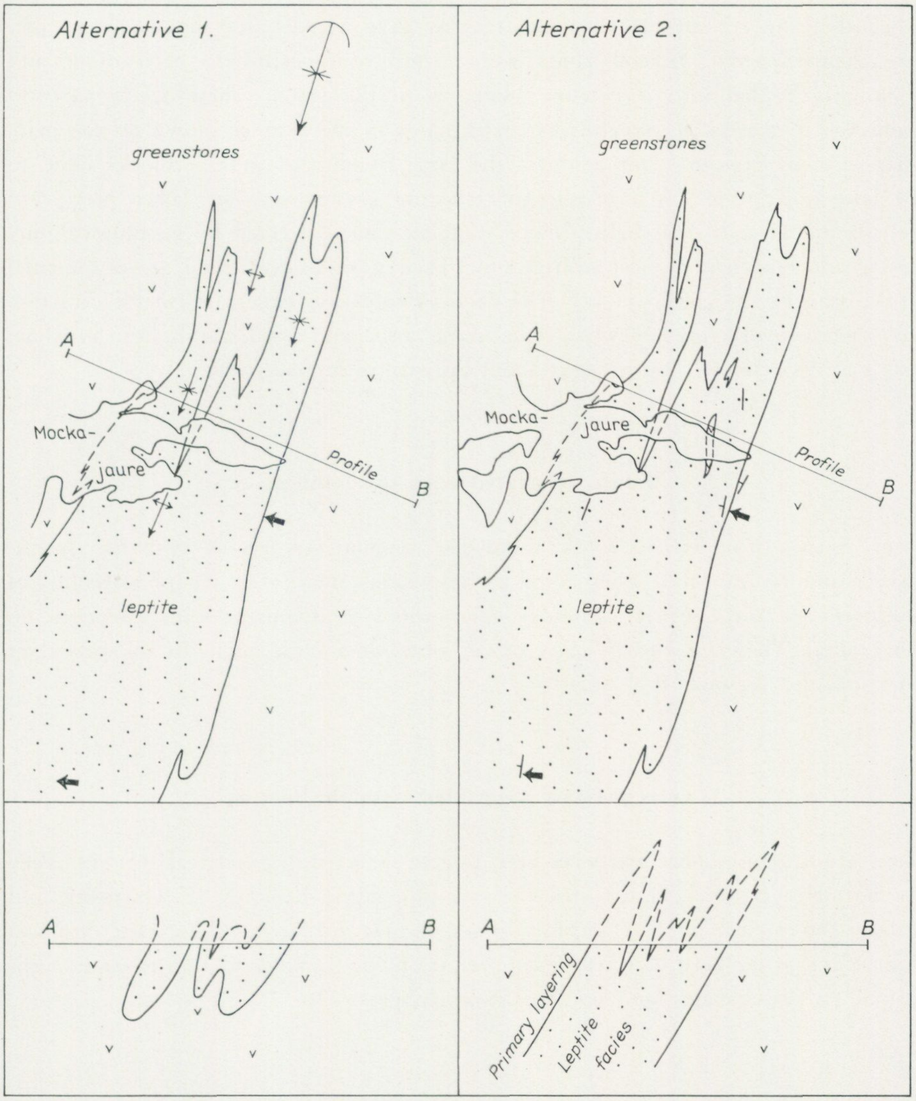

Fig. 15. Alternative explanations for the relation of the Radnekvare Acid Group (dotted) to the greenstones (v symbol). Alt. 1 structural interpretation. Alt. 2 stratigraphic interpretation (facies change). Arrows indicate direction of younging. Other symbols as on map of area (Pl. 1).

Brändudden folding

As pointed out above granite occupies much of the westerly limb of the Ballek syncline. A detailed magnetic survey of part of this granite in the Brändudden area, Lulepotten carried out for economic reasons gave a much less homogeneous picture than expected. Severel zones were found conformable to each other and apparently folded into a syncline plunging to the south. These are apparently connected to the Ballek Syncline by an anticline in the manner shown on the map. There are no exposures but amongst the large number of granite blocks close to the lake Lulepotten are a number of schistose greenstone. The latter may very well be the cause of the slightly more magnetic zones detected by geophysical surveying and represent a ghost stratigraphy. Their position and trend are represented on the map by the gneiss symbol. The deduced fold-axes have a northerly direction and therefore diverge somewhat from those associated with the Ballek Syncline. This may be a later effect brought about by granite emplacement.

Joints associated with the folding

Joints with a pronounced WNW trend are common features of both the Jäknatjavelk and Ballek folds. They form a conspicuous element of the photogeological interpretation and confirm numerous observations of dominant joint directions on the ground. They are clearly cross or *ac* joints at a high angle to the prevalent lineation and regional fold axes.

Faults possibly associated with the folding

These are few in number and have been largely detected by electrical surveys. They are normally parallel to the strike of the prevailing bedding or schistosity and drilling shows them to be essentially zones of brecciation. No significant displacements have so far been detected. Examples are to be found to the north and southeast of Lul. Radnejaure and north of Nimtekjaure.

Gubblijaure Joint Zone

A conspicuous zone of jointing crosses Gubblijaure in a NW-SE direction, oblique to the prevailing NNE strike of the rocks. It is best seen from the photogeological interpretation where distinct linears are discernible south of the lake in the direction of Tjålmak and Stora Laxsjön. The prominent valley occupied by Laxselet seems to be controlled by this tectonic zone as does the northerly embayment of Gubblijaure and the valley which continues north-west from it. Exposures SW of Stora Soggovare show clearly a NW joint trend intersecting the NNE strike of the rocks. There is no evidence for any significant displacement or brecciation as would typify a fault though minor movements may have taken place in some planes.

Svannvik-Plättik Fault System

This is located in the east part of the area and consists of several distinct faults. Their existence is known largely from geophysical surveying using electrical methods. A drill-hole put down north of Tjålmak to investigate one of the strong anomalies showed the rocks to be brecciated granite and pegmatite. Subsequently, brecciated blocks of pegmatite were found to the south close to the continuation of the anomaly in that direction. Otherwise there is very little to reveal the presence of this fault system except for a N-S linear immediately north of Svannvik. The faults are clearly later than all the rocks of the area, are probably water-filled and are possibly related to a tensional phase of tectonism.

Granites

These occur extensively in the west, east and south of the area. They probably occur to the north also but there are no exposures to confirm this. They thus enclose the supracrustals on all sides and probably underlie them at various depths. They form part of more extensive Pre-Cambrian granite terrains typical for northern Sweden. In the present paper their relationships to the supracrustals are of particular interest. Four separate granitic bodies are distinguishable within the limits of the map area and will be described in turn.

The first of these is located south and south-east of the village of Radnejaure and is obviously merely the northern part of a much more extensive granite area to the south.

The contacts with the supracrustals are very poorly exposed but can be traced with a fair degree of confidence with the help of a few exposures, some diamond drilling in the lake area and geophysical data. All indications are that the contacts are steeply inclined. Within the granite proper a few narrow zones of greenstone occur (drill-core information).

The granite is macroscopically light-coloured or reddish with a slightly gneissose texture at some places. Granophyric texture has also been observed while narrow aplite veins are common. Close to the supracrustals a fine-grained marginal zone is evident. In thin section the main minerals are quartz, microcline and plagioclase of low oligoclase composition. A greenish biotite, partly altered to chlorite, is common together with a little muscovite, titanite, fluorspar and carbonate. Micrographic intergrowth is widespread and the partial alteration of the feldspars fairly general. In some sections bending of twin lamellae, and quartz and fluorspar-carbonate veining have been observed. The quartz is normally undulose.

A chemical analysis (Table 5) was carried out on a 2 m long section of homogeneous granite in a drill-core. The material was considered particularly fresh and representative for the granite. It closely resembles an analysis of Arvidsjaur granite published by Grip (1946, p. 13) with which it was equated by Ödman on his map of the county of Norrbotten (1957).

A second area of granite is located in the west and north-west of the area. South of Lulepotten it is very poorly exposed indeed and reliance has had to be placed on the study of blocks, many of which appear to be local. In the north, however, the granite forms a distinct range of hills, one summit of which is called Pesets, hence the name. Here exposures are much better and permit study of the granite in greater detail. On Pesets itself and nearby hills the granite is massive and fairly homogeneous. It commonly contains a blue quartz which serves to distinguish it from other granites of the area. In this respect it resembles the acidic lavas of the Radnekvare region. There is also evidence of a later tectonization marked by jointing, slickensiding and quartz-veining. A broad zone adjacent to the main supracrustal fragment to the east and south is characterized by the occurrence of long rafts of greenstone, gabbro and leptite (see map of area). Exposures here are fewer, the zone coinciding with the easterly flanks of the hills, and interpretation of the geophysical maps is more difficult. However, it seems that gneissic rocks are also present in this zone, a good example being a 200—250 m broad belt of biotitic gneiss on the west side of Sademåive (see also under 'Metasomatism').

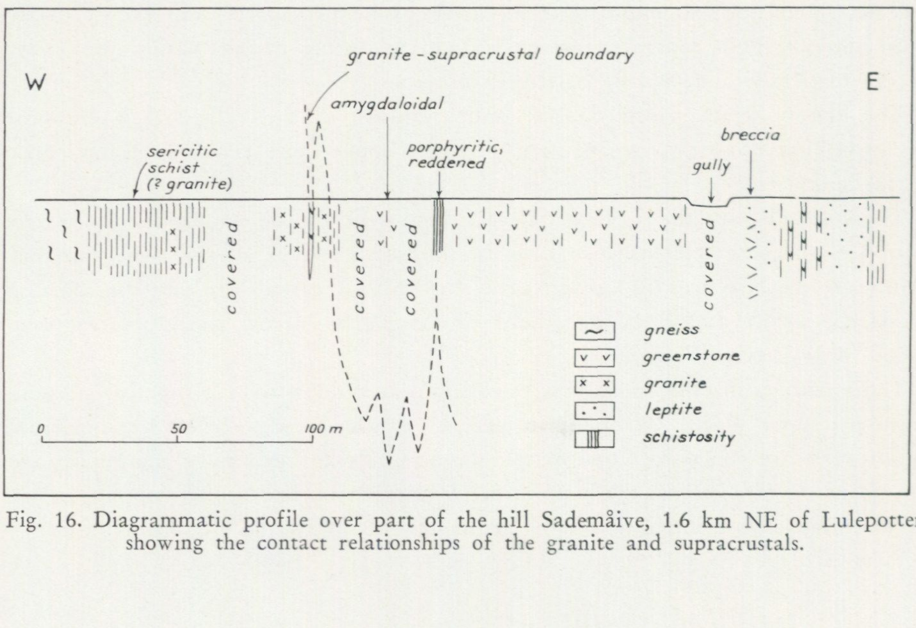

Fig. 16. Diagrammatic profile over part of the hill Sademåive, 1.6 km NE of Lulepotten showing the contact relationships of the granite and supracrustals.

Slightly more magnetic zones are known from geophysical surveying over Lulepotten and these represent a 'ghost' stratigraphy. Normally, however, the granite maintains its grainsize right up to the main supracrustal boundary except for a narrow marginal zone which is somewhat fine-grained. Contacts are usually fairly sharp and steeply inclined as may be seen on Sademåive (fig. 16). Here granitic veins cut greenstone and leptite proving the later age of the granite. No pegmatite veins occur either in the granite or the supracrustals.

TABLE 5. *Analyses of granite from the Radnejaure area*

Anal. no.	2966	2965
	wt %	wt %
SiO_2	73.34	72.98
TiO_2	0.21	0.21
Al_2O_3	13.43	13.50
Fe_2O_3	1.04	1.03
FeO	1.43	1.86
MnO	0.05	0.05
MgO	0.23	0.18
CaO	0.72	0.90
Na_2O	3.75	3.48
K_2O	4.61	4.62
P_2O_5	0.02	0.02
H_2O >110°C	0.73	0.62
H_2O <110°C	0.08	0.08
F	0.15	0.06
CO_2	0.16	0.56
S	0.03	0.01
	99.98	100.16
—O for F, S	0.07	0.02
	99.91	100.14
al	44.7	44.4
fm	13.7	14.8
c	4.1	5.4
alk	37.5	35.4
si	416.7	409.0
k	0.45	0.47
mg	0.15	0.09
qz	+166.7	+167.4

No. 2966 analysis of granite, drillcore (60212) north side of Lulepotten 3 km east of Stensund.
No. 2965 analysis of granite, drillcore (59001), east end of Lul. Radnejaure.
Analyst: A. Aaremäe, Geological Survey, Stockholm.

In thin section the most common minerals are quartz, microcline microperthite with both vein and patch perthites in evidence, titanite and biotite. A little carbonate and fluorite are often present. Secondary muscovite is seen in some sections. Myrmekitic and granophyric textures are common. A chemical analysis (no. 2966, Table 5) carried out on fresh, representative material from a drill-core in the Lulepotten area showed a close resemblance to the Radnejaure granite with abundant potash and low line content.

Granites and granitic gneisses are widespread in the eastern part of the area. Around Svannvik and Jäknatjavelk they form a broad wedge pointing roughly south-west and coincident with the core zone of the Jäknatjavelk anticline and its westerly limb. They probably dip westwards under the Main Greenstone Group and southeastwards under both leptites and greenstones. Three main components can be distinguished: massive granite, partly in the form of thick sheets conformable to the foliation (Jäknatjavelk) and partly filling the apical portion of the Jäknatjavelk anticline (due east of Stora Laxsjön), gneissose granites with darker biotitic and hornblendic lamellae, and finally altered greenstones and leptites which are sometimes mappable units and which help define the fold structure. This heterogeneity apparently disappears northwards in the direction of Tjäutjanåive and Östra Ribbraur where massive granites occur. In the extreme east of the map area massive granites also form hilly ground (Lehatt).

Transitions to supracrustal rocks are common and make mapping very difficult and subjective. Granitization seems to have played a major part but has obviously not gone to completion judging from the number and size of the supracrustal fragments. The anticline has most probably helped to localise the granitization in the first place but thermal effects probably outlived the regional deformation. This is shown by the random orientation of certain hornblende needles in schistose greenstones within the greenstone area. The needles intersect the schistosity and therefore post-date it. The westerly margin of the granite area is somewhat sinuous between lakes Stora Laxsjön and Tjålmak and may be interpreted as indicating plasticity following slight mobilisation of the granitic rocks to the east. This may also be the reason for the westerly rather than southwesterly direction of lineations around the western part of Stora Laxsjön.

Thin sections of the granitic rocks show an abundance of quartz and microcline and a plagioclase of low oligoclasic composition. Smaller amounts of biotite, titanite, epidote, apatite and muscovite are also common. Garnet was seen in one granite 'sill' on Jäknatjavelk.

Pegmatites are very common and show maximum frequency in the Tjålmak and Jäknatjavelk areas. In the former they occur as thick, steeply inclined zones commonly grading into granite. Their probable form and orientation are shown on the map of the area. They coincide with the sinuosity in strike mentioned above and the other rocks of the vicinity are highly schistose. Granite proper occurs a short distance to the east and is itself cut by pegmatite veins (drill-hole east of Tjålmak).

Their mineralogy is normal consisting mainly of quartz, and potash feldspar. To the north (Björkberget), the pegmatites trend N-S and are discordant to the schistosity and foliation.

Over the highest part of Jäknatjavelk occurs a large number of closely spaced pegmatites. These and others in the same general area have a marked ESE trend discordant to the local strike for the most part. The trend, however, is similar to the pronounced *ac* joint direction mentioned under 'Structure' and intrusion may have been controlled by this structural direction. Numerous thinner pegmatites are also present and clearly follow structural planes associated with minor folds. Thus vertical pegmatites are found in the *bc* and *ac* planes as well as concordant with the schistosity. Boudinage effects are common. It is perhaps significant that in the areas of greatest pegmatite frequency massive granitic bodies with vein-like or sill-like forms occur. It seems likely from the mapping that the latter pass into pegmatites though the actual transition has not been observed. With greater distance into massive granite pegmatites become less numerous and finally disappear altogether. Westwards, pegmatites become progressively thinner and less numerous. The westerly limit of pegmatite injection is shown on the map of the area.

Granite occurs widely in the south-east of the area between Tjäurevare and Nimtekvare. Good exposures exist on the higher ground where it is evident that greenstones, gabbros and leptites occur as relicts in the granite (fig. 17). All show constant dips to the south-east and probably form part of the SE limb of the Jäknatjavelk anticline described under 'Structure'. Nor does any significant rotation of the relicts seem to have taken place. The granite in between appears massive for the most part and contacts with the Nimtekjaure Greenstone formation are fairly sharp with perhaps only a narrow migmatite zone (blocks on the SE side of Nimtekjaure). The adjacent greenstones are distinctly magnetic compared with the granite and enable the contact to be drawn with fair accuracy.

On Tjäurevare the granite is pegmatitic and occurs as steep, almost veinlike bodies in the leptites. Continuing along the strike to the north a zone of intense pegmatite injection is encountered. Alteration of both leptites and greenstones is very intense. The zone of pegmatitic injection, however, is sharply defined towards the west, the one and only exception being a gently dipping body 0.5 km east of Lul. Radnejaure. It is of mineralogical interest on account of the presence of a few beryl crystals.

A few thin sections of the granite show the essential minerals to be quartz, microcline, plagioclase (An_{5-12}), and a dark reddish brown variety of biotite (?lepidomelane). Small amounts of apatite, hornblende, epidote, iron ore and muscovite are present in most sections. Though no chemical analyses are available the granite is clearly potassium-rich. A characteristic type is one with the biotite aggregated into dark spots. It commonly occurs in the strike continuation of greenstones and superficially resembles a hornblende granite. Hornblende, however, is virtually absent.

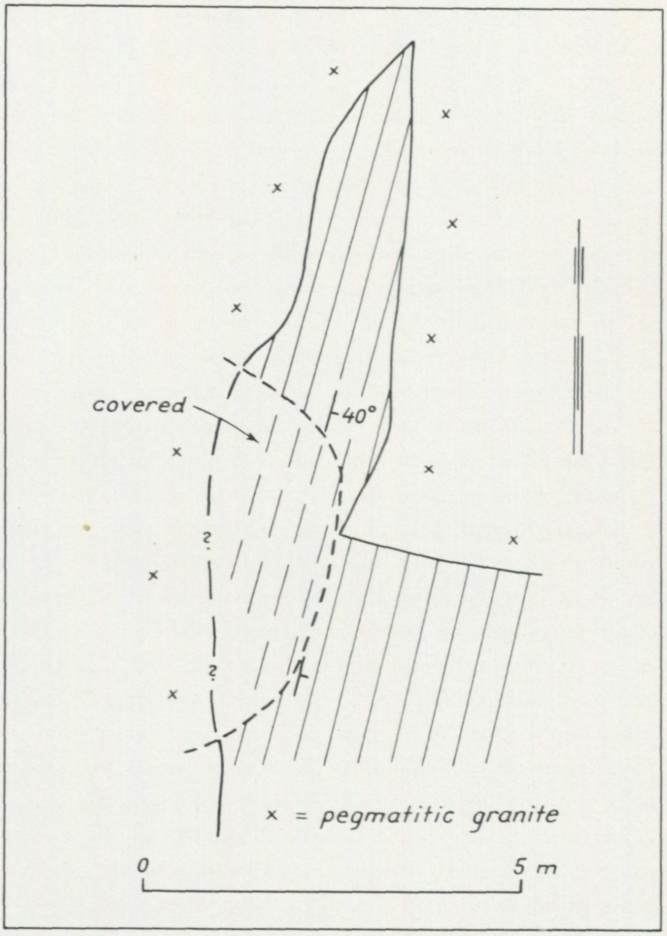

Fig. 17. Schistose greenstone relic (unrotated) in pegmatitic granite approximately 600 m west of the summit of Nimtekvare S.

Conclusions

The granites described above are separated on a geographical basis. Contacts between them are not seen in the area of investigation and therefore their age relationships are unknown. No radiometric age determinations have been carried out.

Each granite is obviously only a small part of an even larger mass extending beyond the limits of the map area. It may therefore be atypical as regards texture, mineralogy and composition.

The granites may be further grouped according to whether they have pegmatites associated with them or not. Thus those in the vicinity of Radnejaure and Pesets are pegmatite-free, often show a granophyric texture, have bluish quartz crystals and contain small amounts of fluorspar. Those in the eastern part of the area, on the other hand, have associated pegmatite swarms which merge to form a broad zone of pegmatite injection. This zone is clearly conformable with the granites and may be expected to extend downwards in the manner shown in the profile (Plate 1). The granite itself commonly has coarse-grained patches which resemble pegmatite. It is also noteworthy that the supracrustal formations are very heavily altered as a rule and granitization effects, e. g. addition of silica and potash, are widespread. The biotite-spotted granite is a common type in this group.

Differences obviously exist between all four granites but this seems mainly to concern texture and grain-size. The bulk chemical compositions and mineral associations are rather similar.

All the granites are clearly younger than the supracrustal rocks and are either contemporaneous with deformation or were emplaced at a late stage of it (late kinematic). The relation to the folding is well seen in the Jäknatjavelk area. Here cases are known where the schistosity is weakened by the growth of new minerals with random orientation, thus demonstrating the later thermal effects of the granite. This mineralogy, with abundant microcline, is also typical for late-kinematic granites (Marmo, 1962). In the case of the granite present in the hill Pesets there is evident discordance between the granite and the Ballek syncline to the east. This may be explained by granite intrusion or a slight upward diapiric movement of the granite as a whole after emplacement. Later, post-granitic movements (faulting) along the contact zone may have further emphasized the discordance in this case.

The evidence thus indicates that all the granites are similarly related to the regional deformation in time. The problem remaining is to account for the presence of a pegmatite phase in connection with some granites and not with others. One can, of course, argue that the granites belong to two different orogenic cycles. Ödman (1957, p. 82) related pegmatites to the late Karelian migmatites but there is little evidence to support this in the present area of investigation. Alternatively the attitude of the granite to the supracrustals may be of significance. Thus where it dips under the latter the accumulation of a pegmatitic phase is to be expected. An anticlinal structure would be even more favourable and may help to explain the high frequency of pegmatites on and around Jäknatjavelk (the Jäknatjavelk anticline). Finally, the composition of the layered formations before granitization may be significant. Potassic, hydrous rocks such as pelitic schists are especially important in this respect but certain proof of their existence is difficult to obtain for the area under consideration.

The occurrence of fluorine

Of possible geochemical and geological interest is the occurrence of fluorine as fluorspar in a variety of rocks of the area. The mineral is normally purple in colour but greenish and colourless varietes have also been noted. It is invariably in small amounts occurring as separate crystals together with quartz and a little hematite in much flattened lenses in the fine-grained lavas and tuffs of the Radnekvare Group. It is also common in the granite at Pesets, particularly the granophyric border zone, where it occurs as small individuals. These are commonly more numerous in thin section and analysis of a representative granite sample gave 0.15 % F (Table 5, analysis 2966). Purple varieties have also been noted as vein-fillings in jointed leptite close to the easterly contact of the granite. An inclusion of greenstone in granite on the hill Tjuorre has more conspicuous fluorspar veining, in this case a distinctive green variety. It is found in association with quartz and chalcopyrite (fig. 18). There seems little doubt that the fluorspar occurrences noted in the supracrustals are related to the granite.

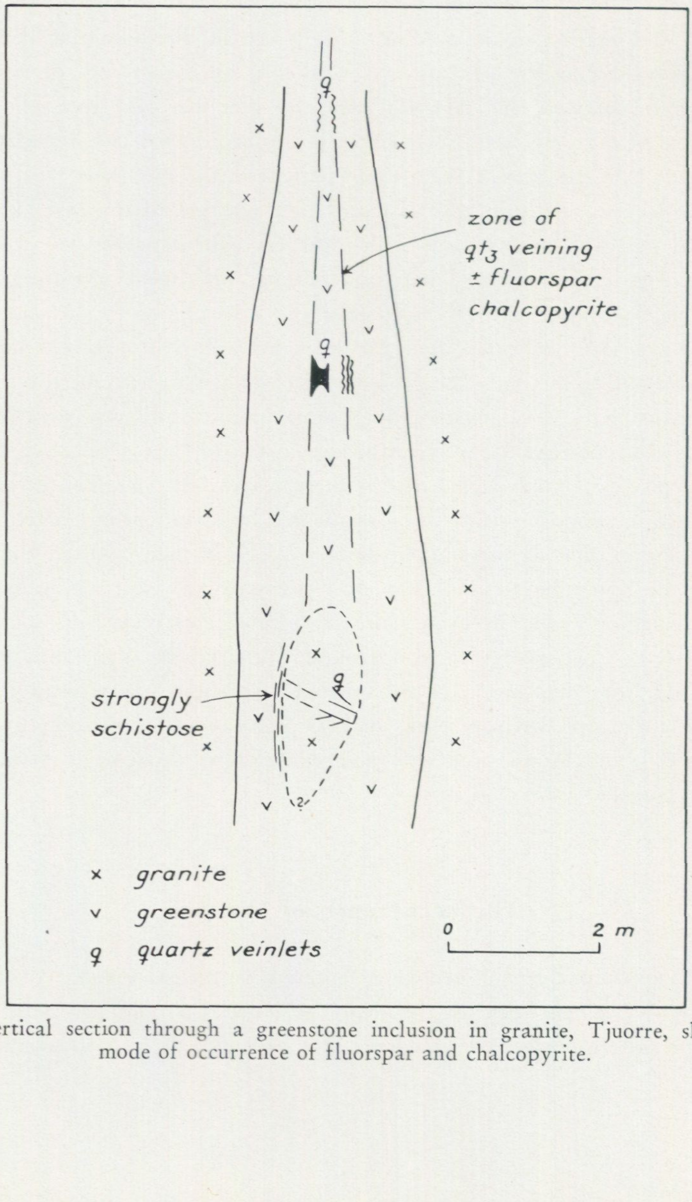

Fig. 18. Vertical section through a greenstone inclusion in granite, Tjuorre, showing the mode of occurrence of fluorspar and chalcopyrite.

The granite at Radnejaure is best known from drilling in the east part of Lul. Radnejaure. Here, small amounts of purple coloured fluorspar are commonly visible in association with quartz veins and a bulk analysis of the rock gave 0.06 % F (Table 5, analysis 2965). It was also seen to occur in the granophyric marginal zone of this granite (loose blocks only).

Elsewhere in the area purple fluorspar has been observed as thin veinlets in pegmatites (Stora Laxsjön-Tjålmak). It is not, however, present in the pegmatite-granites as far as is known.

Metamorphism

It is evident from the geological map of Norrbotten (Ödman, 1957) that the supracrustals of the Radnejaure area are surrounded by wide areas of granite and are in fact relict fragments of a once more extensive cover. Under such conditions it is not surprising that they show extensive metamorphic affects. In the present paper the following aspects are considered: —

1. Regional metamorphism
2. Metamorphic differentiation
3. Dislocation metamorphism

1. Regional metamorphism

This may be most conveniently studied from the mineral associations of different rocks of the area. Thus the widespread basaltic andesites are represented by the association *plagioclase-hornblende-epidote.* This is found in all thin sections of rocks of the Main Greenstone Group where deformation is at a minimum and pegmatites are absent. The primary porphyritic plagioclase has almost invariably undergone some alteration along cracks with the formation of clinozoisit-epidote, quartz, biotite and hornblende. In more extreme cases little remains of the primary mineral though its presence can be readily detected on weathered surfaces. The minerals of the matrix are entirely metamorphic and include quartz, hornblende, clinozoisite, biotite and opaque minerals such as magnetite and hematite. The biotite and hornblende may have a certain parallel orientation and the latter is distinctly poikiloblastic. Plagioclase, when present, has a low andesinic composition and its coexistence with epidotic minerals and hornblende is very characteristic for the Almandine-Amphibolite facies, staurolite-quartz sub-facies (Fyfe, Turner, Verhoogen, 1958, p. 229). No pyroxene has been observed. Using the plagioclase composition as a measure of the metamorphic facies (e. g. Ramberg 1952, p. 150) the rocks clearly belong to the lower part of the amphibolite facies. The fact that the compositions of the primary and metamorphic plagioclases are similar must be considered coincidental.

The acidic formations, represented by the quartzo-feldspathic leptites, show the mineral association *quartz-plagioclase-muscovite-biotite-epidote*. This association is also typical for rocks in amphibolitic facies.

Three other associations of more limited distribution are of interest. These include *almandine-biotite-quartz* seen in numerous local blocks in a zone between Stora Laxsjön and Tjålmak in the east part of the area. These probably denote pelitic or semi-pelitic sediments.

About 1.4 km NE of Nimtekjaure numerous blocks of local origin occur on a scree-covered slope. In some of these the association *tremolite-garnet* is found. It should be added that the area in question is one where sharp folding on ENE-WSW axes is suspected (see map of area).

Numerous large, local blocks and a block train south-west of Stora Laxsjön contain the distinctive assemblage *anthophyllite-cummingtonite-cordierite-garnet*. The cordierite is filled with inclusions and partially altered along grain boundaries to chlorite and sericite. Garnet of almandine type is found, often associated with magnetite grains. A little quartz and biotite are present together with a weak impregnation of ore minerals including chalcopyrite, pyrrhotite, pyrite, magnetite and hematite. Cummingtonite is normally subordinate to anthopyllite. This assemblage is magnesian and has an excess of iron judging from the presence of almandine and magnetite. Eskola (1914) include it in his Amphibolite facies. More recently Fyfe, Turner and Verhoogen (op. cit. p. 514) have assigned it to their Hornblende-Hornfels facies of contact metamorphism, roughly equivalent to the Almandine-Amphibolite facies of regional metamorphism. The rocks occur in a gneissic, semi-granitic environment, but may originally have been schistose greenstones.

Reviewing the evidence of these associations it seems justifiable to refer the metamorphism to Eskola's Amphibolite facies. There is no evident facies zoning due perhaps to the unsuitable nature of the primary rocks. Aluminous and calcareous types which might allow refinements of this sort are almost entirely absent.

2. Metamorphic differentiation

This includes the development of contrasted mineral assemblages from more uniform parent material by processes of metamorphism (Turner and Verhoogen, 1960, p. 581). Several examples are known from the Radnejaure area, particularly where the supracrustal rocks approach granite. Thus, in a drill-hole sited 2.3 km east of the hill Björkberget and 1.5 km south of Gubblijaure massive andesitic basalts of the Main Greenstone Group are strongly foliated and have an amphibolitic appearance with hornblende, plagioclase, quartz and titanite as the main minerals. These pass into rocks consisting largely of parallel orientated hornblende, biotite and lenses or pods of quartz and feldspar. The biotite is probably an indication of incipient potash metasomatism, but otherwise the tendency is for dark and light bands to develop.

Exposures in the greenstone area proper between the above mentioned drill-hole and Björkberget commonly display quartz-epidote veins and more irregular bodies lying both concordant and discordant to the foliation. These are considered to represent a 'sweating out' of certain elements from the host rocks under the influence of thermal metamorphism related to the emplacement of the granite at Svannvik. They represent very local migrations of material. Zoned veinlets with a dark central portion and lighter coloured margins are also common in this thermal aureole and resemble those described by Lundqvist (1962, fig. 17, p. 27). Similar effects are seen in exposures on the south-facing slopes of S. Kåivåive and are fairly general throughout the whole zone of pegmatite injection. (See map of area, Pl. 1).

In exposures SW of Stora Soggovare a remarkable segregation of dark and light minerals has taken place in apparently homogeneous andesitic basalts. Hornblende, magnetite and sulphide minerals such as chalcopyrite and pyrite have accumulated in irregular veins a few mms to 2 cm in width. The matrix is light coloured and consists of epidote-clinozoisite, quartz, titanite and plagioclase. The cause of this differentiation is probably thermal but the irregular vein-like form may have been determined by a pre-existing joint system. Further examples are the magnetic zones which occur in greenstone formations close to granite contacts.

In the acid rocks mineral differentiation is less common but has been observed in an exposure 1 km SW of the lake Plättik in the extreme south of the map area. Here small bodies a few centimetres across consisting of epidote, garnet and coarse-grained quartz occur in a rock of subacidic composition. They are surrounded by light-coloured marginal zones which seem to have been leached of iron. The bodies are explained as segregation products in a granitization milieu. It was impossible to trace any particular elongation or parallel orientation of the bodies concerned.

Finally, mention may be made of the cordierite-anthophyllite rocks reported from blocks SW of Stora Laxsjön. These are rich in Fe and Mg and it is possible that a corresponding depletion in these elements is found in nearby rocks. This cannot be acertained at the moment without exposures but if it does occur may be looked upon as a type of metamorphic differentiation.

3. Dislocation metamorphism

In the west part of the area the rocks of the main supracrustal fragment have very strong schistosity. The planes are steeply inclined, trend N to NNE, and show abundant evidence of secondarily developed platy minerals arranged parallel to each other. In acidic rocks sericite is very conspicuous, in the more basic rocks biotite. These effects may, however, be merely related to the sharp folding postulated for the area, particularly between Lulepotten and Sademåive. The marked schistosity (fig. 16) is then to be interpreted as axial plane schistosity. But there is evidence of mechanical granulation (of granitic rocks in the contact zone), brecciation of acidic rocks with quartz redistributed in veinlets and chloritization of certain greenstones. These effects are taken to indicate the operation of mechanical shearing in addition to mere folding and are therefore mentioned as examples of dislocation metamorphism.

Metasomatism

The operation of metasomatic processes involving change in the chemical composition of the rock by the addition and subtraction of elements is known from several places in the Radnejaure area. Three types of metasomatism have been found, namely, alkali enrichment, iron-magnesia metasomatism and scapolitization.

Alkali enrichment leading to granitization of rocks of supracrustal character is a common feature of the area. Thus in a drill-hole (Bh 60211) sited on the northern shore of Lulepotten in the west of the area a 32 m zone of biotite-microcline-plagioclase gneiss is present. This rock is also known from exposures to the north where it can be seen to lie between leptitic formations.

In both occurrences plagioclase (An_{15}) and microcline form porphyroblasts. Biotite is warped around and occasionally terminates abruptly against the feldspars which are clearly later in origin. The primary rock may have been a mica or quartz-mica schist interlayered with leptites and greenstones. Subsequent addition of alkalis from the nearby granite has then converted it into biotite-gneiss removing in the process all traces of its primary condition. The granite normally shows relatively sharp contacts with other supracrustal formations and has a more even-grained, granitic appearance.

Drill-cores from a point 1.5 km south of Lul. Radnejaure show the porphyritic andesites there to be distinctly bleached due to the addition of silica and alkalis necessary for the formation of quartz and oligoclase at the expense of the darker minerals. The process has obviously not gone to completion, however, as some hornblende is still present. Other minerals include biotite (abundant), titanite and epidote. The occurrence is close to the Radnejaure granite which is known to be potassic and is considered responsible for the metasomatism.

Metasomatic effects are widespread in the eastern part of the area where mapping shows that a relict stratigraphy and structure can be discerned within and around the area designated Svannvik. Clearly significant volumes of layered supracrustal rocks have been granitized and the mineralogy indicates an addition of potash and silica and loss of iron and magnesium. The details of this are, however, only partially known owing to the limited number of exposures available but a few features may be mentioned. Greenstones of basaltic-andesinic composition undergo mineralogical changes involving saussuritization of the plagioclases, replacement of hornblende by biotite: titanite and epidote-clinozoisite are omnipresent. Even weak impregnations of pyrite, chalcopyrite and molybdenite may occur. Strong foliation, sometimes with the development of platy minerals, is also common. The rocks are now paragneisses and with increasing metasomatism metamorphic differentiation becomes more marked. The proportion of lighter coloured material increases in the direction of the granite and the rocks may then be termed granite- or dioritic gneiss. On Jäknatjavelk proper layers and veins of granite occur together with gneissic and paragneissic rocks. Such an association is then called migmatite gneiss.

Where the Nimtekjaure Greenstone is in contact with the Nimtek granite (south side of the lake Nimtekjaure) a narrow migmatite zone is developed. One effect is a silicification of the greenstone accompanied by a weak sulphide mineralization, mainly pyrite and pyrrhotite.

The leptitic formations, being quartzo-feldspathic, are less obviously affected by metasomatic processes but the growth of secondary muscovite and microcline has been noted in some thin sections.

The above metasomatism is in the direction of acidification of the preexisting rock. An *iron-magnesium metasomatism,* however, represented by cummingtonite-anthophyllite rocks is also known from at least one place in the area, namely on the SW side of Stora Laxsjön (see map of area and profile). The occurrence is, however, still only known from a large number of local blocks but these obviously occur in a gneissic environment. A brief description has already been given under 'Regional metamorphism' and need not be repeated here. These rocks may, however, represent a desilication effect (basic front) formed in association with the Jäknatjavelk granite. If so some transference of elements has most probably taken place. The evidence on this point is not, however, conclusive.

Scapolitization is common in PreCambrian rocks in Norrbotten and several occurrences are also known from the Radnejaure area. These are located north of the hill Ballek in the extreme north of the map area. Here the scapolite normally occurs as light coloured individuals 1—2 mm diameter in schistose and biotitic greenstones. These rocks then have a highly distinctive spotted appearance. Inclusions are numerous and the mineral is obviously secondary: it apparently substitutes for plagioclase. Limestone formations are absent from the immediate area. In a diamond drill-hole scapolitization was seen to be most intense close to a zone of sulphide mineralization and a genetic connection between the two seems highly likely. In a small exposure near the road, 800 m north of Ballek, a similar greenstone occurs in tectonically disturbed rocks and here too sulphide veining is seen (fig. 19).

A short distance to the SE transported blocks, believed to be locally derived, contain scapolite. These are of two types: conglomerate (schistose), the scapolite occurring as porphyroblasts in the matrix, and greenstone cut by a dyke, the scapolite in this case being confined to the dyke (fig. 20). Common to all the cases

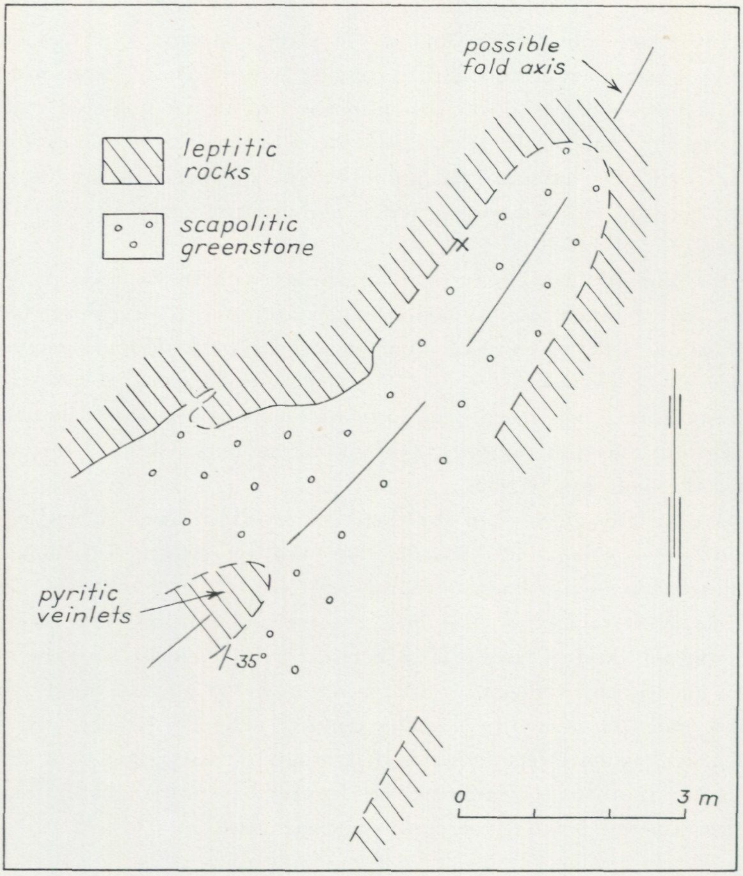

Fig. 19. Scapolitized greenstone in leptitic rocks. Exposure close to road 1.2 km north of the hill Ballek.

cited above is tectonization of the rocks and it seems therefore likely that the elements necessary for formation of scapolite, in particular Cl, CO_2, and Na, were mobile and introduced from elsewhere. A possible source is the nearby Pesets granite. In this connection it may be noted that fluorite is also found in small amounts as a vein-filling in the rocks of the Ballek area and is almost certainly derived from the granite. Even the granite itself is scapolitized to judge from a few local blocks. Scapolite crystals taken from a veinfilling were subjected to partial analysis and gave the values shown in Table 6.

This particular scapolite is thus a dipyre though the amount of chlorine is low. It may, like some of the other occurrences, be classed as hydrothermal.

No other chemical analyses were carried out owing to unsuitability of the material available (inclusions).

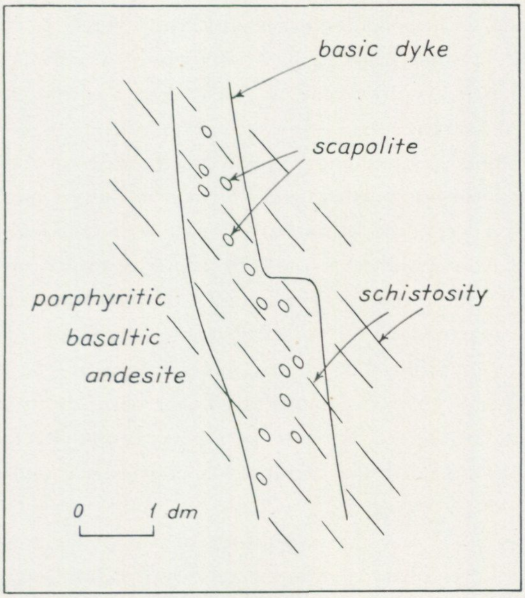

Fig. 20. Scapolitized basic dyke in basaltic andesite. Block of local origin 1.3 km east of the hill Ballek.

TABLE 6

	Wt %
SiO_2	55.26
R_2O_3	22.64
MgO	0.21
CaO	9.52
Na_2O	7.08
K_2O	0.90
Cl	0.15
CO_2	1.26
Sum	97.02

Basic dykes

Basic dykes occur sporadically throughout the area. They are normally vertical or subvertical with parallel walls, 1—5 m apart. In thin section they are seen to consist of hornblende, biotite, andesinic plagioclase, a little titanite, epidote-clinozoisite and opaques. In some cases (e. g. N. Kåivåive) a distinct ophitic texture is recognizable though primary pyroxene is absent. On Radnekvare one dyke has a fine-grained, ?chilled margin.

While similar in mineralogy the dykes can be divided into two groups on the basis of trend. One of these is northwesterly but curves into a more northerly direction in the Sademåive area, the other has an east-west trend and is best seen on Ballek and Tjuorre. Representatives of each trend seem to cut the granite and therefore post-date it. Some dykes intruded into the volcanic rocks are apparently aligned along joints, particularly *ac* joints associated with the regional folds.

There is, however, no proof that all the dykes belong to the same phase of intrusion. Ödman (1943, p. 15) has demonstrated that basic dykes in the Laver area, southern Norrbotten, belong to at least two generations. Recent drilling in the Lulepotten region has revealed the presence of diabase-like bodies in the granite, the latter clearly younger in age.

Finally, it may be noted that the mineralogy of the dykes is no longer primary. It suggests that some later phase of mineral recrystallization has taken place. How this came about and at what stage in the development of the area is unknown.

Acidic dykes

These are few in number and have only been seen on the south side of Mockajaure between Lulepotten and Gubblijaure and at two places south of this. The most convincing example in located 600 m SW of the lake Jopajaurats and consists of a steep-walled dyke 3.5 m wide trending NE. It clearly cuts across the prevailing strike and traces of bornite and chalcopyrite occur along its margins. A schistosity roughly parallel to that of the adjacent 'greenstones' is apparent.

Two narrow felsitic bodies are exposed on the southerly shore of Mockajaure. The westerly one is highly sheared as are the adjacent greenstones and an intrusive origin is difficult to prove. The occurrence may be a disrupted leptite horizon. The easterly occurrence is also a sharply defined, dyke-like body with conspicuous plagioclase individuals (An_{10}) and a plagioclase-quartz-muscovite matrix.

The occurrences clearly pre-date the schistosity of the west part of the area and may possible be related to the extrusion of the acidic volcanics of the Radnekvare Group.

Mineralization

In the introduction to this paper it was emphasized that the location of ore deposits was the main object of the investigations. Interest in the area was first aroused by the discovery of mineralized float by prospectors of the Geological Survey in 1957. Many years previously other prospectors had operated in the area but apparently abandoned it. The main problem then as now is to locate mineralization beneath a widespread morainic and vegetational cover. Thicknesses of 10 m or more are not uncommon. Some idea of the type of moraine is shown in fig. 21. The methods employed in the present investigations have included the search for mineralized outcrops and float by experienced prospectors, ground geophysical surveying, geochemical prospecting and diamond-drilling. Coordination of this programme has been the responsibility of the geologist, in this case the author, who also carried out the geological mapping.

Fig. 21. Blocky moraine in quarry near road, 2 km SE of Radnejaureby.

History of Prospecting

From the initiation of the investigations in 1957 to the time of writing (1964) several distinct phases can be discerned. The first involved tracing certain blocks with a characteristic type of mineralization against the direction of ice movement to the present map area and in particular to a point SE of the lake Lul. Radnejaure. The blocks here consisted of sulphide impregnations in rocks of andesitic-basaltic composition, much altered. The area of supracrustal rocks shown on Ödman's map of Norrbotten (1957) north of Radnejaure seemed a reasonable place for the mineralization to occur especially as the former ice-divide lay only a short distance further west (See map entitled, 'The deglaciation and the highest shore-line in Sweden', 1961). Even so an area approximately 300—400 km^2 in size remained for more detailed investigation. The second stage began with extensive block studies in this area. Several different block types and block trains were rapidly found suggesting derivation from several different mineralizations. Geological studies confirmed that all rock types in the float were represented in the rocks of the area. It was also shown that two zones of mineralization were to be expected, one in the west and one in east. The former was thought to coincide approximately with the granite-supracrustal boundary where some tectonism was noted. The latter had a NE trend roughly following the easterly boundary of the massive andesitic basalts. Thermal alteration was more in evidence here and the mineralizations generally weaker. All mineralizations were, however, of the impregnation type with copper and iron sulphides dominating. Lesser amounts of sphalerite, molybdenite, galena and arsenopyrite were also seen. A few blocks of skarn iron-ore were immediately recognized as comming from a well-known zone near Lövnäs far to the north-west and outside the area of interest.

From the evidence available and for theoretical reasons attention was concentrated on the westerly zone. Geophysical surveying, employing the slingram method, was carried out over a carefully selected area and a promising electrical anomaly obtained. This was drilled in the early months of 1960 and a significant copper mineralization intersected. This immediately explained the source of a large number of mineralized blocks to the south-east and encouraged more intensive activity in the area as a whole. In the subsequent third phase prospecting for mineralized blocks was widely extended and intensified. More widespread geophysical surveying was carried out and certain detailed studies begun. More emphasis was placed on magnetic methods and the study of magnetic anomalies. At the time of writing (1964) most of the geophysical and geological work has been concluded but drilling of various anomalies remains.

Geophysical investigations *

Following customary practice in Sweden areas in which mineralization is suspected have been surveyed geophysically. In the Radnejaure area extensive ground surveys have been carried out using mainly electromagnetic equipment of the slingram type. Supplementary measurements by magnetometer have been made over smaller parts of the area and at one place a detailed electrical potential survey was performed. Determinations of the deviations of drill-holes were carried out systematically using an instrument (curvature meter) designed and built at the Geological Survey. The electrical properties of the holes were logged with single electrode earth resistance equipment.

* Incorporating information included in a report by L. Granar, Geophysicist, Geological Survey of Sweden.

The first slingram surveys in the Radnejaure were made with instruments built by engineers of the Survey and earlier used for detecting compact pyrite bodies in the well-known Skellefteå field. The operating frequency was 3 600 p/s and the indications obtained rarely exceeded 1 % of the imaginary component. At the same time geological studies indicated that no ores of the compact sulphide type or graphitic schists were to be expected. The ore minerals (pyrite, chalcopyrite, bornite, sphalerite, molybdenite) occurred as impregnations in a variety of rocks but had such a low bulk conductivity that it was questionable whether zones of this type could be detected or distinguished from anomalies arising from lake muds or water-filled fault zones. To date, only two anomalies known to be due to copper mineralization, have given appreciable negative imaginary values (about 1—2 %) at 3 600 p/s and 60 m coil separation.

To improve the sensitivity new slingram equipment was constructed for operation at a frequency of 18 000 p/s giving a response 5 times greater over weak conductors. As the background scatter also increases with increase in frequency, the resolution is only significantly improved in areas of high resistivity. Special disturbances due to telegraphic transmitters operating in the very-low frequency band and having a world-wide range have been noticed. Sometimes the level is so high that it upset the readings for many hours. About 2/3 of the total area was surveyed geophysically at the higher frequency.

Smaller, limited areas have been surveyed at both frequencies and comparison of the results shows clearer definition of the mineralization at the higher frequency. One mineralization (north of Ballek) located by drilling on the basis of geological studies only gave a clear anomaly (1 %) at the higher frequency.

Surveying by magnetometer has been restricted to slingram anomalies and to certain zones such as contacts between granite and greenstone where mineralization was suspected or at least had a theoretical possibility of occurring. It proved a useful complement to the slingram survey. Most surveys were carried out with an Askania instrument.

The electrical potential method has also been used to help in evaluation studies of known mineralizations, particularly as regards their area of outcrop, shape and depth. In the mineralization subjected to most careful investigation (north of Ballek) the bulk conductivity was, however, so small that a constant potential value could not be obtained over the whole of it. The potential field, therefore, gave a diffuse picture of the outcrop but the strike of the mineralization was clearly indicated.

Geochemical investigations

Geochemical methods of prospecting have won increasing respect in recent years as an aid to mineral prospecting. Normally their greatest value is in tropical climates and when used in conjunction with geological and geophysical evidence. The Ore Investigation Department of the Geological Survey has also made use of the methods though largely on an experimental basis. In the Radnejaure area they were employed to help locate secondary dispersions caused by base metal mineralization of the bed-rock. Attention was concentrated on areas of limited extent, in particular geophysical anomalies (magnetic and electrical) and places where mineralization was suspected for other reasons. It was also used on regional scale in the east part of the area where conditions of drainage were favourable.

Practical problems met with were the depth of overburden (commonly 10 metres or more) consisting of glacial blocky moraine and frost-shattered bed-rock, poor drainage, and a severe Arctic climate for most of the year (latitude 66 degrees north) which has restricted rock weathering. There was, however, little likelihood of artifical contamination.

The chief methods employed were sampling of stream and lake waters, stream silts and soils. Sampling of water was carried out rather extensively and the heavy metal contents (Cu, Zn and Pb) determined directly in the field using Huff's method (1948, pp. 675—684). The greatest success by this method was in the Nimtekjaure area where one stream gave consistently higher values. No satisfactory explanation of this has yet been found and investigations continue. On the other hand known mineralizations elsewhere in the area gave no significant anomalies in waters draining across them. Sampling of heavy metals in stream silts using Bloom's method (1955) was tried but only on a limited scale owing to difficulties in getting samples of silt. When obtained their heavy metal values showed some correlation with those for the water. At one place (W of Ballek) a significant anomaly in stream silts proved to be due to manganese (spectral analysis). Sampling of soils was carried out at several places and in a systematic way using the geophysical grid, the material being sent to the laboratory for spectrographic determination of the copper, zinc and lead. Distinctly anomalous values were found in the Ballek area and the dispersion patterns coincided with the distribution of float. In effect, clearer definition was obtained of the fans of ice-transported ore boulders and the patterns may be classified as syngenetic clastic (Hawkes and Webb, 1962, p. 146). They are elongated in the direction of ice movement and decay rapidly with increasing distance from the source. Inhomogeneities are probably due to the coarse grain of the material.

Description of occurrences

1. LULEPOTTEN

Interest in this locality was first aroused by the discovery of several mineralized blocks close to the eastern shore of a small embayment on the north side of the lake Lulepotten. These contained bornite and chalcopyrite impregnations, partly in association with quartz veins. Some brecciation was also seeen in the rocks. A slingram survey gave a weak but distinct anomaly on the imaginary component roughly coincident with the long axis of the embayment and orientated NE-SW. No exposures could be found in the vicinity. In February 1960 a drill-hole intersected a significant copper mineralization thereby explaining the geophysical anomaly and the float. Subsequent drilling has shown the mineralization to occur as impregnations in steeply inclined zones approximately conformable with the schistosity and bedding of the rocks and with a granite contact (fig. 22). Most of the mineralization is found in schistose volcanic rocks and sediments but some occurs as vein-fillings in the granite. The general features of the deposit are shown in a demonstrative profile (fig. 22). The main ore minerals are chalcopyrite and bornite.

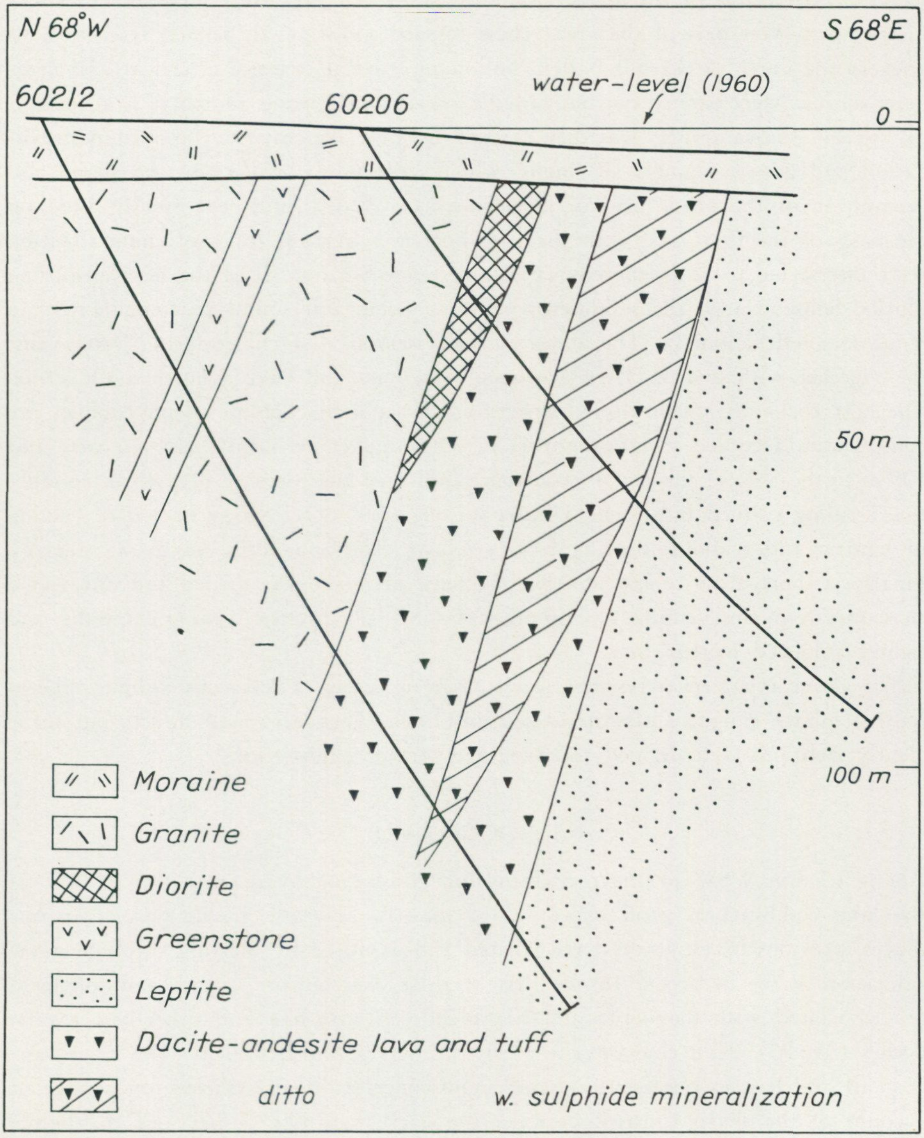

Fig. 22. Profile through the Lulepotten copper deposit based on drill-hole data.

In polished sections minor amounts of chalcocite and hematite are visible. Magnetite is more common, particularly in some of the supracrustal rocks and gives rise to a significant magnetic anomaly. Common associations of sulphide minerals include (chalcocite)-bornite-chalcopyrite and chalcopyrite-pyrite. Quartz and quartz-carbonate veining are common, occasionally with a little tourmaline and fluorite.

2 a—2 c. BALLEK

In 1958 prospectors of the Survey found a number of promising mineralized blocks in the north-west part of the area. These formed a distinct dispersion trail with its apex to the north of the hill Ballek. Following normal practice electrical and magnetic surveys were carried out but failed to reveal any strong anomaly. A geochemical survey (soil-sampling) was then carried out over the suspected area of mineralization and gave a number of 'highs' which collectively confirmed the shape and orientation of the block trail or dispersion fan. A drill-hole was finally sited on the basis of the float and with the first hole two narrow zones of mineralization were intersected (= 2 a), thereby explaining some but not all of the ice-transported blocks. Subsequently, the suboutcrop of these zones was found to coincide with a weak magnetic anomaly. The zones consist essentially of chalcopyrite-pyrite veining together with quartz. They are steeply inclined and have a north-south strike. The host rocks are much altered greenstones in which scapolite porphyroblasts are conspicuous. Detailed slingram surveying at a higher frequency (18 000 p/s) and 400 m to the SSV of the above occurrence indicated the presence of a weak conductor. Drilling proved this to be a narrow zone (2 b) of chalcopyrite-pyrite veining in leptitic and scapolite-bearing biotite schists. The zone dips SE at 75 degrees. Finally, a short distance east of 2 b a magnetic anomaly was drilled and intersected chalcopyrite-pyrite veining and impregnation in porphyritic andesitic basalts and lighter coloured leptitic rocks (= 2 c).

The above occurrences resemble each other in having a relatively simple mineralogy, a quartz gangue and scapolitized host rock. They are small in size but sufficiently rich and well defined to encourage further exploration.

3. SOGGOVARE

About 1.5 km WSW of the prominent hill Stora Soggovare and 400 m NW of the lake Gubblijaure, good exposures of massive andesitic basalt occur. At two places, previous investigators have located and explored by blasting sulphide mineralization in the bed-rock. In the first of these chalcopyrite, pyrite and sphalerite are associated with magnetite and hornblende in vein-like and other less regular bodies (fig. 23). Thin chalcopyrite-pyrite veinlets are also present. The occurrence is small and has no obvious economic significance. It is nevertheless interesting on account of the sharp contrast between the dark, vein-like bodies and the lighter coloured, more acidic matrix. A form of elemental segregation seems to have taken

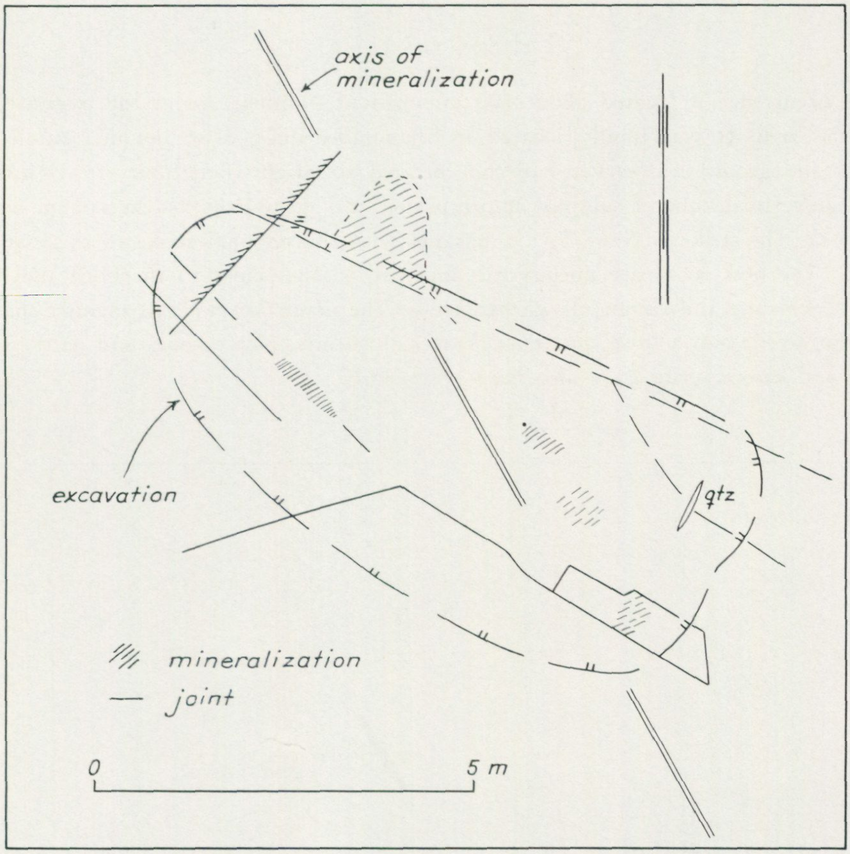

Fig. 23. Sulphide mineralization as joint fillings and irregular bodies in an old excavation in andesitic basalt, 1,3 km SW of Stora Soggovare.

place, probably in a somewhat jointed rock. The second occurrence in this area is even smaller and consists of a chalcopyrite stringer together with quartz trending N 30 E (fig. 24). It is clearly a joint filling.

Both occurrences are located close to the estimated NNW continuation of the Gubblijaure Joint Zone. A tectonic control of the mineralization seems therefore a strong possibility.

4. NIMTEKJAURE

The occurrence is located about 700 m north of Nimtekjaure in the eastern part of the area. It was finally located by diamond-drilling after detailed studies of float and geophysical survey had concentrated attention to the area. It consists of a near-vertical zone of sulphide impregnation and veining with a maximum width of 3 m. The strike is N 65 E, i. e. parallel with the regional strike in this part of area. The host rocks are porphyritic andesitic basalts: close to the zone they are dark, schistose and commonly garnetiferous. The main ore minerals include chalcopyrite, pyrite and a little sphalerite. Traces of bornite, molybdenite and native copper and arsenopyrite have also been observed.

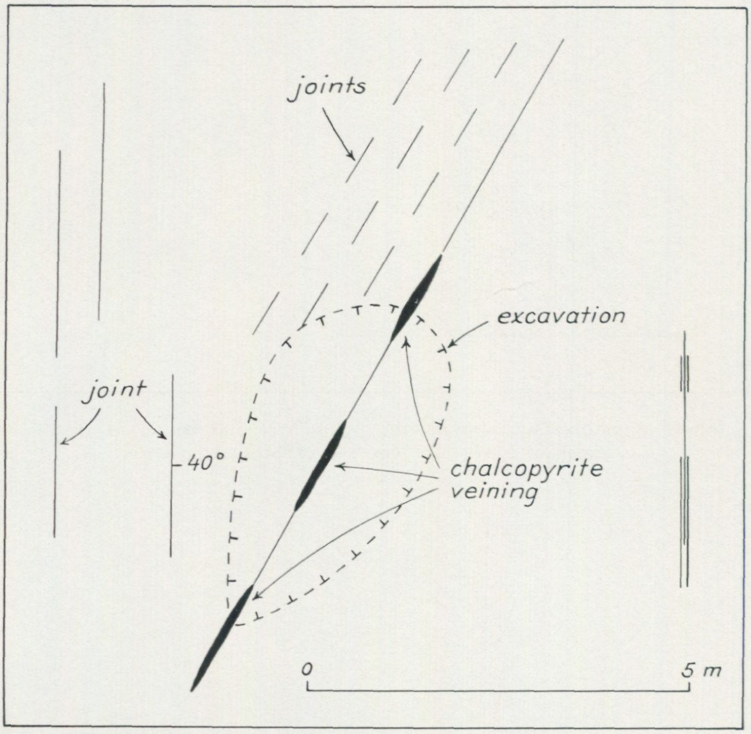

Fig. 24. Chalcopyrite stringers in andesitic basalt, 1.3 km SW of Stora Soggovare.

5. RADNEJAURE

Studies of float indicated the possibility of a mineralization about 1.3 km SSE of the lake Lul. Radnejaure. Indeed the ore-bearing blocks which first led prospectors to the Radnejaure area belonged to this train. Geophysical surveying gave, however, only one poor electrical anomaly (which turned out to be a fault zone) and a strong magnetic anomaly close to the road to Moskosel. The latter proved to be granitized andesite in which some weak sulphide impregnation occurs. Chalcopyrite and pyrite are the two main ore minerals. Some doubt remains, however, whether certain blocks in the block train are derived from these zones and further investigations are necessary.

6. MISCELLANEOUS

In addition to the above, traces of sulphides have been observed at a large number of places, in particular in the more basic rocks and where these lie within the zone of pegmatite injection and thermal alteration. Many ice-transported blocks are also known which have not yet been satisfactorily related to any of the mineralizations described above. Investigations continue.

Conclusions regarding mineralization

The presence of several distinct mineralizations in different parts of the area and in rocks of different type has been demonstrated. Other mineralizations suspected from the study of float and currently under investigation, suggest even greater diversity. They are exclusively of the impregnation type and when sufficiently strong can be detected with slingram equipment widely used in the Skellefteå field in the search for compact sulphidic ore bodies. Definition under certain circumstances is better when working at a higher frequency.

The commonest mineral associations are chalcopyrite-bornite-(chalcocite) and chalcopyrite-pyrite-(sphalerite-molybdenite). Generally the mineralogy is fairly simple and alteration of the host rocks limited. The persistent occurrence of copper sulphides in a wide varity of environments suggests that the area, even if only slightly, is geochemically anomalous as regards copper.

Those mineralizations known to date are mainly located in supracrustal rocks and usually at no great distance from the granite. Even marginal parts of the granite may be mineralized though no tendency was noticed for excessive concentration in the contact zones. Local tectonics clearly play a significant part in the localization and attitude of the mineralizations.

The Lulepotten mineralization is clearly located in a tectonic zone of post-granitic age. It is to all appearances epigenetic and can in no circumstances be considered syngenetic with respect to its immediate surroundings. The ultimate source of the metallic elements, in this case copper, is unknown and therefore any views expressed in this matter are purely speculative.

The Ballek and Nimtek deposits are known to occur in areas where some brecciation of the host rocks has taken place. This is most evident in the case of leptite: greenstones, on the other hand, tend to be highly schistose. Wall rock alteration is marked by chloritization, sericitization, the development of garnet or scapolite suggesting the operation of hydrothermal processes. The ultimate source of the ore minerals is, however, unknown.

The Soggovare occurrence, though small, is of considerable theoretical interest. Here it seems as if the metallic elements, including iron, have been removed from the host greenstones and concentrated in joints and fissures. This is a kind of secretion effect and suggests the greenstones are in effect 'source beds' of the mineralization. The elements may, therefore, have moved to areas of lower temperature or pressure, in this case a fracture zone (the Gubblijaure Joint Zone). It is however, impossible to get any quantitative estimate of the amount of metallic elements removed from the greenstone but the latter are known to contain up to 230 ppm Cu (See Table 3). It is possible that the Cu of the Lulepotten, Ballek and Nimtek occurrences was sweated out of greenstones at depth and subsequently mobilized. The thermal effect of granite may have been significant in this connection.

The derivation of metallic elements from volcanic rocks has received greater attention in recent years. The 'source bed concept' (Knight, 1957), while favouring a syngenetic origin for the metallic elements, also recognized the possibility of migration under the influence of metamorphism and deformation (op. cit. p. 816). More recently Goodwin (1961) has tried to demonstrate the relationship of several mineralizations in the Michipicoten region, Ontario, Canada to rocks of the volcanic suite. His arguments are similar in many respects to those offered for the occurrences in the Radnejaure area. The problem is to demonstrate convincingly in the field all stages in the concentration of the elements and apportion correct significance to each factor concerned, e. g. primary volcanism and primary element abundances, erosion (mechanical and chemical) and chemical concentration, tectonics and granite emplacement. Clearly the elements form part of a major geochemical cycle our knowledge of which is far from complete.

Geological History of the area

In previous chapters considerable emphasis has been placed on a careful description of the geological features and of the age relationships existing between them. From the evidence presented it is possible to gain some idea of the geological history of the area as a whole. No radiometric age determinations have yet been carried out and it is therefore still impossible to relate the geological events to any international time-scale. The order of events is, however, fairly well established, a summary of which is given in Table 7. Several distinct phases can be distinguished beginning with the successive accretion of the supracrustal series. (No 'basement complex' can be recognized). This took place by volcanic eruption and deposition of volcanic detritus, mainly under terrestrial as opposed to marine conditions. Gabbroic rocks, some basic dykes and acid dykes were then intruded, possibly representing the close of the volcanic activity. Phase 2 began with folding on a regional scale accompanied by granite emplacement and regional metamorphism. Some mineralization (Nimtekjaure, Radnejaure) may belong to this phase. Phase 3 is essentially post-granitic and includes the Lulepotten-Ballek zone of faulting and the accompanying sulphide mineralization, the Svannvik-Plättik fault system (apparently unmineralized) and possibly the Gubblijaure joint zone. The intrusion of some basic dykes also seems to belong to this phase. Erosion almost certainly took place throughout and has continued down to the present time.

TABLE 7

Phase 3	Intrusion of basic dykes. Mineralization (Lulepotten-Ballek). Faulting.
Phase 2	Regional metamorphism, granite emplacement, metasomatism and possibly some sulphide mineralization (Nimtekjaure, Radnejaure). Regional folding.
Phase 1	Intrusion of gabbro, acid and basic dykes. Formation of the supracrustal rocks.

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Berggrunden och mineraliseringen inom Radnejaureområdet, Norrbotten, Sverige

Uppsatsen handlar om berggrundsgeologien och kopparmineraliseringen inom ett ca 350 km^2 stort område, som ligger huvudsakligen norr och öst om byn Radnejaure, 2 mil E om Arjeplog (Blad 25 I Stensund). Arbetet har bedrivits av Sveriges Geologiska Undersökning (Malmbyrån) i malmletningssyfte och har pågått i olika etapper med början år 1957. Den geologiska karteringen utfördes av författaren 1958—1961 med kompletteringar 1962—1963. Området har aldrig tidigare detaljkarterats, men vissa tektoniska och stratigrafiska drag har behandlats av Grip (1946). Vår tidigare kännedom finns sammanställd på Ödmans karta över Norrbottens län (1957). Kartan, som nu föreligger (Pl. 1) och beskrivningen till denna, är en sammanställning av alla data t. o. m. dec. 1963. Sålunda bygger den inte enbart på geologiska karteringar utan även på geofysiska markmätningar (magnetiska och elektriska metoder), blockstudier och diamantbergborrning.

Områdets bergarter består av 2 stora enheter: en mäktig suprakrustal serie samt graniter. Den förstnämnda uppbyggs av sura och basiska vulkaniter samt klastiska derivat av dessa. Något äldre bergartskomplex under de suprakrustala bergarterna kan inte spåras.

Sex formationer med stratigrafisk betydelse har kunnat urskiljas:

6) Radnekvaregruppen	Sura lavor och tuffer med en del klastiska led.
5) Huvudgrönstensgruppen	Andesitiska basalter.
4) Laddokleptiten	Ljus kvarts-fältspatbergart av sedimentärt ursprung.
3) Nimtekjauregrönstenen	Andesitisk basalt.
2) Nimtekjaureleptiten	Ljus kvarts-fältspatbergart av sedimentärt ursprung.
1) Jäknatjavelkgruppen	Växlande sura och basiska led.

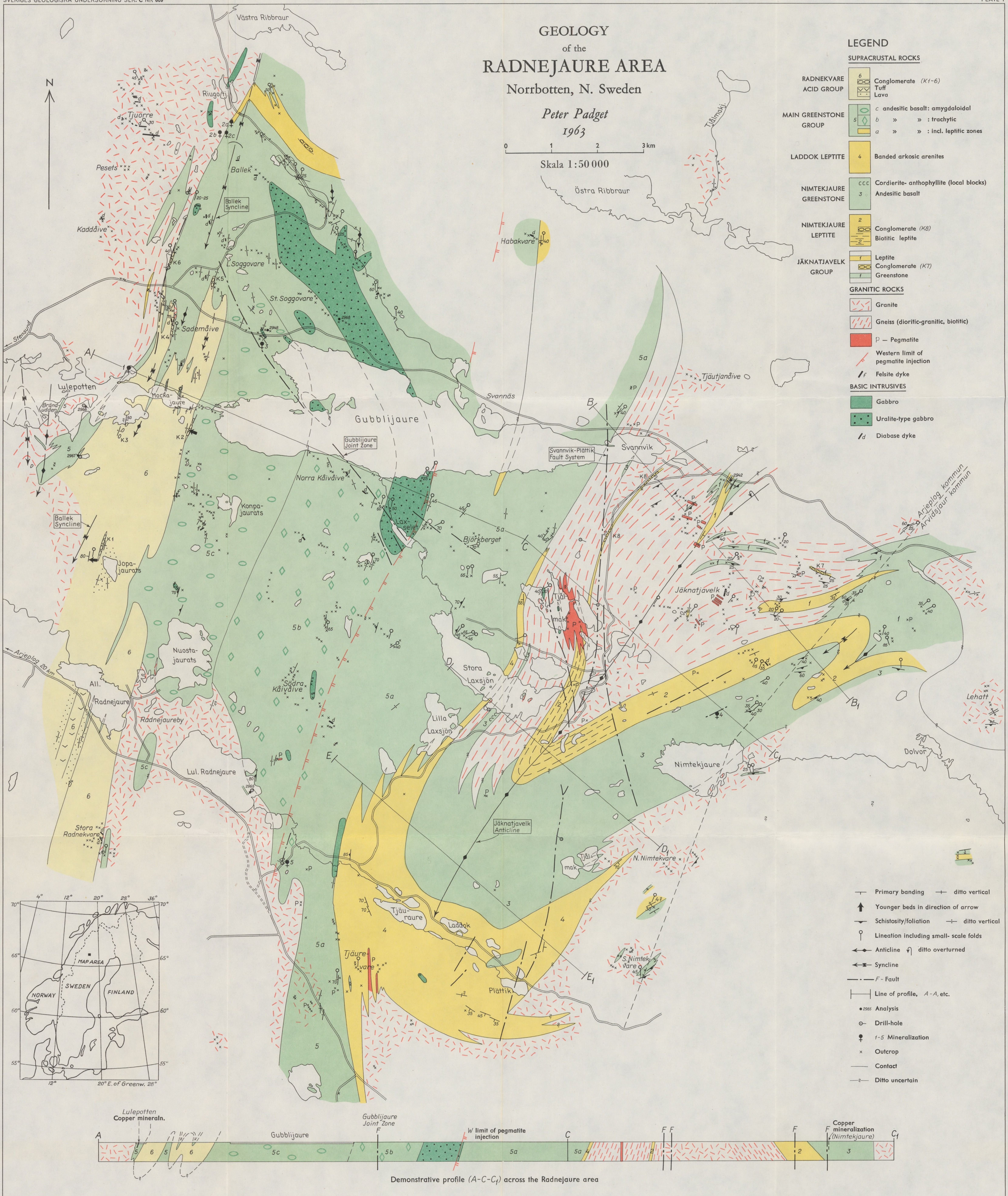
Formationerna växlar hastigt i mäktighet och övergår i andra bergartstyper (primära faciesväxlingar). Sålunda är en korrelation med liknande bergarter i södra Norrbotten svår att genomföra och kanske rentav missvisande.

Suprakrustalbergarterna är veckade och två strukturer av regionalt mått kan identifieras: Jäknatjavelkantiklinalen i områdets östra del och Balleksynklinalen i dess västra del. Båda har en axialstupning mot SSV. Tillhörande strukturer såsom småveckningar, stänglighet och sprickbildningar är beskrivna. Möjligheten att Radnekvaregruppen i själva verket är en faciestyp och inte utgör kärnan i Balleksynklinalen diskuteras.

Andra tektoniska drag består dels av ett kraftigt spricksystem (Gubblijaure Joint System på kartan) samt förkastningar (Svannvik-Plättvik Fault System på kartan). En markant förskiffringszon karakteriserar gränsen mellan graniten i V och suprakrustalbergarterna och längs denna förekommer kopparmineralisering. De östliga graniterna (Jäknatjavelk och Nimtekområdena) åtföljs av pegmatitgångar. Dessa avtar i frekvens och mäktighet mot väst.

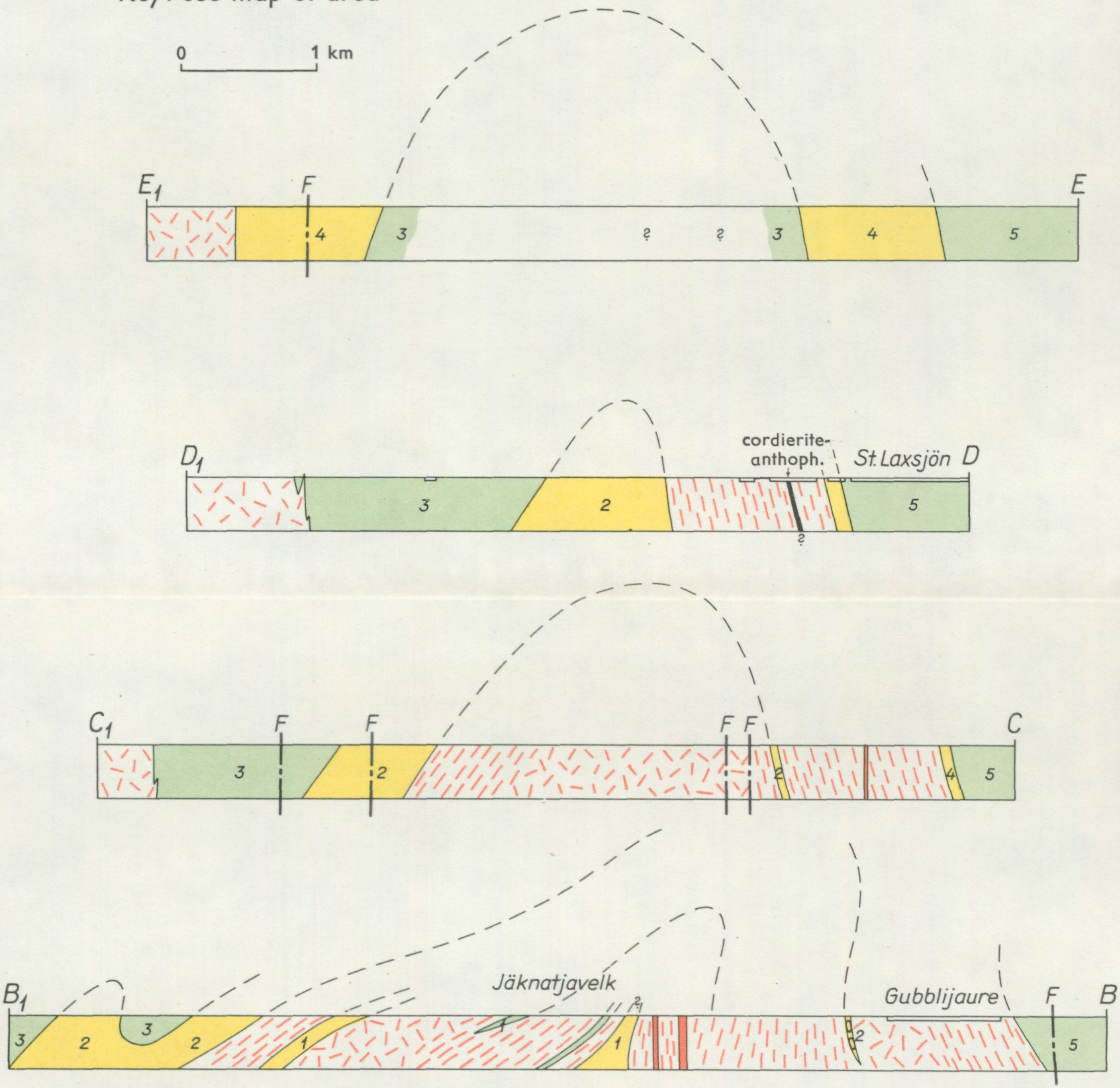
Samtliga suprakrustalbergarter är metamorfoserade och visar mineralassociationer motsvarande den undre delen av Eskolas amfibolitfacies. Mot E och inom zonen för pegmatitintrusion är metamorf differentiering och förgnejsning allmän. En kordierit-antofyllitbildning (lokala block) vid sjön Stora Laxsjön härstammar troligtvis från denna zon. Metasomatiska omvandlingar omfattar även skapolitbildning (Balleområdet) och kaliumanrikning (Lulepotten-Sademåiveområdet). Fluor (i flusspat) finns i små mängder i graniterna vid Pesets och Radnejaure.

Diabasgångar förekommer här och var och tycks vara både äldre och yngre än graniterna. Gabbro förekommer i skilda kroppar som är metamorfoserade och förmodligen äldre än graniterna.
Malmletningen har omfattat inte bara geologisk kartering utan även blockletning, geofysisk markmätning, geokemisk provtagning och diamantborrning. Hittills har mineraliseringar påträffats i borrningar på 5 olika platser (se kartan, Pl. 1). Samtliga är morän- eller vattentäckta. Den mest lovande fyndigheten, Lulepotten, hittades 1960. Den består av bornitkopparkisimpregnationer i granit och angränsande suprakrustala bergarter. Koppar- och svavelkisimpregnationer karakteriserar de andra fyndigheterna. Malmletning, särskilt diamantborrning, fortsätter i området.


GEOLOGY
of the
RADNEJAURE AREA
Norrbotten, N. Sweden
Peter Padget
1963
0 1 2 3 km
Skala 1:50 000
LEGEND
SUPRACRUSTAL ROCKS
RADNEKVARE ACID GROUP
Conglomerate (K1-6)
Tuff
Lava
MAIN GREENSTONE GROUP
c andesitic basalt: amygdaloidal
b » » : trachytic
a » » : incl. leptitic zones
LADDOK LEPTITE
Banded arkosic arenites
NIMTJEKJAURE GREENSTONE
Cordierite- anthophyllite (local blocks)
Andesitic basalt
NIMTEKJAURE LEPTITE
Conglomerate (K8)
Biotitic leptite
JÄKNATJAVELK GROUP
Leptite
Conglomerate (K7)
Greenstone
GRANITIC ROCKS
Granite
Gneiss (dioritic-granitic, biotitic)
P — Pegmatite
Western limit of pegmatite injection
Felsite dyke
BASIC INTRUSIVES
Gabbro
Uralite-type gabbro
Diabase dyke
Primary banding
ditto vertical
Younger beds in direction of arrow
Schistosity/foliation
ditto vertical
Lineation including small- scale folds
Anticline
ditto overturned
Syncline
F - Fault
Line of profile, A-A, etc.
2965 Analysis
Drill-hole
1-5 Mineralization
Outcrop
Contact
Ditto uncertain
Västra Ribbraur
Östra Ribbraur
Gubblijaure
Svannvik
Nimtekjaure
Jäknatjavelk
Stora Laxsjön
Lilla Laxsjön
Tjäuraure
Laddok
Plättik
Radnejaure
Ballek Syncline
Gubblijaure Joint Zone
Svannvik-Plättik Fault System
Jäknatjavelk Anticline
Arjeplog kommun
Arvidsjaur kommun
NORWAY
SWEDEN
FINLAND
MAP AREA
20° E. of Greenw.
Lulepotten Copper mineraln.
Gubblijaure Joint Zone
W limit of pegmatite injection
Copper mineralization (Nimtekjaure)
Demonstrative profile (A-C-C1) across the Radnejaure area

PROFILES
ACROSS THE JÄKNATJAVELK ANTICLINE

Key: see map of area



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