

SVERIGES GEOLOGISKA UNDERSÖKNING

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SER. C

AVHANDLINGAR OCH UPPSATSER

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ÅRSBOK 53 (1959) N:o 2

ROCKS AND STRATIGRAPHY OF  
THE LEDFAT AREA, VÄSTERBOTTEN  
COUNTY, NORTHERN SWEDEN

By

JAN OFFERBERG

WITH TWO PLATES

*Pris 10 kronor*

STOCKHOLM 1959

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*Abstract.* The pre-Cambrian supercrustal rocks of the Ledfat area in the northern part of Västerbotten county, Sweden, are described. The Ledfat series rests unconformably upon volcanics belonging to the Archaean Arvidsjaur series. The Ledfat series is a non-marine equivalent to the mainly marine Elvaberg series of the Skellefte field. The stratigraphy of the Ledfat series is described.

## Acknowledgments

As a student of Professor Sven Gavelin, I had my first opportunity to carry out geological mapping within the Ledfat area. Professor Gavelin's interest in this work and his willingness to put at my disposal maps and thin sections have been of greatest value for the present map and description.

As an assistant to State geologists Tryggve Eriksson and Gunnar Kautsky, and geologist Hans Sarap, of the Geological Survey of Sweden, I was enabled to extend the mapping which led to the publication of the present paper. Thanks to their keen interest and readiness to discuss problems connected with the work, it has been possible to finish it.

Finally I take the opportunity of expressing my sincere gratitude to Mr. John Berge, B. A., geologist at the Liberian American Swedish Minerals Company, who has spent much work on the translation of the paper into English.

## Introduction

The so-called Ledfat area lies in northern Västerbotten near latitude  $65^{\circ} 30'$  N, and longitude  $0^{\circ} 20'$  E, within the topographic map 42 Malå. The area which has got its name from Lake Ledfat at the Skellefte River, has been

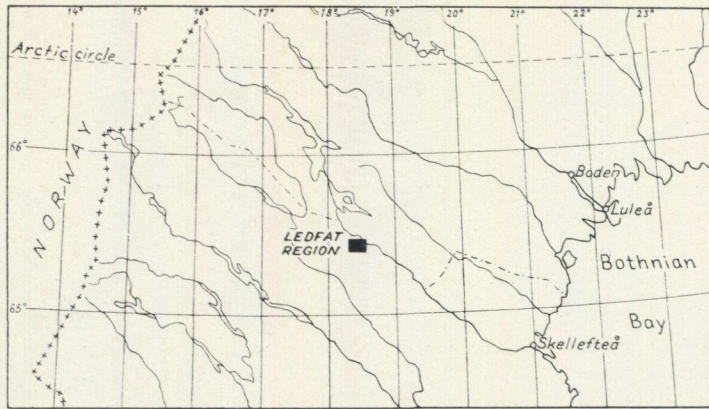


Fig. 1. Situation map of the Ledefat region in the Västerbotten County, N Sweden.

known since 1921 as a geologic occurrence belonging to the Precambrian Vargfors formation. The Vargfors rocks, which are comprised largely of conglomerates, cover a rather circular area immediately to the south and south-west of Ledefat, or Levattnet, as the lake is occasionally called. In addition to the principal occurrence of Vargfors sediments, there are several smaller localities, one of which is situated in the south of Norrbotten county, to the north of Lake Ledefat. A variety of rocks appear in the smaller separate subareas, but they can be recognized as different members of the areal stratigraphy.

The Ledefat region was first mentioned by B. Asklund (1931, p. 202) and by Alvar Högbom (1931). The age and relative position of rocks in the Ledefat area have been subjects of later investigations. For example, in 1953, E. Viluksela delivered a lecture on the geology of the Ultevis—Sjöfall area in connection with which the age of the Ledefat rocks was discussed. Contributions to this discussion have been published in the Transactions of the Geol. Soc. of Sweden (GFF) vol. 75, 1953. The formations in this area are also described in S. Gavelin's comments on the geological map of Västerbotten county (Gavelin 1955).

Through G. Kautsky's work in the Skellefte field, it has become evident that the geological position and stratigraphy of the whole Vargfors formation must be reconsidered. The Ledefat area shows a highly varied sequence of rocks of considerably more than 1,000 meters in thickness. A detailed knowledge of its stratigraphy may be valuable in this discussion even though facies changes make it possible to trace only isolated members of the Vargfors formation over long distances with any degree of accuracy.

The aim of this investigation has been to obtain as complete a picture as possible of the stratigraphy and sedimentary environment of the rocks of the Ledefat area, and then to determine their relationship to Svionian formations such as the Arvidsjaur porphyries. In carrying out these aims, it was necessary to find out whether the sediment complex consisted of one single and continuous sequence of rocks, or if there was a disconformity between two formations

or groups of formations of entirely different ages. In the latter case, the lower sediments would be of Svionian age, and the younger sediments of Karelian age. If, as the works of G. Kautsky seem to indicate, also the rocks of the Vargfors formation are to be thought of as Svionian, there would still be a considerable age difference between a lower group of finer clastics, and an upper group of conglomerates. The presence of boulders and pebbles of granite, observed only in the upper group of Ledefat sediments, could be used as evidence for the latter point of view. Furthermore, the similarity between the Ledefat sediments and the sediments of the Ultevis—Sjöfall area may be used as arguments for both alternatives. Since the work on the latter area is as yet unpublished, the relationship between the two areas can not be discussed or interpreted here.

S. Gavelin has mapped the Ledefat and surrounding areas on scales of 1:20,000 and 1:50,000 respectively during a revision of the geological map of Västerbotten county. At Gavelin's suggestion, the author spent the summers of 1952 to 1954, and of 1956, in carrying out a detailed mapping of the whole area on 1:10,000. Certain smaller sections were mapped on 1:1,000 or even 1:200. The work was originally concentrated to the lower group of finely clastic sediments which cover a smaller area, and are not so well exposed as the upper conglomerates. During the summer of 1956, the larger areas of conglomerates were mapped on the same scale. In 1953, expenses for field work were defrayed by grants from the University of Stockholm, and in 1956, work was done while I was in the service of the Geological Survey of Sweden. I have made use of maps, sketches and sections drawn up by S. Gavelin during his earlier survey. I could also use his specimens and thin sections, which proved to be of great help. In the summer of 1956, all previously uncovered outcrop surfaces were well exposed, and thus the area was well suited for excursions. A lumber road into the central part of the area makes access easy.

The sediments show a characteristic rough topography which is often in contrast to that of the surrounding granites and porphyries. The sedimentary boundaries may be roughly traced on the general topographic map in 1:200,000. To the north, the sediments border on a featureless terrain underlain by granite, which is practically devoid of outcrops. Therefore the boundary was traced with the aid of recent aerial photographs with boulders as the only geologic control. To the northwest and west, the granites are replaced by rocks of the Arvidsjaur series which are likewise peneplaned. To the south, the relief becomes more pronounced both within and beyond the investigated area. On the southeast, the sediments border again on a featureless granite terrain. Here the boundary between the sediments and the granite is a fault with the exception of the southernmost part where the granite is found intruding into the sediments.

Within the area of sediments, the character of the formations is frequently reflected in the topography. Steeply dipping sandstones and mudstones form hills which are elongated in a direction roughly parallel to the strike of the

Dolerite			
Sorsele granite and granite porphyry. Adak granite with pegmatite, aplite and quartz dikes			
LEDFAT SERIES	Vargfors Conglomerates	Upper Vargfors conglomerate	Mainly grey conglomerates with numerous granite pebbles — boulders.
	Lower Ledfat Formations	Lower Vargfors conglomerate	Partly red conglomerates. Numerous sandstone intercalations. No granite pebbles.
		Tuffite formation	Red or brownish violet tuffites, sandstones and mudstones. Minor conglomerate beds
		Sandstone formation	Sandstones, feldspar sandstones, quartzites and conglomerates.
		Andesite formation	Andesitic lavas, largely vesicular. Conglomerates, tuffs and tuffites.
Unconformity			
Jörn granite, Arvidsjaur granite			
ARVIDSJAUR SERIES		Liparites Volcanic breccias, agglomerates Dacites Andesites	

sediments. Gently dipping conglomerates form smaller ridges. The central part of the area is a flat, somewhat circular, depression underlain by the youngest conglomerates which are generally horizontal but occasionally gently folded. The southern segment of the Ledfat area is characterized by a fault topography. Buttes with steep sides and flat tops are usual. There is an obvious top level constancy. Bedding is mostly horizontal.

The strike and dip of the conglomerates is frequently apparent from the topography, and may be occasionally determined from aerial photographs. Outcrops have been modified to a degree by glaciation, and crevasse systems have resulted in shapes that may be mistaken for outcropping strata at some distance. Morphology was a great help in tracing the boundaries in the eastern part of the area.

As a result of the now completed mapping, a rather detailed stratigraphy of the rocks of the Ledfat area has been obtained. A summary follows below. A more detailed description of stratigraphy will be given in a section dealing with the petrographic analyses of the various formations. Large parts of the sediment complex were known through the earlier mappings of Alvar Högbom and S. Gavelin. Correlation may be obtained between certain components of the Ledfat area and G. Kautsky's stratigraphy of younger formations of the Skellefte field. Large parts of Kautsky's Elvaberg series are lacking in the Ledfat area. On the other hand, certain rock types in the latter region do not seem to be represented in the eastern segment of the Skellefte field. Introduc-

tion of new formational or group names to the stratigraphy of the Skellefte field would at the present time not be desirable. For the sake of convenience, however, the rocks of the Ledefat area had to be divided into formations. Only for the younger conglomerate formations, there was an adequate and sufficiently well known name in current use. Thus the name Vargfors conglomerates was adapted for these sediments. In this description of the Ledefat area, the Vargfors conglomerates have been divided into a lower and an upper formation. However, the reasons for this division may be rather locally restricted. The older Ledefat rocks have been divided into three different formations. Each formation has been named after some characteristic member, even though there are always other rock types within each particular formation. The whole rock complex has been called the Ledefat Series. Roughly, the Ledefat Series might be designated as a non-marine equivalent to the mainly marine Elva-berg Series of G. Kautsky. The alluvial Vargfors conglomerates are common to both series.

Under the name Vargfors formation are included all supercrustal rocks supposedly of Karelian age within the Skellefte field. As the Ledefat rocks comprise more than one formation, the designation Vargfors formation has been avoided in this article.

## Description of Rocks

### The Porphyry Basement

Rocks of the Arvidsjaur series have been subjects to detailed mapping only in the region of their contact with the Ledefat sediments. Exposures are usually rare, and it has consequently been impossible to define accurately a sequence for the investigated area. A detailed sketch (scale 1:1,000) has been drawn of the Vargfors rocks on the mountain immediately to the east of Lake Bockträsk, located somewhat to the south of the Ledefat area. A short section of the Arvidsjaur volcanics is shown in this sketch. Volcanics similar to those on the so-called Bockträsk mountain may be recognized on the Mountain Lilla Granberget and on the western slope of the hill Granliden. The distribution of rocks, together with a few strike observations, indicate a general north-west strike. A strike of  $N 33^{\circ} W$  was measured on well-developed fluidal banding in an intermediate somewhat agglomeratic lava on the north-western slope of Granliden. On the mountain at Bockträsk, the contact between two volcanic beds was uncovered in several places to a total length of approximately ten meters. This contact strikes  $N 43^{\circ}-44^{\circ} W$ . Fluidal bandings on either side of the contact are parallel to this strike. These two observations are of particular interest as in both cases the Arvidsjaur porphyries appear in close proximity to outcrops of the Vargfors formation. Only at Bockträsk the two groups are in actual contact. (Plate II.)

The material for the Ledfat sediments is largely derived from the Arvidsjaur porphyries. Therefore a description of the outcropping volcanics of this series follows. Where possible, the rocks have been classified according to E. Grip's terminology (1925).

The section at Bockträsk is drawn on a scale of 1:1,000. The length covered is approximately 300 meters perpendicular to the strike. No vertical limits have been set. The rocks are steeply dipping, and are composed of lavas and agglomerates. At the south-western end of the profile, there is a greenish black porphyry, rich in phenocrysts, which also occurs in outcrops to the south of the mapped area. The rock is frequently fragment-bearing, but not to the extent of the subsequently described type. Relatively large portions are composed of homogeneous lava. The porphyry contains close-lying plagioclase phenocrysts of widely varying dimensions in a chemically altered groundmass. These phenocrysts are idiomorphic and prismatic or do they form short laths. Zoning is frequent, and is easily seen in ordinary light by the distribution of included particles. Judging from light refraction, the plagioclase has approximately the composition of oligoclase, but it is probable that original phenocrysts contained larger amounts of calcium. No primary textures are preserved in the groundmass. This consists of biotite and chlorite in clusters of fine flakes. The latter mineral appears also as larger porphyroblasts. Titanite is fairly abundant. Epidote occurs in a somewhat lesser quantity. Quartz and apatite appear as scattered small grains. There are no opaque minerals, but the titanite may perhaps be derived from ilmenite. With respect to shape, size and frequency of the phenocrysts, the porphyry resembles the following volcanic member, which is of a dacitic type. Its groundmass is considerably more mafic, and the rock is, macroscopically, of a darker colour. It may therefore be described as a separate type, possibly the equivalent of an andesite.

The next member is a 50 meter thick brecciated or agglomeratic porphyry of intermediate composition. This same type occurs on the western slope of Granliden, where it is somewhat better preserved. The description is therefore based on specimens taken from the latter area. The porphyry has close-lying elongated or platy feldspar phenocrysts in a dense dark or light grey groundmass. The phenocrysts may measure up to five millimeters, and are reddish, grey or white. Amygdales are fairly rare. Microscopic examination shows phenocrysts of all sizes occupying a large proportion of the space. Plagioclase is the only feldspar, and shows a pronounced zoning. The crystals have their cores strongly altered on occasion, but are, as a rule, quite fresh. Some grains show resorption at the fringes, otherwise the shape is idiomorphic. The twin *lamellae* are extremely thin. Most of the phenocrysts are of the same type, and the cores consist of basic oligoclase. (Pole curves for Carlspad twins gave, for two examined grains, values of  $An_{25}$  and  $An_{26}$  respectively. Angles of extinction, perpendicular to P and M gave for other grains values of  $An_{22-23}$ .) However, some grain cores contain considerably more calcium. In one case, pole curves for Carlspad twins gave the figure of  $An_{50}$ . (All plagioclase determinations have been made according to Tröger's tables 1956.) To a less extent, there

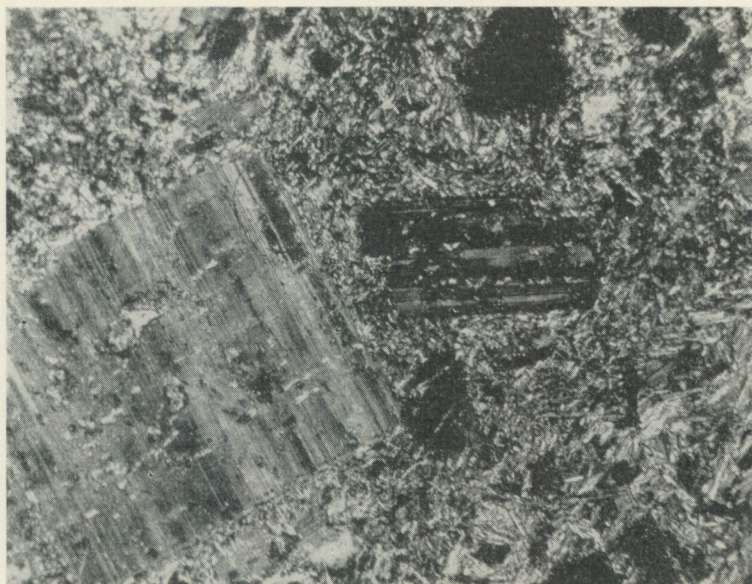


Fig. 2. Dacitic Arvidsjaur porphyry. Western slope of Granliden. — Crossed nicols. Magnification approx. 115.

are pseudomorphs of femic phenocrysts. These consist of biotite and ore minerals, or of pale green—yellowish green amphibole. The primary mineral has been a pyroxene or an amphibole. The texture of the groundmass is masked by mafic minerals and by ore pigments, but seems to have been of felsitic type. The components are, apart from quartz and feldspar, biotite, amphibole, titanite, and ore minerals. The ore mineral is evidently titano-magnetite, which frequently has been partially altered to titanite. Apatite appears as an accessory. According to Grip's nomenclature, the rock may be classified as a dacite.

The next member of the Bockträsk section is an heterogeneous volcanic breccia, or agglomerate measuring 180 m in thickness. Certain variations are apparent, but a finer division is not possible. The rock is partly brecciated, and contains sharply angular fragments of varying sizes. These fragments are dark grey or brown violet or on weathered surfaces, greenish. They may also appear as streaks or schlieren. The matrix is always strongly epidotized. The fragments consist mainly of intermediate or basic porphyry, and of a dense brownish volcanic with few, if any, phenocrysts. The latter appear also in smaller separate, relatively homogeneous, portions. At other points, the more basic fragments predominate to such an extent that the rock appears similar to a greenstone. The previously mentioned dense brownish or brownish violet volcanic is itself somewhat variant. Exposures of this rock usually show fluidal streaks with thinner, dark red bands on a brownish violet background. The banding may sometimes be very fine and spaced at a distance of a few millimeters. Under the microscope, also, the rock is inhomogeneous. Where phenocrysts are preserved, they consist of plagioclase, which is to a large extent strongly corroded. This

†1—590225. *SGU. Ser. C 564. Offerberg*

feldspar has been decalcified, and contains a large amount of epidote. The dark red portions of the rock also contain pseudomorphs of mafic phenocrysts. These are always surrounded by opaque fringes, and dissected by fine opaque veins, which may reflect original cleavages. In shape the phenocrysts are usually equidimensional, though sometimes a little elongated. Apart from ore minerals, they contain pale micaceous minerals, amphibole, and some chlorite. Relict cleavage is sparse and irregular. As pebbles in younger conglomerates, the same rock has been observed to contain similar pseudomorphs. Judging from the shape, the original mineral may have been olivine. The groundmass has a trachytic texture, and consists mainly of needles or laths of feldspar microlites. There is usually a fine powder of ore pigments which may be occasionally arranged as margarites. Vesicles, when present, are filled with quartz or epidote. Judging from the angle of extinction, and angle of optical axes, the feldspar phenocrysts have oligoclase composition. Their strong alteration makes closer determination impossible, and their decalcification indicates an originally higher calcium content.

The north-easternmost member of the section consists of a homogeneous, liparitic lava, of which the contact against the above described rock type has been exposed at several points. The contact dips  $75^\circ$  to the south-west. The liparite is on the fresh surface dark violet-grey, and reddish brown. It has numerous 1—5 mm large, reddish feldspar phenocrysts. On the weathered surface, it is greyish violet with darker or lighter fluidal streaks. Quartz phenocrysts are lacking, and the feldspar is a microcline-perthite, and to a lesser extent, an epidotized, sericitized plagioclase. Near to the border of the Vargfors formation, the liparite has weathered to an orange colour and is somewhat brecciated. This phenomenon may be ascribed possibly to the effects of ancient weathering.

The youngest members of the section are in all probability to the north-east. This may be indicated by the development from the basic to more acid types of volcanics. In the liparite, fragments of what may be considered to be the next oldest member have been observed. Numerous fragments of the basic porphyry have been found in the agglomerate component. The whole section is then slightly overturned.

The agglomerates contain a couple of half meter wide sills of granite porphyry, which is dense, and fluxion banded. In appearance it resembles seams of acid lava. However, these sills are apophyses of a wider dike of granite porphyry further to the east.

The Arvidsjaur volcanics found in the environs of the Lefat area have, in general, the same appearance as those described from the Bockträsk section. In some cases, it has been difficult to decide whether separate outcrops should be assigned to the Arvidsjaur series or to the younger Lefat sequence. It appears that there are basic lavas also in the lower parts of the Lefat series. More acid volcanics are represented at higher levels in this series as tuffites. There is, however, little chance for confusion over acid lavas, since they are of subordinate importance to the south of the Skellefte River.

### The Ledfat Series

The name Ledfat series is used provisionally in this article to designate the younger rock formations of the Ledfat area. The formation name Vargfors has been avoided here. It was originally named after the Vargfors Rapids on the Skellefte River, an area of rocks which are now assigned by G. Kautsky to the Elvaberg series (1957). On the other hand, the name Elvaberg has been avoided as a designation for rocks of the Ledfat area. The Elvaberg series consists mainly of conglomerates, effusive greenstones, and slates. Only some of the conglomerates bear any obvious resemblance to corresponding types within the Ledfat area. The thick lower divisions of both series show wide lithological dissimilarities so as to make correlation between the two geographically separate areas hazardous. Boundaries have been drawn according to whether rocks were formed in volcanic environments or derived from purely sedimentary origin. The upper sediments have been assigned to a separate division owing to their generally coarse clastic character. The total thickness of the series, where it is thickest, would appear to be around 2,000 meters.

#### THE ANDESITE FORMATION:

The thickness of the andesite formation amounts to several hundred meters. This formation is represented by few outcrops, and numerous local boulders on the western slope of Granliden. The lower contact with the Arvidsjaur series is not exposed. However, the formation includes certain characteristic rock types which, in combination with bedding attitudes and conditions, have made it possible to separate them from the porphyry basement. The picture presented by the few exposures is completed by pebbles of the volcanic formation contained in somewhat younger comparatively monomictic conglomerates. The scattered nature of the outcrops, and presumably variations in thickness and lateral extension, make it impossible to define accurately any stratigraphy. Below is a brief outline of the probable sequence.

Tuffs and tuffites

Conglomerate, mainly composed of pebbles of acid volcanics

Effusive greenstone

Conglomerate composed of pebbles of acid volcanics

Effusive greenstone

In reality a more complex interstratification between the separate types may occur. The greenstone, in any case, seems to be composed of a large number of thin beds. It is not possible to state whether or not the lowest part of the formation consists of greenstone lava. It appears from the distribution of outcrops that a conglomerate underlies the effusive greenstones. On the other hand, it is evident from the position of outcrops and local boulders that effusive greenstone is in turn overlain by a conglomerate. In the greenstone exposures, thin intercalations of tuffs and breccias have been observed.

The lavas have a somewhat variant appearance. They are usually black or



Fig. 3. Basic vesicular lava. Western slope of Granliden. — Approximately  $\frac{2}{3}$  of natural size.

green black, and frequently have a mottled appearance owing to the presence of epidote. Phenocrysts vary in size and frequency. Vesicles are generally abundant, and in some cases so closely spaced that the weathered surface of the rock resembles a fine pebbly conglomerate. The vesicles may measure up to five or six cm, and are always filled with secondary minerals.

The texture of the lavas is sometimes pilotaxitic, in other cases basaltic. Plagioclase laths appear in a mass consisting mainly of secondary mafic minerals. The feldspar phenocrysts are to a large extent strongly altered, and only in exceptional cases it has been possible to perform plagioclase determinations. The phenocrysts of less strongly altered porphyries show a marked zoning which is emphasized by the occurrence of extremely fine particles mostly in the outer sections. In a single phenocryst, the zones may be fairly numerous. The calcium content varies considerably within the individual laths. In one case values of  $An_{62}$  and  $An_{36}$  were obtained for the core and the margin of one grain. In general the centers of the phenocrysts seem to have a composition equivalent to labradorite. Pseudomorphs from femic phenocrysts are common. They are inset with uraltite, or with chlorite and ore, or with a mixture of all three. Fringes are frequently characterized by streaks of opaque particles. The original mineral has in many cases been a pyroxene. Actinolite and chlorite prevail among the mafic minerals of the groundmass. There are numerous ore grains, which are sometimes altered to titanite. Biotite and epidote are found to occur frequently. According to Grip's nomenclature, the rocks may be classified as andesites, which partly tend towards basalt.

The vesicles vary with regard to fillings. They are frequently surrounded by an outer rim of ore particles. Inside this rim there is often a zone of radially

oriented hornblende crystals. The core is usually occupied by a fine-grained quartz mass. In some cases, the quartz is replaced by microcline, which occurs as one or only a few relatively large grains. Similar phenomena have been described by Grip who believes that in certain cases alkali feldspar has originated from zeolite. One group consists of relatively large vesicles. Inwards from the rim is a zone of fairly coarse pyroxene or hornblende. Where both minerals occur together, the hornblende often occupies an outer zone. Epidote is also common in this type of vesicles, and is in other places the only mafic mineral present. The innermost portion is empty or is occupied by one single large microcline crystal. The pyroxene has the composition of diopside, and has evidently originated through skarn formation in the vesicles as have the hornblende and epidote. Finally there is chlorite with or without quartz as vesicle filling.

One variety of this rock type has a characteristic appearance under the microscope. It contains numerous small whitish plagioclase laths in a dense blackish groundmass. The texture is pilotaxitic, and frequent well-formed fluidal structures have been observed. The larger plagioclase phenocrysts are strongly altered, and no determinations could be made. The smaller laths in both phenocrysts and groundmass are better preserved. Pseudomorphs of mafic phenocrysts are lacking in this type. The plagioclase of the groundmass has An percentages of 23—24 %. The plagioclase of the smaller phenocrysts has a composition of  $An_{28}$ — $An_{29}$ , while the somewhat larger phenocrysts may contain up to 48 % An in the core. (All figures were obtained by using Rittmann's zone method.) A well-preserved fragment of the same rock found in a younger sediment had An values for three phenocrysts of 30—33 % (pole curves for Carlspad twins). The groundmass between the plagioclase laths consists largely of opaque ore particles. The result is that the texture is emphasized, and the rock has a very dark colour. There is also biotite and quartz. The ore pigments appear as coils or pearlbands encircling the larger grains or as thick clusters. In certain cases, fine plagioclase crystals are oriented in a sub-parallel attitude whereas ore particles form elongated, statistically oriented margarites. The biotite of the groundmass forms small thick plates which have a definite tendency towards an idiomorphic form. It is sometimes replaced by pale actinolite, and the two minerals seem to substitute for each other. The quartz appears frequently with the biotite as small streaks, aggregates or separate grains. Epidote, apatite, and titanite appear as accessories.

The previously described porphyries occur abundantly as grains or larger fragments in younger sandstones and conglomerates. In these situations, they vary widely as regards grain size, and degree of ore pigmentation. However, textures are usually well preserved. The groundmass is in many cases completely opaque, probably due to a secondary rearrangement of the ore minerals. Thus, under the microscope, the feldspar laths are outlined against a black background. The ore has then frequently been altered to hematite, so that fragments lacking in phenocrysts may macroscopically greatly resemble jasper. Tuffaceous variants of this rock have also been observed as fragments in younger sediments.



Fig. 4. Porphyry with iron pigments, Western slope of Granliden. — One nicol. Magnification approx. 115.



Fig. 5. Porphyry fragments in a younger sediment. Amygdales and plagioclase phenocryst in a groundmass of plagioclase lathes and iron ore margarites. — One nicol. Magnification approx. 115.

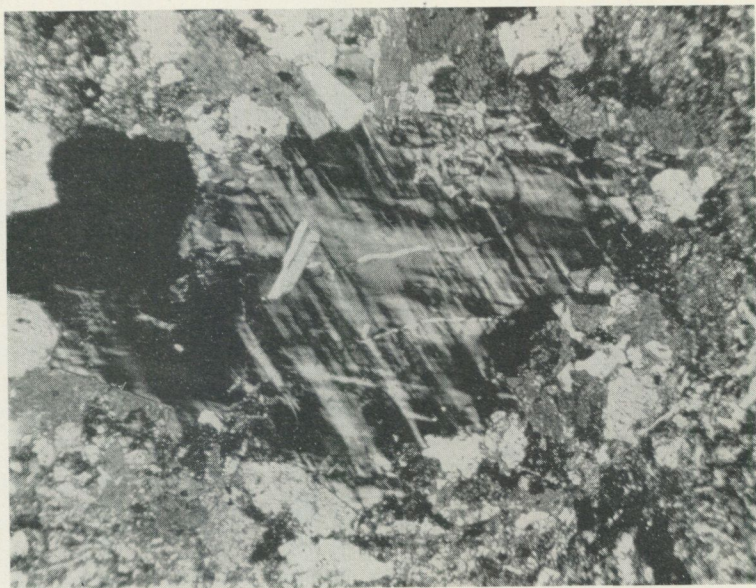


Fig. 6. Amygdale in lava. A core of microcline is surrounded by diopside. Granliden. — Crossed nicols. Magnification 25.

Another variety of these lavas is void of phenocrysts, but is highly vesicular. Vesicles measuring some centimeters and down to very small dimensions will occupy almost half of the rock volume. The intervening mass consists almost entirely of small grains or porphyroblasts of hornblende. Ore occurs only in scattered small grains. The vesicles are filled with quartz, and a subordinate amount of acid plagioclase.

In a few outcrops, an interstratification between vesicular lava and tuffs or breccias has been observed. In one case there are thin bands, several centimeters thick, consisting of a dense grey or brownish violet rock, which alternate with vesicular lava beds of one to a few decimeters in thickness. The layers of "helleflinta" are partly torn and folded. At other points, streaks of jasper have been seen in greenstone and adjoining sediments. In general, the fragments of jasper which occur in all conglomerates within the Ledefat area may be ascribed to this horizon. The lavas are sometimes fragmented with pieces of quartz porphyry or liparite.

The conglomerates are usually coarse, and contained pebbles are well worn. Finer conglomerates are occasionally seen, and within certain horizons, there are thinner sandstone intercalations. Miniature cross-bedding observed in one of these sandy layers indicates that the top of the stratum is to the east or towards the centre of the Ledefat area.

On the weathered surfaces, the conglomerates are generally tinted red or red grey due to the prevalence of acidic porphyry gravel. Occasionally there are also intermediate or basic porphyries represented. Pebbles of pyroclastic or sedimentary material are almost lacking, and there are no indications of plutonic

rocks. The matrix is, as a rule, quantitatively subordinate. Under the microscope, the gravel appears to be altered, and without preserved groundmass texture.

Further to the south on Granliden, an angular conglomerate or breccia has been found. The rock is monomictic, and consists of dacitic Arvidsjaur porphyries rich in phenocrysts, similar to those found in outcrops on the lower slopes of Granliden. The fragments vary as to the degree of wear, but they are seldom rounded. There is very little matrix, and at times, the rock resembles a homogeneous porphyry. It is frequently penetrated by epidote-rich veins which often cut right through the fragments. Under the microscope the rock proves to be a porphyry gravel, with close-lying fragments of angular or subangular porphyry fragments. The matrix is recrystallized and contains epidote and quartz. The fragments are not as fresh as the original porphyry in outcrop. In some portions, there are numerous pseudomorphs consisting of fine clusters of feldspar, amphibole, mica, and andalusite. It is quite probable that in some cases the primary material was phenocrysts of plagioclase. Therefore, *e.g.*, the andalusite may be indicative of a certain degree of fossil weathering.

Only one outcrop of tuffs or tuffites has been encountered. On the other hand, they are extremely well represented within the conglomerates of the overlying formation, which makes it possible to know more about them. Boulders of the same rock have been found at certain locations.

In this single outcrop, the weathered surface of the rock is grey or violet. The fresh surface is dark brown violet, and shows very thin laminations. The thickness of the *laminae* usually varies around 1 millimeter. The consistency of the sediment ranges from dense to more sandy. There are some layers of epidote which are broader and frequently dissected. Considerable variations in grain size make the laminations easily visible under the microscope. Composition varies somewhat with the laminations. Dense layers are very fine-grained but contain scattered coarser grains and rock fragments. The primary texture has been obscured by sericitization. Coarser layers have an arenaceous nature. There are preserved remnants of the idiomorphic shape of the quartz grains which are often splintered. The feldspar grains are strongly turbid, but consist at least partly of microcline. The small rock fragments, which are all of the same type, contain a large proportion of feldspar, and have a microgranitic or perhaps, to some extent, microgranophyric texture.

Local boulders with laminations of skarn minerals were observed. Tuff *laminae* are dark violet grey. Skarn bands are composed of diopside, hornblende, zoisite, and a little quartz. The outer fringes are rich in zoisite while the center consists of diopside or hornblende. Quartz grains, when seen, are relatively large, and are located in the centers of the skarn bands. Some of these bands have been dissected to small oval or elongated lenses.

An occurrence of a jasper-like sediment on the western slope of Granliden has been mentioned by S. Gavelin (1948). The rock is composed mainly of quartz and plagioclase and is veined by pigments or clustered flakes of iron oxide. Andalusite is fairly abundant.

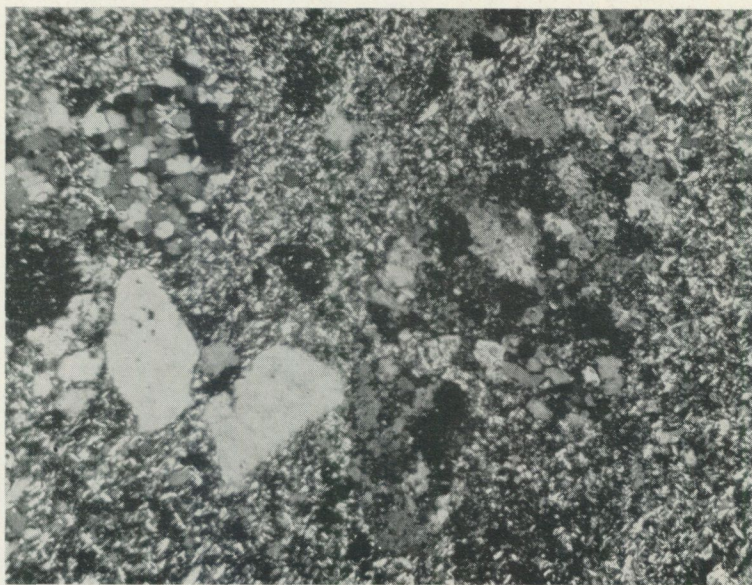


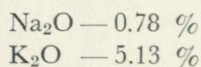
Fig. 7. Tuffite. Western slope of Cranliden. Grains of quartz and feldspar together with small rock fragments in a dense sericitized groundmass. — Crossed nicols. Magnification approx. 115.

As gravel in younger conglomerates, sediments of a more or less pyroclastic type have been observed. Among others, there are tuffs with numerous small but angular splinters of an extremely fine-grained volcanic in a quantitatively subordinate, very fine-grained matrix. There are also light-coloured, dense pebbles containing almost exclusively felsic components. Under the microscope, in ordinary light, the rock may exhibit a marked tuffaceous texture with closely spaced devitrified glass fragments.

The volcanism, from which the above-described tuffs and tuffites have originated, has evidently been of an acid nature. No corresponding lavas outcrop in the Ledefat area. If pebbles of the acid Vargfors lavas should be present in the conglomerates, it is impossible to distinguish them from the Arvidsjaur porphyries. Small rock fragments in the tuffs may constitute more reliable specimens of the lavas in question, but in this case, only the groundmass is obtained. The fragments are salic with extremely small ore inclusions as the only coloured components. The rock is aphanitic to the point where grains are cryptocrystalline. Coarser grains have a pronounced microgranophytic texture. The content of the pigment varies. The ore particles are frequently arranged in thin, undulating bands which are derived from original fluidal structures. They are independent of the crystallization of the groundmass, and pass straight through the grains. Judging from light refraction, the feldspar appears to be potassic.

As yet, no alkali analyses have been made on the pyroclastic sediments. Microscopy reveals that microcline is an important constituent of the rocks.

The strata immediately overlying the volcanic formation consist of sandstones and conglomerates which are largely, if not solely, derived from the tuffs, tuffites or possibly their extrusive equivalents. Alkali analyses have been run on a fine grained sandstone member, and the results are as follows:



(Analyst: A. Aaremäe, Geological Survey of Sweden.)

#### THE SANDSTONE FORMATION

The total thickness of the Sandstone formation seems to be about 650 meters. The main extension of this formation is on, and a little to the east of Granliden, and on the northern part of the Mountain Stora Granberget. There are smaller occurrences in other places. On the northern slope of the hill Sätmyrliden, one outcrop and one accumulation of boulders belonging to this formation have been found. On the Mountain Aspavaberget, there are large and small fragments of the formation found in granite. To the east of the Mountain Njuonjesvare, in Norrbotten county (map sheet 34 Storavan), there are several outcrops which may belong to the same formation. The latter area is included in O. Ödman's map of the county of Norrbotten and in his description of this map (1957).

The lower portion of the formation is sparcely represented by outcrops, and hence it is difficult to draw a definite boundary between this and the underlying formation. There is probably no sharp division between the tuffs and tuffites of the andesite formation, and the basal sediments of the Sandstone formation. The separation between the formations has been made on the basis of the cessation of volcanic activity as indicated, for example, by the frequency of quartzitic rock types in the upper parts of the Sandstone formation. A disposition of the most important members of the formation follows.

Arkoses and feldspathic quartzites with scattered thin conglomerate intercalations, or single pebbles .....	c. 300 meters
Monomictic or oligomictic conglomerates alternating with sandstones .....	c. 100 »
Dark grey or brownish violet sandstones composed of supercrustal rock material .....	c. 250 »

The figures given for thickness are only approximations. When using the term arkose, the meaning is taken in accordance with American standards, that is sandstone rich in quartz and feldspar. The feldspar volume percentage exceeds 25, and there is a low content of fine-grained or originally clayey matrix. Whether or not these rocks can be genetically classified as arkoses can hardly be decided with certainty. Fine pebble or granule conglomerates have not been treated as arkoses in this article.

*Dark Grey or Brownish Violet Sandstones*

At the base of the formation, these sediments are macroscopically dark to violet grey, and have a sandy consistency. They contain frequently thin, blackish, denser layers which may sometimes be broken into lines of intraformational fragments. Truncated cross-bedding has been observed in local boulders and at one point in outcrop. In the latter case it is beautifully accentuated by the occurrence of thin *laminae* of magnetite sand on a lighter background. It is of the concave type with broom-shaped radiating sets of layers. Cross-bedding on a large scale seems to be restricted to the lower sandstone beds. Higher up in the sequence, the sandstones are generally finer grained and more evenly and thinly layered. The layers are frequently graded, and sometimes miniature cross-bedding can be observed. Mudstone variants of the sediments are very thinly laminated with less than one millimeter thick *laminae* in sets of several hundred. Boudinage structures are fairly common in these types. Epidote-tinged layers appear, contrary to the usual conditions in the more finely clastic sediments, not in the sandstones at the bottom of the formation.

The sandstones are poorly sorted as to grain size and shape with a predominance of angular or edge-worn mineral grains. Small rock fragments occur fairly infrequently. Larger grains are mostly quartz originating to a large extent from quartz porphyries. Many grains show remnants of idiomorphic shape while others are granulose and rounded as in certain types of liparites or quartz porphyries. Since the quartz grains have been derived, at least partially, from porphyries, it is impossible to decide whether those having the more rounded shape have been worn during transportation by water, or if they have been resorbed by lavas. Feldspar occurs in varying amounts, and consists largely of microcline and microcline-perthite. Dark minerals occur usually in the fine-grained portions, and are biotite, ore, and amphibole. Single small grains are titanite, apatite, tourmaline, and zircon. Microscopic examination sometimes shows traces of miniature cross-layering. The scattered rock fragments are of the same type as those occurring in the underlying tuffs. There are also quartz amygdales from porphyries.

In the more finely clastic sediments, layering is easily visible as sorting of grain fractions, and is emphasized by thin *laminae* rich in ore grains. Larger grains are usually somewhat edge-worn, while smaller grains are splintery. The latter are triangular, wedge-shaped or gently bow-shaped. A large portion of the quartz grains are drastically elongated so that their width may be only one tenth of the length. In this case, there is no coincidence of the axis of elongation and the crystallographic *c*-axis. The grains probably originate from tuff material. The feldspar is still microcline or microcline-perthite, while plagioclase is practically lacking. These sediments are in composition similar to the underlying tuffites. Two alkali analyses have been performed on sediments from this part of the Tjärnmyr formation. One of these analyses has been mentioned already in connection with the description of the tuffs and tuffites of the volcanic formation. The other one was made on a brownish violet mudstone type of sediment from the top of the division, and was as follows:

Na<sub>2</sub>O — 0.62 %K<sub>2</sub>O — 6.06 %

(Analyst: A. Aaremäe, Geological Survey of Sweden.)

Both assays indicate a strong predominance of potassium. Microscopy done on other samples also points in the same direction.

*Conglomerates, mainly monomictic or oligomictic*

The conglomerates are exposed almost exclusively on Granliden. On the north-western peak of Stora Granberget (Bergtjärnvallberget), there are also beds of conglomerate alternating with sandstones. The lower beds of the conglomerate alternate with beds of the previously described sandstone. The upper conglomerate beds alternate with the more arkosic or feldspar-quartzitic sandstones. There appears to be a successive transition between sandstone types.

The conglomerates, in general, have a fairly characteristic appearance. They are never coarse, but have pebbles up to five or six cm in diameter. The matrix varies in quantity. It has usually a sandy consistency and is more or less rich in epidote. Pebbles are usually worn, but may be subangular. They are very often elongated due to the fact that they have been derived from layered, mostly finely clastic sediments of the lower parts of the Ledfat series. Thus, on the fresh surfaces, these pebbles are dark grey, brown violet or brownish. They are generally fine-grained. To a lesser extent, there are also light reddish aphanitic pebbles. The monomictic character of the conglomerates is illustrated by the following table which shows the results of a pebble count from Granliden.

Pebble type	Number of pebbles counted
Fine-grained sediments and aphanitic types (" <i>helleflintas</i> ") . . . . .	523
More sandy sediments . . . . .	13
Grey, intermediate or basic porphyry . . . . .	3
More acid porphyry . . . . .	4
Total . . . . .	543

Pebbles of deep-seated rocks have not been encountered. At one point though, pebbles likely to be vein quartz have been observed. Further on it is possible that certain of the dense pebbles actually consist of a ground mass of dike porphyries. The same exposure that bears the pebbles of vein quartz is also more polymictic. Among other things jasper has been observed there. The aphanitic pebbles in the conglomerates are frequently surrounded by zones of alteration where the colour has changed from dark grey or brownish violet to light red. As this phenomenon is more frequently observed on the weathered surfaces, it must, at least in part, be ascribed to recent weathering which has started in the more porous matrix and proceeded inwards towards the center of the pebble. The matrix consists of a poorly sorted mass of quartz and microcline, epidote, and amphibole. The latter two minerals are frequently in the shape of por-

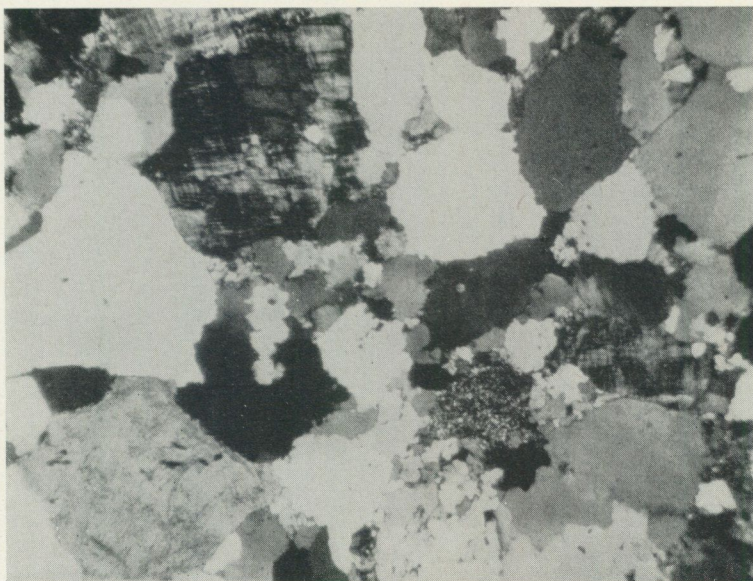


Fig. 8. Feldspar quartzite. Granliden.— Crossed nicols. Magnification approx. 25.

phyroblasts. The quartz grains frequently have the same shape as phenocrysts in porphyry. The thickness of the conglomerate beds is widely variant. The maximum thickness of one separate bed may amount to several tens of meters.

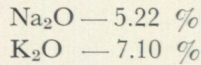
#### *Arkoses and Felspathic Quartzites*

The arkoses and felspathic quartzites constitute a fairly uniform group of sediments within the Ledefat area. They are light grey, whitish, or light red in colour. Their layering is usually indistinct, if present at all. Cross-bedding is rare, but has been observed in four separate cases. Apart from a varying but generally low content of small rock fragments, the sediments are composed almost exclusively of quartz and feldspar. Coloured or opaque minerals form a low percentage of the total volume. Size and shape of the sandstone grains is relatively uniform and the sediments are usually considerably coarser than other arenaceous rocks within the Ledefat area. Fine-grained or originally clayey matrix is subordinate or completely lacking. Mineral grains are frequently well rounded, but the rocks are as a rule recrystallized so that most grains have lost their original shape. Even in the better preserved types, many of the grains are closely interwoven. Sometimes thin ring-shaped lines of mica minerals mark earlier crystal boundaries within quartz aggregates. Feldspar, more often than quartz, has a tendency to lose its original clastic grain shape. The boundary between quartz and feldspar crystals is frequently defined by fine clusters of both minerals which often form oriented intergrowths. These clusters seem to be recrystallized micro-breccias which have been caused by friction at the grain boundaries. The relatively high grade of recrystallization may be ascribed to a

lack of matrix which has caused the larger grains to come into close contact with each other during deformation. The feldspar consists mainly of microcline or microcline-perthite. The coloured components are ore, chlorite, mica, epidote, and to a lesser extent, tourmaline or zircon.

The quantity of feldspar, which varies, may at times be equal to that of the quartz. All transitional grades between relatively pure quartzites and arkoses will be found. The small rock fragments are usually aphanitic, and weather to a red colour. They sometimes contain small corroded phenocrysts of quartz and microcline. They are highly potassic. There are also fragments of a fine-grained rock composed of quartz and microcline. The latter may equally well be an aplite as a recrystallized sediment. Hence, it appears quite possible that at least some of the rock fragments are derived from acid dikes. The separate mineral grains, too, could then possibly come from granites. Pebbles of microcline granite have been encountered in the youngest conglomerates within the Ledfat area. Thus, in the case of certain of the previously described sediments, the designation arkose may be justified from both genetic and petrographic standards.

A group of well-layered mudstone-type sediments sometimes appear together with the sandstones. An alkali analysis performed on a sample taken from this group shows the following results:



(Analyst: A. Aaremäe, Geological Survey of Sweden.)

The lower sediments of the Sandstone formation evidently reflect a rapid erosion of the products of the preceding volcanism. The subsequent sandstones show a higher degree of maturity indicating more peaceful conditions.

#### THE TUFFITE FORMATION

The Tuffite formation is well exposed. The principal distribution of this formation is within the northern and north-western parts of the Ledfat area, and to the west of Lake Laggträsket. At the tarn Holmtjärn to the east of Granliden, the formation shows signs of wedging out, but here granite intrusions make it difficult to follow. Further to the south, the Tuffite formation is omitted, and the overlying Vargfors conglomerates rest directly on the Sandstone formation. The widely varying thickness seems natural when the local character of the sediments is considered. To the east of Granliden, it may be about 400 meters thick. Both the top and bottom of the formation may be studied in the field. There is concordant deposition in both cases. The formation is composed of more or less pyroclastic sediments and sandstones which are partially, if not entirely, derived from volcanic rocks. The tuffitic sediments mostly resemble mudstones, and may grade into aphanitic rock types ("*helleflintas*"). Conglomerates are insignificant. Principal macroscopic divergence

from the underlying formation is in colour and bedding. Predominant colours in the Sätmyr formation are brown and red violet, and red. Layering is pronounced. Since many layers do not persist for any distance it is difficult to outline a detailed stratigraphy, which is true, incidentally for the whole area. However, there are three main divisions which can be made.

Sandstone, mostly brownish violet in colour.

Brick, greyish, or violet red tuffite with subordinate intercalations of brownish violet sandstone, and light, white-weathering "*helleflintas*", and occasional conglomerate.

Brown violet sandstone and mudstone with intercalations of violet red tuffite. A conglomerate occurs near the base.

The lowest beds of the formation are exposed a little to the east of Granliden in the immediate vicinity of outcrops of light red feldspar quartzite. Strikes and dips are the same on either side of the formation boundary. A sediment which resembles mudstone, lies on top of the quartzite. It is a few meters thick, and is coloured yellow, orange, grey or greyish green on the weathered surface. On the fresh surface, the rock is light or dark grey. It contains numerous skarn bands, and within certain layers there are zoned skarn spots. Under the microscope, the rock is fairly evenly grained. Grains are frequently elongated, and sometimes even slightly bow-shaped. The matrix is sericitized. The feldspar is made up of both plagioclase and microcline. The mudstone is overlain by a graded conglomerate which weathers to a red colour. Cobbles may be up to 25 cm large at its base. This conglomerate is only a few meters thick, and wedges out to the northwards at a distance of perhaps 10 meters to be replaced by a more sandy sediment. However, it reappears at other points. Acid and intermediate porphyries, arkose or feldspar quartzite, and dense rock types ("*helleflintas*") are all represented in the fragments within the conglomerate. Upwards, the conglomerate quickly becomes more sandy. Certain layers contain closely spaced, small angular rock fragments. The sediment is dark red in colour. Tuffite is emphasized in the matrix which contains small splintery crystal fragments of quartz and feldspar. With ordinary light it is possible to see small devitrified glass fragments. The feldspar consists of both plagioclase and microcline. The red colour previously mentioned is caused by fine hematite dust, which frequently accentuates the texture. This particular sediment rapidly changes to a homogeneous, fine-grained, brownish violet sandstone or mudstone.

Subsequent to these are brownish violet or grey, well-layered sandstones alternating with brown violet or red mudstones. The latter have a partially tuffitic character. There are thinner intercalations of dense, light coloured or dark brown violet sediments. The sandstones have a purely sedimentary texture. Their sorting is comparatively good and the grain size varies with the layers. There are numerous epidote-coloured bands or streaks. Small rock grains occupy a large part of the volume. They consist of varying extremely fine-grained volcanics. Quartz nodules loosened from porphyries can be seen occasionally. Quartz, partly of phenocryst type, potassium feldspar and plagioclase, appear as

separate mineral grains. Rock fragments and mineral grains are relatively well rounded or subrounded. Epidote is concentrated within certain layers but may also occur as single grains. Manganese epidote may be seen occasionally, partly in intergrowth with common epidote. A large number of feldspar grains and many of the rock fragments are strongly sericitized. The matrix seems to occupy an insignificant portion of the total volume of the sediments, and hardly any originally clayey matrix appears to exist. The brownish violet tinge is caused by the presence of small rock fragments. Where these decrease in number, the colour tendency is towards a grey. The sandstones were probably deposited in a volcanic *milieu*, and would be called, according to American standards, volcanic arenites. Cross-bedding occurs, but not so frequently as in the upper parts of the tuffite formation.

The sandstones and mudstones alternate with tuffitic sediments. The latter are not so pronouncedly pyroclastic as the more collected tuffites higher up in the sequence. The pyroclastics grade into nonvolcanic types, and frequently the rocks can not be distinguished from one another with the naked eye.

On the northern side of the hill Sätmyrliden, thin intercalations of a light grey or dark violet brown, aphanitic type ("*helleflinta*") have been observed in a group of sandy or muddy sediments. Current bedding may be seen occasionally on the weathered surfaces. Layers of small intraformational conglomerates are also found. Within the conglomerate, there are elongated fragments of the same rock which have a sub-parallel arrangement. *Boudinage* structures are fairly common on the layer boundaries. The rock is extremely fine-grained, and even with the strongest magnification, only scattered mineral grains can be seen in a cryptocrystalline groundmass. The visible grains consist mainly of quartz, and the rock as a whole is quite felsic. In all probability, the rock type in question is a result of more distant volcanic activity.

On such a fine-grained sediment, one alkali analysis was performed:

Na <sub>2</sub> O	— 2.32	%
K <sub>2</sub> O	— 6.16	%

(Analyst: A. Aaremäe, Geological Survey of Sweden.)

It is not possible to draw a sharp boundary between the previously described, and the immediately subsequent group of sediments which are of a more pronouncedly pyroclastic character. Within the transition zone, there is an interstratification of brown violet, or grey, muddy sediments, red tuffites, and aphanitic rock types which weather to a white on the surfaces. In a couple of outcrops, conglomerate was also observed. This conglomerate is generally brown violet or red, and contains pebbles or cobbles of varied sediments and volcanics. Its thickness may amount to a couple of meters.

The following component is a group of red tuffitic sediments with a thickness of approximately 200 meters. Within this component are a number of less important intercalations of brown violet sandstones. Rocks of this type are well exposed on Sätmyrliden. They are also exposed, but less frequently, in other



Fig. 9. Crossbedded red tuffite. Sätmyrliden. — About  $\frac{1}{2}$  of natural size.

parts of the Ledefat area. Both the tuffites and other parts of this formation have been previously described by S. Gavelin (1955).

Weathered surfaces accentuate the thin layering of the tuffites. Cross-bedding is very frequently observed, and truncations show angles of up to  $30^\circ$ . Current ripples which occur to a lesser extent are restricted to the lower portions of this particular division. The sediments are fine-grained, and have a finely sandy or muddy consistency. There are also more aphanitic types. The rocks are generally brick red, reddish grey, or violet. The brick red colour is particularly characteristic, and may appear over large areas or as thin intercalations with other colours. It is a result of a high content of hematite pigments which may appear in streaks or in whole horizons. Epidote-tinged layers or spots are also abundant. The bright red layers may weather to a pale red grey with small light spots on a dark ground. The mottled appearance may be due to reticular penetrations of hematite pigments. Within the lower parts of the tuffite division, there are numerous thin layers containing small angular aphanitic rock fragments (a few millimeters in length).

Microscopic examination using ordinary light shows that the tuffites often have very distinctive and decidedly pyroclastic texture. This texture is often most easily seen in rocks having the bright red colour because of the fact that it is accentuated by hematite pigments. The sediments are to a varying amount composed of small, elongated bent or branched pyroclasts consisting solely of silic minerals. Under ordinary light, the pyroclasts appear to be homogeneous, but between crossed nicols, fine clusters of quartz and feldspar are visible. These are glassy particles which have been devitrified. Between the pyroclasts, there is a fine mass of quartz and feldspar. There are also numerous, coarser, mostly angular mineral grains of quartz, potassium feldspar, and plagioclase. Some idiomorphic remnants appear among the quartz and feldspar. Mafic minerals are either lacking or are present in insignificant quantities. Manganese epidote is a characteristic accessory. Other accessory minerals, which appear in

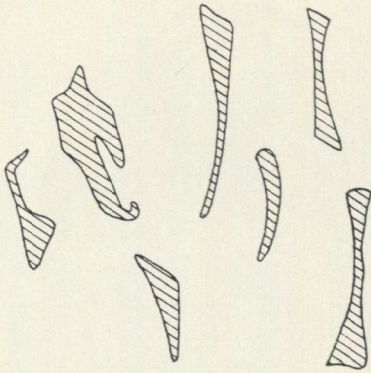


Fig. 10. Sketch of some pyroclasts from a sandy sediment. — Scale approx. 4:1.

single grains, are tourmaline and andalusite. Epidote occurs abundantly within certain layers. Easily discernible rock fragments are widely scattered and few in number. Those to be seen are so fine-grained that exact determination is impossible.

An isolated boulder has been observed which shows a number of dark pyroclasts visible to the naked eye. These pyroclasts lie parallel to the layering of a red sandy sediment.

To the west of Lake Lagträsket, the tuffites deviate a little in appearance from those previously described. They are mostly orange or yellowish pink, and are quite often strongly fractured or dissected by numerous epidote-zoisite veins which may result from a fault zone close to the granite. The rocks have variable grain size and a splintery clastic texture. The fine-grained matrix is strongly sericitized, no primary texture being preserved. In these tuffites, small fragments of feldspar quartzites have been observed.

Two alkali analyses have been performed on the tuffites:

- A) Reddish violet, fine grained sediment, northern slope of the hill immediately to the east of Sätmyrliden:

$\text{Na}_2\text{O}$  — 0.82 %

$\text{K}_2\text{O}$  — 8.70 %

- B) Orange, fine-grained sediment to the west of Lake Lagträsket:

$\text{Na}_2\text{O}$  — 1.26 %

$\text{K}_2\text{O}$  — 5.40 %

(Analyst: A. Aaremäe, Geological Survey of Sweden.)

The tuffites grade upwards for a short distance into brownish violet or grey sandstones, which form a bed of about 100 meters' thickness. Just as in the case of the tuffites, the sandstones are cross-bedded and contain epidote. They consist of angular or subangular rock and mineral grains in a quantitatively very subordinate matrix. The mineral grains are frequently idiomorphic, but they also show the effects of wear. Both potassium and plagioclase feldspars are found, the latter often being so strongly sericitized that it can be distinguished

from the finer grained matrix only with difficulty. Very fine-grained matrix is present only as a network of sericitized material.

Throughout the entire formation, there are round, oval, or elongated, partially zoned spots. The usual diameter is one or more centimeters, but some are much larger. These spots vary somewhat in appearance, but they are usually fringed by a bleached zone through which the sedimentary layering can be traced. The boundaries of this zone are ill defined. The next zone inwards is, in some cases, a porous grainy zone. In other cases, the zone is coloured red and has the appearance of jasper. The next zone towards the center usually consists of quartz. The core may contain ore grains or it may be void. The oval or more elongated spots are generally oriented parallel to the layering which is convex around the spots. In exposures which show cross-bedding, the spots follow the layering of the surrounding sediment. Thin sections of the spots show that relatively large ore grains and mica flakes occupy the core. The surrounding ring is made up of fairly coarse-grained quartz which becomes more fine-grained outwards from the center and finally grades into the encompassing sediment. However, the border is marked by a thin selvage of hematite. The primary texture of the outermost bleached zone has been preserved.

A group of especially beautiful, but sparsely distributed, larger spots contain up to eight different concentric zones. The hollowed out portions have probably had a certain lime content. In recently blasted boulders along the new forest road through the Ledefat area, limey spots have been observed. Both small and large spots show varying degrees of elongation, and forms occur which are transitional to actual layers. Similar phenomena have been mentioned fairly frequently in literature where they have been called "ellipsoidal formations", "cigar structures", "pseudo-nodules", "rolled up structures", "Sediment Rollen", and "*Schneeballen Strukturen*", etc. In Sweden they have, for example, been mentioned by M. Beyer (1954), P. Geijer (1923), A. Hadding (1931) and N. H. Magnusson (1925). A fairly detailed list of literature on this subject has been compiled by P. Macar (1948). The formations have been given several different interpretations. The hypothesis that might best apply to the concentric spot formations in the Ledefat area has been presented by P. Macar and other authors. This hypothesis is centered around subaquatic ground slides which occurred almost simultaneously with the deposition of the sediments. During these slides, certain of the thinner but cohesive layers may have been rolled up.

It has been previously pointed out that the Tuffite formation is lacking within the southern part of the Ledefat area. Both the older and younger sediments are preserved. This implies that either this particular formation was never deposited, or it was eroded immediately after deposition. In both cases it must be presumed that vertical movements of some kind were taking place at the time of deposition of the formations. The concentration of granite and granite porphyry intrusions in the same part of the Ledefat area must also be mentioned in this connection. Apart from the intrusive dikes, there is a relatively high occurrence of crevasses here as compared to other sections of the area.

## THE MOUNTAIN AT BOCKTRÄSK

As is shown in plate II, the Arvidsjaur series and Vargfors formation are both represented within a small area. The Arvidsjaur volcanics have already been described. On the eastern side of the mountain, the younger rocks form a pocket which cuts through the older rocks in an angular unconformity. Both formations are intruded by granite porphyry and dolerite.

At the base of the younger sediments is a conglomerate layer, which is quite thin, or in some places completely lacking. It appears that the conglomerate is thickest towards the center of the original basin, and thins out towards the edges. The lowest part has the appearance of a basal breccia with half meter large angular fragments of volcanic rocks in an epidote-rich matrix. This breccia also contains fragments of arkose or feldspar quartzite which excludes the possibility of its being a breccia within the Arvidsjaur series. Upwards, the breccia grades rapidly into a conglomerate with rather well rounded pebbles and cobbles of varying size in quantitatively small matrix. The cobbles may be up to 25 cm large, or in some cases larger. However, there may often be a finer pebbly consistency to the conglomerate. Among the pebbles are liparitic, dacitic or more basic volcanics, arkose or feldspar quartzite, fine pebbly conglomerate, brown violet sandstones or mudstones, and banded light coloured aphanitic types ("*helleflintas*"). Under the microscope, it is possible to see numerous fragments of porphyry which resemble the greenstone lavas of the lowest division of the Ledfat series. The conglomerate is devoid of granite pebbles.

This conglomerate is overlain by aphanitic, well-layered sediments ("*helleflintas*") which vary in appearance and colour. Where the basal conglomerate is lacking, these rocks rest, with almost perpendicular unconformity, upon the Arvidsjaur series. The unconformity is best visible at the point of the contact between the sediments and the liparite, since both rocks show strike and dip. This contact is exposed for several meters on the north-eastern precipice of the mountain. The contact between the sediment and an intermediate agglomeratic Arvidsjaur volcanic is also exposed. The boundaries undulate to some extent, but are as a whole fairly straight.

The banded sediment, which may have a thickness of up to 15 or 20 meters, is often very thinly laminated with colours from dark violet red to yellow grey. It is extremely fine-grained. Even under the microscope, using the greatest magnification, grain fractions are barely visible. It is very felsic, and in a few samples, small radiating spots or streaks of colourless chlorite were the only femic components observed. Occasionally, there may be single small grains of tourmaline. The violet, or deep red colour of some of the rocks is caused by innumerable ore microliths which are frequently concentrated in layers. Somewhat larger crystal fragments consist mostly of quartz. Where feldspar grains occur, they are too highly sericitized to be identifiable. The quartz grains are either splintered, or they may have a fairly well preserved idiomorphic shape.

In one sample, numerous idiomorphic remnants of partially or completely altered andalusite were observed. The grains, or pseudomorphs are small, but

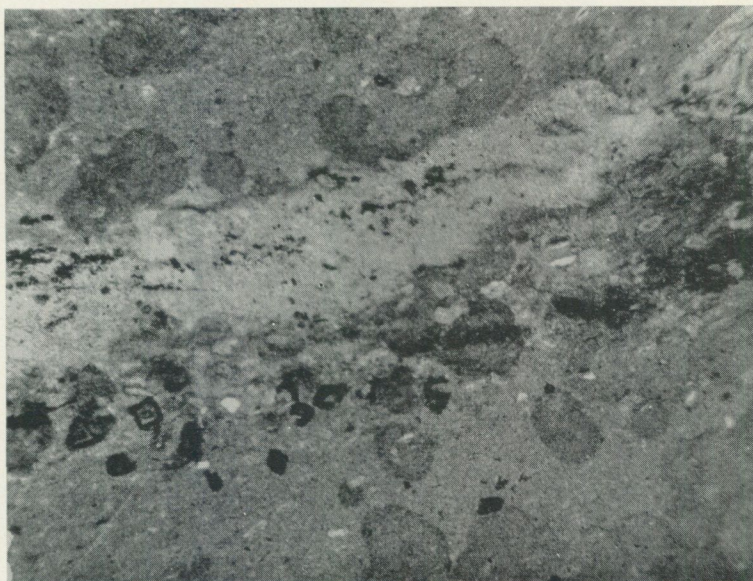


Fig. 11. Banded sediment from the mountain at Bockträsk. Andalusite pseudomorphs (dark) and diffuse rounded spots. — One nicol. Magnification 25.

easily distinguishable even using a weak magnification. Many are sharply defined, but others again may appear as more diffuse spots. In the same section, there are numerous ill-defined blotches which have a rounded shape, and which frequently lie in such close proximity that they touch one another. They have somewhat darker edges, and are easily visible with weak magnification. When a stronger magnification is used, they become indistinguishable from the rest of the rock. In certain cases, they have a higher mica content. The spots may also be derived from andalusite grains which have been decomposed and assimilated by the groundmass.

An alkali analysis has been performed on one sample of this rock:

$\text{Na}_2\text{O}$  — 0.61 %

$\text{K}_2\text{O}$  — 4.18 %

(Analyst: A. Aaremäe, Geological Survey of Sweden.)

The banded sediment is followed in turn by a conglomerate. The contact is a small disconformity. This conglomerate is similar to the previously mentioned basal conglomerate on the mountain, both with regard to appearance, and material.

Judging from the composition of the lower conglomerate, which contains pebbles of arkose or feldspar quartzite, it is evident that the sediments on the mountain at Bockträsk must be classed with the younger formations within the Ledefat series. On the other hand it is impossible to decide whether the sedi-

ments should be correlated with some of the divisions of the Tuffite formation or with a dense pyroclastic horizon at the top of the lower Vargfors conglomerate. A granite-looking pebble which has been found in the upper conglomerate on the Bockträsk mountain would appear to be evidence in favour of the latter assumption. In either case it is evident that the main part of the lower Ledfat formations is lacking at Bockträsk. In a similar way, conglomerates of the Vargfors type are in many other places the only representatives of the Ledfat series. (*E.g.* in the Johannisberg area to the south-west of the Ledfat district.) The total thickness of strata that can be proved as lacking at Bockträsk between the Arvidsjaur series and the Ledfat rocks may exceed a thousand meters. The value of the Bockträsk locality is therefore somewhat diminished. It is impossible to decide whether the unconformity there corresponds just to this column of absent strata or if it is of greater magnitude. Incidentally, the unconformity between the Arvidsjaur porphyries and the andesite formation of the Ledfat series is not as obvious as that on the Bockträsk mountain. However, the hiatus between the Arvidsjaur and Ledfat series is proved to include one granite cycle. The Arvidsjaur porphyries are intruded by granite, pebbles of which are found in the upper Vargfors conglomerate of the Ledfat and other areas. It does not seem likely that there is room for this granite cycle within some thousand meters of missing strata which are, furthermore, of a rather rapidly assembled type.

#### VARGFORS CONGLOMERATES

##### *Lower Vargfors Conglomerate*

The lower Vargfors conglomerates are among the best exposed sediments within the Ledfat area. They form several different varieties, of which the bright red one has attracted most interest. There are variations in thickness. The steeply upturned layers on Sätmyrliden are a little more than 100 meters thick, whereas the thickness is probably less in most other places. As is shown by the geological map, the conglomerates rest conformably upon the underlying, more finely clastic sediments. The fact that the conglomerates within the southern part of the area rest directly on feldspar quartzites of the sandstone formation does not necessarily mean that there exists any considerable hiatus at the base of the conglomerate. In the field it is in many places possible to observe the conglomerates resting conformably on the uppermost brown violet sandstones of the Tuffite formation.

These conglomerates vary somewhat in appearance, but among the lower beds there are two extreme types with transitional forms. One of these has bright red colouring, and occurs within the north-eastern parts of the Ledfat area. The other type is greenish, and occurs further to the south. The difference is less conspicuous with than without microscopic examination.

To the north, the lower, and larger part of the formation consists of intensely red or red mottled, partly coarse, conglomerates intercalated with thinner beds

of fine pebbly sediment or brown violet sandstone. Towards the top, the alternating beds become more closely spaced, and at times, the conglomerate acquires a more brown violet or greyish tinge. The formation is topped by a horizon of pyroclastic sediment ("*helleflinta*"), which is followed by granite-bearing conglomerates. Cross-bedding has been observed in the sandstone beds.

The conglomerates are rather polymictic. The pebble material consists to a large extent of sandy and more finely clastic sediments from the lower parts of the Ledefat series. Even fragments of earlier conglomerates are encountered. The sandstone pebbles are usually bright red or brown violet. The red pebbles consist of arkose or feldspar quartzite with worn or rounded grains. They are apparently derived from the Sandstone formation. Because of the red colour, they differ from corresponding rocks in solid outcrops. Pebbles of mudstone or aphanitic consistency are tuffite or possibly jasper. The latter may also be porphyries without macroscopically visible phenocrysts. Variegated but usually acid porphyry pebbles are abundant in the conglomerates. A bright red, coarse porphyry with large, closely spaced, phenocrysts of quartz and feldspar is a characteristic variety. The quartz phenocrysts were originally idiomorphic, but they have been heavily corroded and surrounded by coronas which consist of quartz and feldspar in oriented intergrowths. The optical orientation is the same as that of the phenocrysts. The feldspar phenocrysts are blurred, and usually lack well preserved outer contours. Identifiable grains have been revealed as microcline. The groundmass is irregularly granophyric. The only coloured minerals are scattered ore grains and a small amount of epidote. This rock may well be derived from a dike porphyry. There are more fine-grained variations of the same porphyry, but which are definitely of an extrusive type. In these porphyries, the feldspar phenocrysts are still predominantly microcline with irregular grid laminations. These are frequently surrounded by thin rims of quartz. The groundmass is very fine-grained and microgranophyric. Hematite appears as disseminated aggregates of smaller grains and microliths, which, together with numerous small grains of manganese epidote, contribute to the red colour of the rock. There are also calcite-filled vesicles. The porphyry may belong to the Arvidsjaur series, but it is also possible that it may be a lava equivalent of the pyroclastic sediments within the Ledefat series. The conglomerates also contain, in abundance, pebbles of dacitic porphyries with sometimes large phenocrysts of plagioclase on a grey ground. These phenocrysts are oriented in sub-parallel fashion. More basic porphyries occur to a considerably lesser extent. Smaller, macroscopically red and jasper-resembling volcanic pebbles consist of pilotaxitic, fine-grained porphyry, abundantly powdered with hematite. Abyssal granites have never been observed in this type of conglomerate. It is, however, quite possible that some of the red pebbles are derived from hypabyssal sources.

On Sätmyrliden, a number of pebble counts were made at evenly spaced intervals along a line perpendicular to the strike direction. From a total count of 1736, the following percentages were obtained.

Conglomerate .....	0.3 %
Red sediments (tuffites, arkoses, feldspar quartzites) .....	41.7 %
Brown violet sediments (sandstones, tuffites) .....	12.7 %
Fine grained red types (partly porphyry groundmass, perhaps partly jasper) .....	3.6 %
Intermediate and basic porphyry .....	8.3 %
Acid, mostly bright red porphyry .....	33.4 %
	100.0 %

Scattered counts with a smaller total number show figures that are not unlike those above. On the hill immediately east of Sätmyrliden, the following percentages were obtained as a result of 108 counted pebbles.

Red sediments .....	46 %
Brown violet sediments .....	11 %
Intermediate and basic porphyry .....	17 %
Acid porphyry .....	26 %
	100 %

These counts can at best only give a very approximate idea of the volume percentages of the various rock constituents in the conglomerates. Certain of the rocks, such as bright red arkosic sediments, brownish violet sandstones, conglomerates, and acid red porphyries, may form much larger fragments than the intermediate and basic porphyries, and the jasper-like rocks.

The matrix of the conglomerates is a fine pebbly to fine-grained mass of small rock fragments and separate mineral grains, of which the latter are partly of porphyry phenocryst type. Epidote, and now also calcite, are common minerals. Manganese epidote occurs fairly frequently as small grains. Pale hornblende appears as small needles in the finer grained matrix. Small scattered andalusite grains have been observed.

Towards the top of the formation, the conglomerates become more greyish. The sandstone intercalations, too, assume more greyish tinges. The most conspicuous change in the pebble material is the disappearance of the red-coloured sediments, whereas porphyries and brown violet, finely clastic sediments are still abundant. The acid porphyry has changed from red to red grey or red violet. Under the microscope, fragments of the ore-rich porphyry are still visible in large numbers. To the naked eye they are now darker in colour and not so easily distinguishable from the more fine-grained sedimentary types. Near to the top of the formation on Sätmyrliden, one single pebble of porphyric granite has been observed.

The change in appearance of the conglomerates is more conspicuous without than with the microscope. This is apparently due to a change in colour of the included pebbles rather than to a change in petrographic composition. Hence it may give an impression that fossil weathering of some of the contained rocks is responsible for the colour of the red conglomerates.

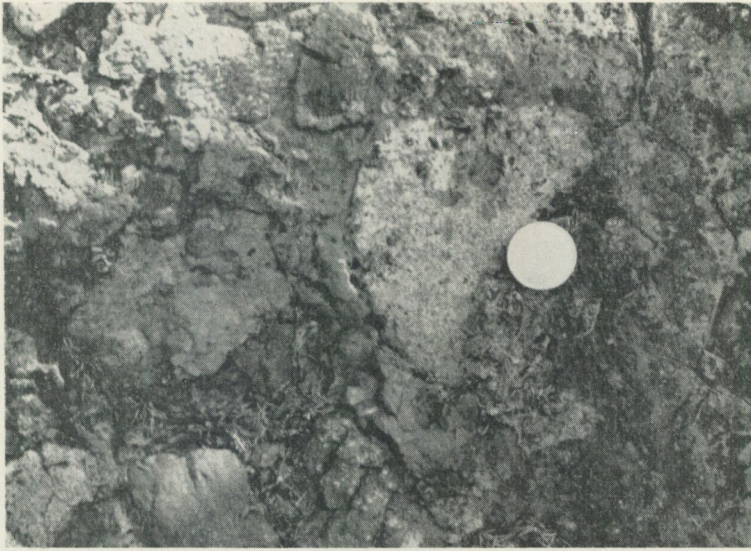


Fig. 12. Conglomerate at Laggräsk with balls of red porphyries and different sandy and silty sediments. Sätmyrliden.

The thickest sandstone intercalation observed in the red conglomerates has a depth of about 10 meters. It is possible to trace this bed for about 1 kilometer. To the west-south-west it is replaced by conglomerate, which is also true for many of the other sandstone beds. The red conglomerates thin out to the east-north-east within this part of the Ledefat area. Within the sandstones, there are small, concentrically zoned spots of the type described earlier.

On Sätmyrliden, and on the hills to the east of Sätmyrliden, there is a pyroclastic horizon at the top of the conglomerates which has been followed for a distance of almost two kilometers. The greatest exposed width is 8 meters, and apparently it diminishes to the east-north-east. The bed is graded, and contains macroscopically visible phenocrysts near the base. These disappear in the upper parts of the horizon. Microscopic examination reveals that the porphyric type has a pyroclastic texture and contains numerous, relatively large, mineral grains and splinters in a predominantly very fine grained groundmass. The visible grains vary greatly in size, and generally have an idiomorphic shape. The quartz grains sometimes appear to have been resorbed. Elongated grains are oriented strictly parallel to the bedding. The rock is very felsic, and the only significant minerals are quartz and feldspar. The feldspar is predominantly microcline-perthite. Apart from the felsic minerals, the groundmass contains a few ore grains, and scattered grains of mica, titanite, epidote, zoisite, and more rarely apatite.

An alkali analysis has been performed on one sample of this rock ("*helleflinta*") taken from approximately three meters above the lower boundary,



Fig. 13. Pyroclastic sediment (»hellefinta») at the top of the lower Vargfors conglomerate. Sätmyrliden. — Crossed nicols. Magnification approx. 115.

$\text{Na}_2\text{O}$  — 1.39 %

$\text{K}_2\text{O}$  — 4.20 %

(Analyst: A. Aaremäe, Geological Survey of Sweden.)

At one point, small dark oval rings have been observed in large number within certain layers of the sediment. These rings were up to six mm in diameter. They can be seen only on weathered surfaces. In appearance they resemble mud pellets as described in connection with investigations into recent volcanic areas.

To the west of Lake Laggträsket, there are red conglomerates similar to those just described. However, in this area, there is an increasing frequency of surfaces mottled in red and green. The green tinge is due to an increasing content of skarn minerals in the matrix. The bright red conglomerates are here also to be found at the base of the sequence. Later in the sequence the red is replaced by a dull colour. In the latter type, there are often numerous pebbles of a light yellow grey, felsitic porphyry with irregular dark spots, streaks and phenocrysts of quartz and acid plagioclase. Two closely spaced granite pebbles have been observed in this violet grey conglomerate. Near the top of the sequence, moreover, there are some fragments of granite which are strongly decomposed by some chemical action. The largest pebble of this granite is so strongly altered, that merely a skeleton of quartz grains remains. Few feldspar grains are still visible. Within the interstices are relatively large crystals of later introduced hematite. These and other granite pebbles in the

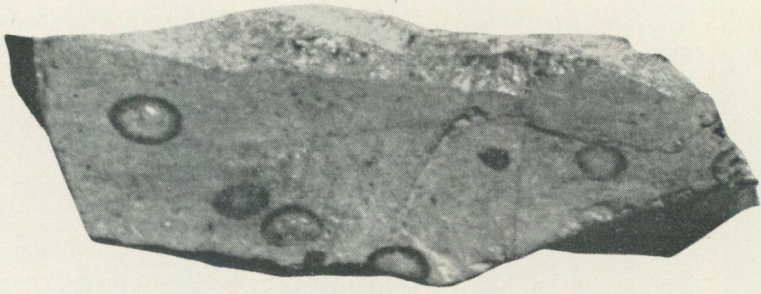


Fig. 14. Tuff («hellefinta») with ring structures (mud pellets?). The hill just to the East of Sätmyrliden. — Scale.

same vicinity have a green epidote tinge. Sandstone intercalations in the conglomerate have traces of cross-bedding.

The pyroclastic horizon, which to the north-west serves as a boundary horizon between the upper and lower Vargfors conglomerates, is missing in this part of the Ledefat area. The boundary is marked by the sudden appearance of granite pebbles in large numbers. Usually it may be determined with an accuracy of a few meters. It is also morphologically discernible sometimes.

Further to the south, and especially to the west of the mountain Gråberget, there are occurrences of a greenish Vargfors conglomerate. Within the lower beds, the cobbles are in general fairly large, and quite frequently rather angular. They consist of red quartz and feldspar porphyries together with varying sediments from the lower parts of the series. Among these sediments, arkoses and feldspar quartzites are prominent. Intermediate and basic porphyries also occur as smaller but numerous pebbles. The matrix is rich in epidote and hornblende and, together with the more basic fragments, gives the conglomerate its greenish tinge. Sandy and more finely clastic sediments appear as thinner intercalations, although one horizon reaches a thickness of from six to ten meters. They are grey or dark brown violet, and contain thin layers of conglomerate with small angular, dark aphanitic fragments.

Within the upper layers, the pebbles are generally smaller, and better rounded. The conglomerates here have alternating green and green orange mottled surfaces. Where recent weathering has been stronger, the conglomerates are sometimes entirely orange or even reddish. Similar colours appear at the contacts of intrusive dikes.

#### *Upper Vargfors*

This conglomerate is the youngest of the preserved sediments within the Ledefat area. Its thickness cannot be given since it varies from place to place. Within the northern part of the area it may amount to a couple of hundred meters.

Within the eastern and central parts of the area, the conglomerates are dark grey on fresh surfaces weathering to grey. Fragment sizes vary from boulders of up to one meter down to pebbles. Comparatively fine grained, dark grey sandstones sometimes occur as thinner beds. In general, bedding is indistinct.

Fragments are usually well rounded. To the south, the conglomerates assume a slightly different appearance; fragments decrease in size, and at the same time frequently become more angular. Bedding disappears, and there are few, if any, sandstone intercalations. The exposures are more or less pronouncedly green in colour. This conglomerate appears in regions which are rich in granite and granite porphyry intrusions. The change to the grey conglomerate is successive.

The upper Vargfors conglomerates differ from all earlier conglomerates in the Ledefat area as to the content of granite pebbles. The appearance of the granite fragments in the bottom of the formation is very sudden. Where the grey upper Vargfors conglomerate is in contact with older conglomerates, the boundary may be delimited to a stretch of one or a couple of meters across the strike direction. In places where the lower Vargfors conglomerate is overlain by a thin pyroclastic horizon, granite pebbles occur immediately above this rock. The greenish type of Vargfors conglomerate mostly contains fewer fragments of granite, thus it is more difficult to locate the base of the formation within the southern part of the Ledefat area.

Eight to thirty percent of the total number of fragments in the grey conglomerate are granite, with ten to twenty percent being the most common range. Granite boulders may be up to one meter large. There may possibly be a tendency of the granite fragments to increase slightly in size from the base upwards. There are several different types of granite. By far the most common type is a fairly coarse-grained, grey pink or reddish porphyry granite resembling the Revsund granite. The red variety, which can also resemble the Arvidsjaur granite, is more common in the greenish conglomerates, but is also present in the grey type. In smaller quantities, there are fragments of grey, evenly grained granite, of grey or faintly yellowish, typical Jörn granite, and of bright red, medium or fine-grained microcline granite. There are rare pebbles that may be granite porphyry.

The grey Vargfors conglomerates are very polymictic. They contain an abundance of different rocks belonging to the Arvidsjaur and Ledefat series. Intermediate, dacitic and keratophyric porphyries are thus very common. More basic volcanics that may be derived from both series are also abundantly represented. Basic porphyries rich in iron ore microliths are now usually black in colour. Hence, they differ in appearance from similar fragments in the red lower Vargfors conglomerate. Liparitic porphyries are less common than in the lower Vargfors conglomerate, with percentages of from five to ten of the total number of pebbles. The bright red quartz porphyry is very rare. The finely clastic, brown violet, or grey sediments from the lower formations of the Ledefat series are always well represented, and usually constitute 25 % to 35 % of the pebbles. There are also rather numerous pebbles of light grey, whitish or pink arkose, or feldspar quartzite. Red tuffitic sediments and light coloured, aphanitic volcanics are quantitatively less important. Jasper-like fragments appear sporadically.

The matrix of the conglomerates consists of small fragments of supercrustal rocks, and of separate mineral grains. There is usually a certain content of

calcite and epidote. The sandstone intercalations contain the same material as the matrix of the conglomerates. They contain a large percentage of more or less worn rock fragments together with quartz grains. Among the rock fragments, there is frequently a fine-grained siliceous variety, with small polygonal grains, which are often hexagonal. They do not tooth into each other, but instead they have straight edges. They may be quartz nodules originating from porphyries.

There are transitional varieties between the previously described conglomerate and the greenish one which occurs to the south. The fact that the latter type appears within an area heavily intruded by granites might give rise to the suspicion that the green colour is due to metamorphism. Skarn minerals apparently contribute to the green colour of the sediments. There are, however, differences between the grey and green conglomerates which cannot be caused by metamorphism. Field indications are that the contact influence of the granite and granite porphyry is restricted to a comparatively small area in the country rock.

In the usual condition, the rock consists of relatively small and often little-worn pebbles of intermediate and basic volcanics together with light-coloured aphanitic types. The latter are usually weathered to red. The matrix is green and contains skarn minerals. The exposures therefore have a characteristically green pink mottled appearance. Granite pebbles occur sporadically. They may occasionally be more abundant within certain beds. The pebble material includes smaller amounts of fine grained, brown violet sediments, and grey or reddish arkoses or feldspar quartzites. Acid porphyries are more rare. On fresh fractures it may be difficult to distinguish separate fragments, and it is also sometimes impossible to do so under the microscope, owing to the recrystallization of amphibole. There is also much epidote in the matrix.

This more extreme variety generally seems to be restricted to the lower parts of the formation. Higher up in the sequence, it is replaced by conglomerates which resemble more closely the grey type which occurs to the north. However, the weathered surfaces still retain a greenish tinge. As the attitude of the rocks is almost horizontal, transitional varieties frequently occupy the higher sections of mountain knobs. A pebble count may illustrate the composition of such a conglomerate.

Granite . . . . .	8 %
Acid porphyries . . . . .	7 %
Effusive greenstones . . . . .	45 %
Fine-grained brown violet sediments . . . . .	25 %
Arkose or feldspar quartzite . . . . .	14 %
Jasper? . . . . .	1 %
	100 %

As has been mentioned already, the Vargfors conglomerates prove to rest conformably on the next older member, when present, of the Ledefat series. The

boundary between the tuffite formation and the lower Vargfors conglomerate can be followed for comparatively long distances. Within the northern and north-western parts of the area the formations dip steeply on either side of this boundary. At times they are even slightly overturned. The strikes are always parallel, and sedimentary structures in both formations indicate that tops are in the same direction. Within the eastern part of the area, both the tuffites and sandstones, and the overlying lower Vargfors conglomerate vary from gently dipping to horizontal. The lower Vargfors conglomerate alternate with brown violet sandstones of the same type as those alternating with pyroclastic sediments in the Tuffite formation. The Vargfors conglomerates mark a sharpened relief of the country, which was predicted in the underlying sediments by a growing frequency of cross-beddings. In certain places within the Ledfat area, Vargfors conglomerates rest on rocks older than the tuffite formation. In one case, they even rest directly on an effusive greenstone. Outside the Ledfat area, conglomerates of the Vargfors type are to a large extent the only representatives of the series. This may be partly ascribed to the local character of several of the members of the Ledfat sequence. Rocks deposited in a volcanic environment, of course, are often subjected to considerable variations in thickness and areal extent. The high frequency of pebbles derived from Ledfat rocks within the conglomerates, however, reflects the fact that the lower formations have been exposed to erosion at the time of deposition of the Vargfors sediments. Even parts of the sedimentary area present still preserved must have been above the erosion base at that time.

The Vargfors conglomerates appear to have been deposited in fluvial *milieu*. Some of the more locally restricted types in the southern part of the Ledfat area may result from alluvial cones or may perhaps be fanglomerates. The source area of the Vargfors conglomerates of the Skellefte field has generally been assumed to lie to the north. Judging from the pebble material, this may also be true for the younger conglomerates of the Ledfat area. The abundance of pebble material from the Arvidsjaur porphyries would add to this possibility. Gneiss fragments have never been observed in the conglomerates of the Ledfat area. No definite current directions have been obtained from the structures within the sediments.

### Intrusive Rocks

Within the Ledfat area, granites, granite porphyries and dolerite cut the youngest of sediments. These rocks have been described previously by Alvar Högbom (1937) and S. Gavelin (1948, 1955). Hence, a detailed description is not necessary.

The Adak granite constitutes a large part of the rocks around the periphery of the sediment area. It also appears in a couple of smaller intrusives within the sediments. In the vicinity of the granites, there are frequently dikes of pegmatite and aplite in the sediments. Pure quartz dikes have occasionally been observed.

Granite porphyries of varying appearance occur in a large number of dikes within the southern part of the area. The porphyries are concentrated into those parts of the sediment area where the Adak granite is most abundantly represented. The granite porphyry dikes are sometimes quite wide. In these cases the core may be purely granitic. At greater distances from the Adak granite, the porphyry dikes become narrower, and the rock may become so fine-grained that it will be difficult to distinguish it from extrusive lavas. Over short distances, they usually have a zigzag pattern. The marginal zones of the common granite porphyries are aphanitic and sometimes show fluidal streaks. The granite porphyry has, in most cases, been intruded into fracture zones, but there are some cases of sill intrusions. The larger discordant intrusions of granite porphyry have at times caused alteration of the country rock. This may result in rusting, partly sericite quartzitic types. The small occurrence of chalcopyrite at the mountain Gråberget is mentioned in other literature (Gavelin 1955). In other places, there are small streaks or fissure fillings of hematite in the country rock or in the granite porphyry itself.

Grey yellow, or reddish, porphyritic Sorsele granite occurs as outcrops and boulders at the mire Tjärnmyran on the mountain Stora Granberget. This granite is uniformly coarse-grained, even at the lobing or curving contacts with the country rock. In the vicinity, there are dikes of the ordinary red granite porphyry, which may constitute apophyses of the massive granite.

A grey granite porphyry forms a large sill within the lowest sediments of the sandstone formation on the western side of Granliden. Similar granite porphyry has been encountered in scattered boulders in other parts of the Ledefat area. The rock contains numerous, closely spaced, whitish feldspar phenocrysts. Other phenocrysts are brown grey or sometimes blue, largely rounded and granulated quartz grains. The groundmass is grey. It is sometimes glomeroporphyritic with aggregates of feldspar phenocrysts which may be more than 3 cm in length. The individual feldspar phenocrysts vary in size, the maximum being approximately 15 mm, the minimum somewhat larger than the grains of the groundmass. The edges are often rounded. Quartz grains may range up to 8 mm in size. Under the microscope, many quartz phenocrysts prove to be idiomorphic, with a bipyramidal shape. Corrosion is strong. In many cases, there is very little that remains of the phenocryst except an oriented intergrowth between quartz and groundmass, which has nevertheless maintained the original crystal shape. Feldspar phenocrysts are both plagioclase and microcline. The plagioclase is usually idiomorphic, and is sharply prismatic or tabular shaped. The microcline is allotriomorphic. Judging from light refraction, the plagioclase is sodic. Pole curves for pericline-acline twins gave  $An_4Ab_{96}$ . It appears that certain phenocrysts have been somewhat decalcified. There are also small pseudomorphs of mafic minerals. They are filled by biotite, epidote and ore minerals, and, in smaller quantities, chlorite and carbonate. Judging from the shape, the original mineral has been hornblende. The grain size of the groundmass is generally 0.1–0.2 mm, but as it is of microgranophyric type, it gives the impression of being considerably more fine-grained. It contains microcline, plagioclase and

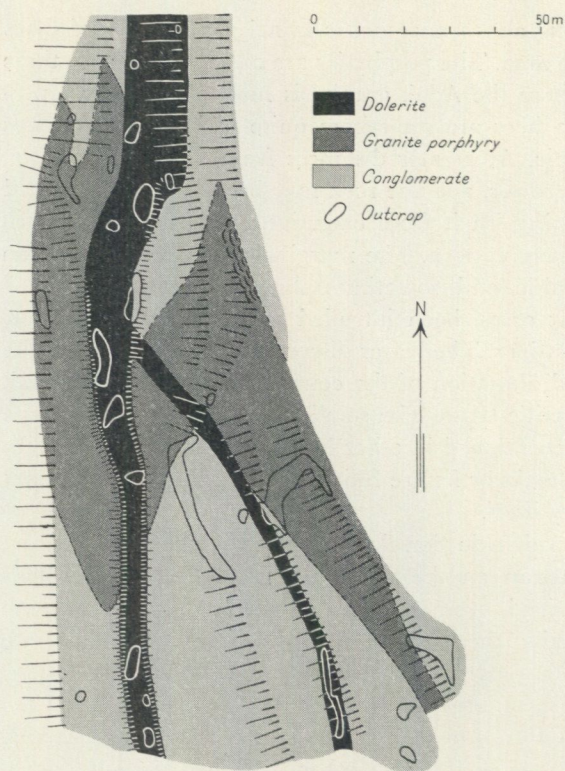


Fig. 15. Sketch map showing dolerite and granite porphyry intruding conglomerate. South-eastern slope of St. Gransberget.

quartz together with the same biotite as in the pseudomorphs. There is also some ore, with apatite and zircon as accessories.

In one outcrop the granite porphyry is exposed in contact with the sediments. It is either of the same consistency clear to the contact, or there may be a dense marginal zone several cm wide. This marginal zone contains feldspar phenocrysts, but no phenocrysts of quartz are visible to the naked eye.

This grey porphyry is probably a variation of the red granite porphyry. However, it may have been a more deep-seated intrusion.

Contrary to the granite porphyry, the dolerite appears in dikes which are relatively evenly distributed over the entire area. The width of these intrusions varies from a matter of decimeters, to about ten meters. As has been pointed out by S. Gavelin (1955), the basic dikes cut the granite porphyries in the Ledefat region. The latest mapping has shown other localities where it has been confirmed that the dolerite is younger than the acid intrusives. The best example of this is a dolerite dike some 1.5 m wide which cuts sharply the large granite porphyry at the mountain Gråberget. In other places, xenoliths of granite porphyry have been observed in dolerite. In many cases, the dolerite has emerged along fracture zones which had been previously intruded by granite porphyry. When following one of these fractures it is possible to find alternating intrusions of granite porphyry and dolerite.

## Tectonic main Feature

As appears on the geological map, the Ledefat district is roughly a basin where the older formations occur around the periphery, and the younger ones towards the center. The oldest formation is preserved only in the western sections. The Sandstone formation has a much wider distribution. The outer sections of the basin have been reduced or obscured chiefly by the intrusion of younger granites. An early erosion must also have contributed to areal reduction of older sediments. Some of the rocks must be assumed to have had an originally limited distribution. Around the peripheral parts of the basin, the general dip is steeper than towards the center of the basin. On Sätmyrliden, however, there are often vertical, and occasionally even overturned, strata. Near the center of the basin, the dip usually becomes quite low, and at times almost horizontal. In the north-western corner of the area, the strike of the formations changes at almost right angles over a short distance. At this point there is a glen which is devoid of any outcrops. This glen evidently represents the boundary zone between areas of different inclinations. Towards the center of the basin area, the glen is still indicated by a belt of elongated mires which trend in the same north-west—south-east direction. Numerous crevasse zones in the sediments trend in the same general direction, although other directions are represented. These fissure zones appeared during an early period, and have been subsequently intruded. Within coherent, well-layered sedimentary areas, no larger faults have been established. This may be due to difficulty in tracing the individual beds for any great distance. Small dislocations of one or more decimeters are not uncommon. Within the southern part of the district, it may be concluded from the distribution of the sediments that faults have occurred. At Gråberget, there are outcrops of mylonite which tie in with a zone of crushing visible on the map as a trend of narrow mires.

Schistosity is almost entirely lacking in both the sediments and the porphyry basement. Close to the crevasse zones or intrusive dikes, pressed and discoloured conglomerates may sometimes be seen. Metamorphism is of a more chemical nature, and manifests itself as decalcification and sericitization of plagioclase, uralitization of pyroxene, and often the continued altering of hornblende to chlorite or biotite. Skarn formation on a small scale is common.

## Summary

The Ledefat district is underlain by a thick, mainly concordant, sedimentary sequence which rests unconformably upon a basement of Arvidsjaur volcanics. The total thickness of the sedimentary formations may approach 2,000 meters. However, many of the components are of such a nature, that considerable variations in thickness may occur.

The Ledefat sequence may be divided into two groups of formations. The first of these consists of sandy or muddy sediments with minor conglomerate and

greenstone intercalations. The second group consists of conglomerates with unimportant intercalations of sandy or fine pebbly sediments. The lower group is in this paper called the lower Ledfat formations, and the upper group the Vargfors conglomerates. Each group may be further subdivided.

On the basis of appearance and origin, the lower Ledfat rocks are divided into three different formations. They are here called the Andesite formation, the Sandstone formation, and the Tuffite formation. These names refer to characteristic components of the formations although there are always other rock types present in each particular formation.

The Andesite formation is principally of volcanic origin. It is composed of basic lavas, conglomerates, and fine-grained, brown violet or grey tuffs and tuffites.

The sandstone formation is of a non-volcanic origin. The lower part consists of sandstones and conglomerates which are largely derived from the underlying formation. At higher levels, there are feldspar sandstones and quartzitic sediments, which may possibly contain some granite material.

The tuffite formation, on the other hand, consists of a sequence of rocks deposited in a volcanic *milieu*. The sediments have accentuated colours, red, violet, brown violet, and brown predominating. Tuffitic sediments alternate with sandstones composed of porphyry material. No lavas corresponding to the acid tuffites have been encountered in solid outcrop. On the other hand, red, acid porphyry boulders and pebbles occur abundantly in the overlying conglomerates, and certain of those porphyry types may possibly be equivalents to the Ledfat tuffites.

As a group, the Vargfors conglomerates of the Ledfat area may be correlated with many other occurrences of conglomerates within the Skellefte and Arvidsjaur fields. There are, of course, local variations in appearance depending on the nature of the source of material. Even within the limits of the Ledfat area, the conglomerates vary rather much in appearance. In the present paper, the Vargfors conglomerates of the Ledfat area have been divided into one lower and one upper formation.

The lower Vargfors conglomerate is practically devoid of granite pebble material. Altogether, a half a dozen pebbles or cobbles of granite have been observed within this comparatively well-exposed formation. They were all found near the top. The lower part of the formation consists to a large extent of bright red conglomerates. At higher levels, the colours become increasingly dull, and finally, near the top, the colours do not differ from those of the upper Vargfors conglomerate. The lower Vargfors, unlike the upper Vargfors conglomerate, is usually quite well bedded, and contains numerous sandstone layers. The red colour at the base of the formation, and the increasing dullness in the upper segments is ascribed to the erosion of a weathered land surface which has supplied the sedimentary area with material. As the surface layers were eroded off, fresher rock material was delivered to the upper parts. Granites can as yet not have been exposed to any significant extent within the erosion areas.

The upper Vargfors conglomerate differs from the lower one in that it contains numerous boulders of granite. Bedding is usually less well-developed, and there is a noticeable decrease in the quantity of sandy or pebbly strata. The upper Vargfors conglomerate marks continued and deepening erosion of older Archaean areas.

The entire sedimentary series of the Ledefat area may be characterized as being rather rich in potassium.

Taken as a whole, all formations of the Ledefat sequence constitute a concordant series. Throughout every exposed section, the different formations have parallel strikes, and the tops all face in similar directions. Almost all members show structures from which the original top may be determined. Each formation has certain characteristics which exclude the possibility of repetition through overthrusting. Of special significance with regard to the consideration of the original problem of this district is the fact that the Vargfors conglomerates rest conformably upon the next older components of the sequence.

The Ledefat series belongs to the pre-Cambrian Vargfors formation. In the present paper, the latter name has been avoided. The name Vargfors is only used in connection with the conglomerates in the upper part of the Ledefat sequence. In the classification recently suggested by G. Kautsky (1957), the name Vargfors formation has been replaced by the name Elvaberg series. The rocks now referred to as the Elvaberg series are predominantly marine, but there is also a group of conglomerates of alluvial type. Of the latter, there are one lower and one upper division, which have been called the Abborrtjärn and the Dömanberg conglomerate respectively. Between the two, there is a minor disconformity. The conglomerates are grouped together under the name of Vargfors conglomerate.

The lower Vargfors conglomerate of the Ledefat area shows a striking similarity to the Dömanberg conglomerate of the Elvaberg series. Colours, pebble material, sorting and sandstone intercalations are about the same in both. At the top of the Dömanberg conglomerate, granite pebbles begin to appear. This stratigraphic level may then correspond to the upper Vargfors conglomerate of the Ledefat area although the latter is preserved to a much greater thickness.

The Abborrtjärn conglomerate is very rich in pebbles to boulders of Jörn granite. Consequently no obvious correspondence exists between this conglomerate and members of the Ledefat series when stratigraphic positions are taken into account. The Abborrtjärn conglomerate intercalates with andesitic lavas. In this respect it shows some similarity to parts of the sandesite formation of the Ledefat series. In the latter formation, there are also conglomerates alternating with andesitic lavas. The lack of granite pebbles in this area may be due to local conditions. Thus it appears to be quite possible that the Abborrtjärn conglomerate is contemporary with the lowest formation of the Ledefat series. In this case, the magnitude of the disconformity between the Abborrtjärn and Dömanberg conglomerates corresponds to the time required for the deposition of the Sandstone formation and the upper tuffite formation of the Ledefat area.

The Ledefat sequence diverges in two respects from the Elvaberg series of

the central and eastern sections of the Skellefte field. The first difference is that true marine sediments do not seem to occur in the Ledfat area. None of the sandstone or mudstone formations is entirely devoid of current or cross bedding. The rocks are not very well sorted as to grain size, and in no place is there any steady tendency towards gradation. There is no evidence of graphite-bearing shales. Lime content is not high, even if the epidote content in most of the sediments and the calcite content in the upper formations is taken into account.

The other main difference is the existence of acid pyroclastic sediments within the Ledfat area. The tuffites apparently correspond to mainly potassium-rich liparitic volcanism.

The entire Ledfat series was evidently formed under diastrophic conditions. Changes in topography during its time of deposition are indicated by great variations in thickness over short distances and rapid elevation of formations above the erosion base. Changes in intensity and direction of currents are reflected by the abundance of conglomerate beds and cross beddings in the lower formations. Generally speaking, the structures of the sediments indicate a gradually increasing diastrophism. Its culmination is represented by the more widely distributed coarse Vargfors conglomerates. The lack of granite pebble material in the lower formations may be due to local conditions, the conglomerates there being of a less polymictic nature than the younger Vargfors conglomerates. However, granites might possibly have been exposed within the source areas of the Ledfat sediments when the Sandstone formation was deposited. If the Andesite formation is contemporary with the Abborrtjärn conglomerate, granites were by that time exposed in other places.

On the Bockträsk mountain, rocks of the Ledfat series are exposed in contact with the older Arvidsjaur porphyries. The contact is an angular unconformity. Using a stereographic projection of strikes and dips, an angle of  $82^\circ$  was obtained between the stratigraphic tops. On the western side of Granliden, an angle of  $48^\circ$  was similarly obtained. In this part of the district, however, the actual contact is nowhere exposed.

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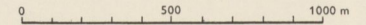
# GEOLOGICAL MAP OF THE LEDFAT AREA

VÄSTERBOTTEN COUNTY SWEDEN

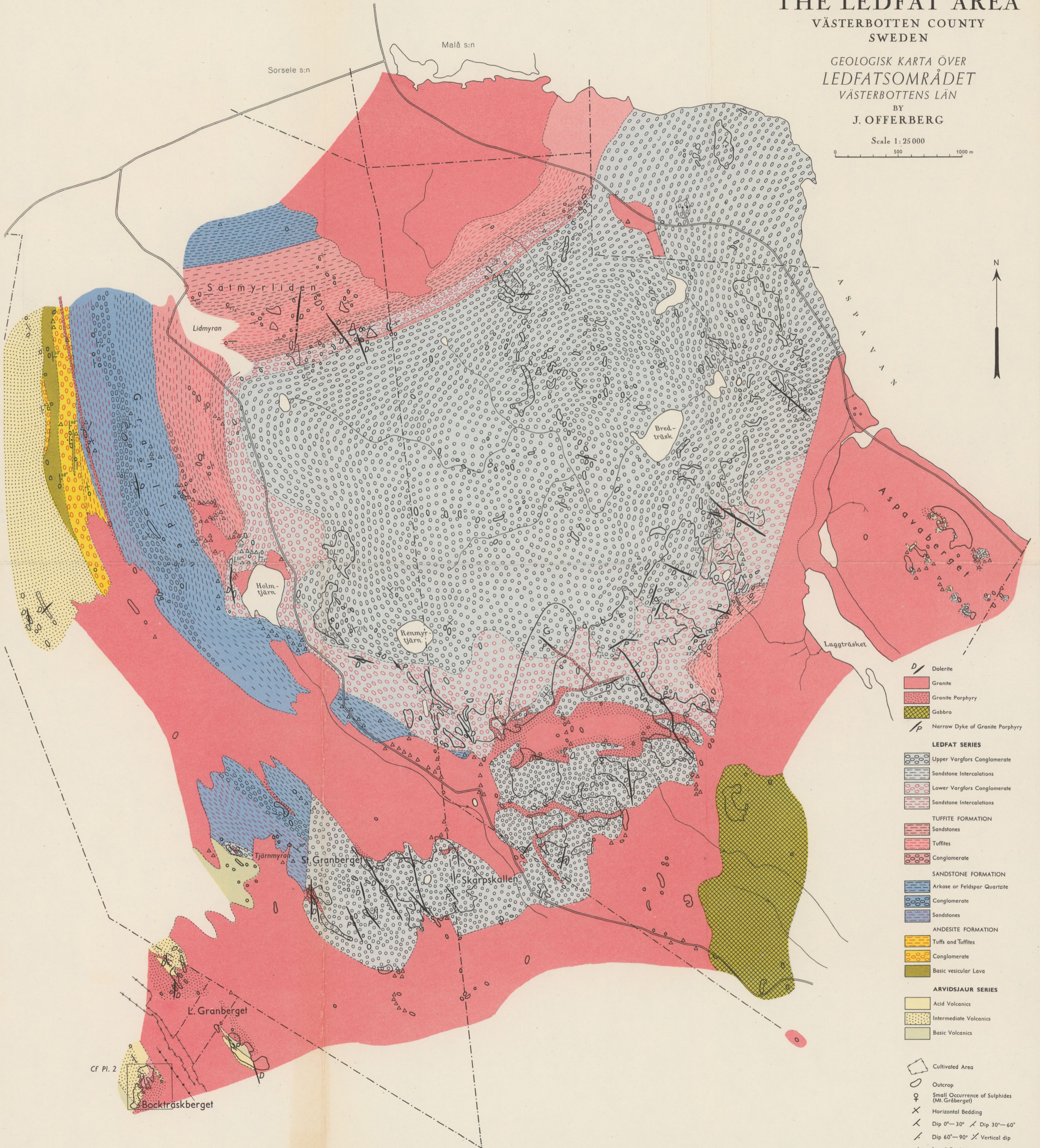
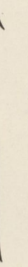
GEOLOGISK KARTA ÖVER LEDFATSOMRÅDET VÄSTERBOTTENS LÄN

BY J. OFFERBERG

Scale 1:25 000



N



- Dolerite
- Granite
- Granite Porphyry
- Gabbro
- Narrow Dyke of Granite Porphyry
- LEDFAT SERIES**
- Upper Vargfors Conglomerate
- Sandstone Intercalations
- Lower Vargfors Conglomerate
- Sandstone Intercalations
- TUFFITE FORMATION**
- Sandstones
- Tuffites
- Conglomerate
- SANDSTONE FORMATION**
- Arkose or Feldspar Quartzite
- Conglomerate
- Sandstones
- ANDESITE FORMATION**
- Tuffs and Tuffites
- Conglomerate
- Basic vesicular Lava
- ARVIDSJÄUR SERIES**
- Acid Volcanics
- Intermediate Volcanics
- Basic Volcanics
- Cultivated Area
- Outcrop
- Small Occurrence of Sulphides (Mt. Gråberget)
- Horizontal Bedding
- Dip 0°-30°
- Dip 30°-60°
- Dip 60°-90°
- Vertical dip
- Local Boulders

cf Pl. 2

Bockträskberget

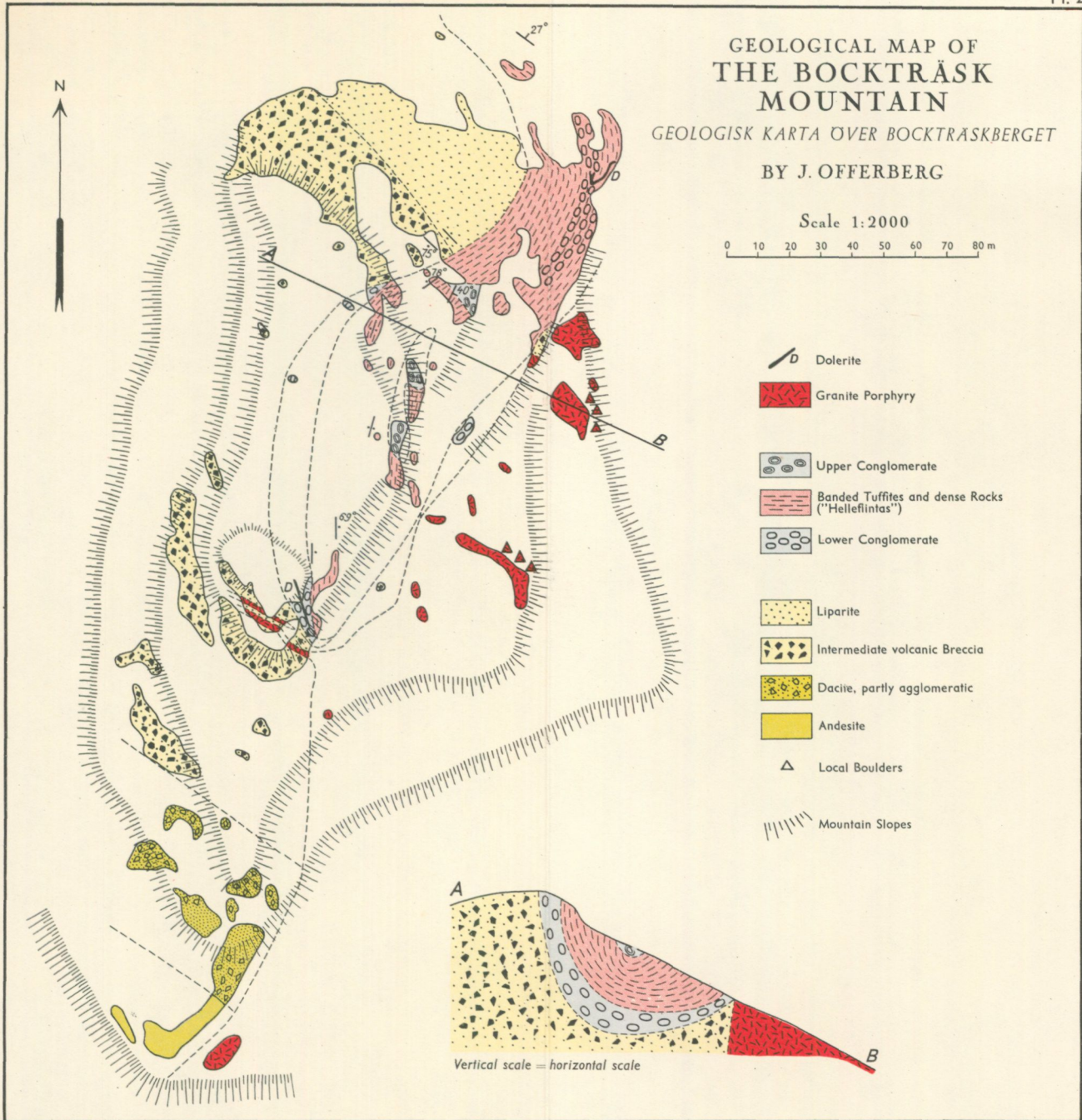
# GEOLOGICAL MAP OF THE BOCKTRÄSK MOUNTAIN

GEOLOGISK KARTA ÖVER BOCKTRASKBERGET

BY J. OFFERBERG

Scale 1:2000

0 10 20 30 40 50 60 70 80 m



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