SVERIGES GEOLOGISKA UNDERSÖKNING
BERGGRUNDSGEOLOGISKA OCH GEOFYSISKA KARTBLAD
I SKALA 1:50 000
Serie Af · Nr 5—8

PETER PADGET

BESKRIVNING
TILL BERGGRUNDSKARTBLADEN
TÄRENDÖ NV, NO, SV, SO

DESCRIPTION OF THE GEOLOGICAL MAPS
TÄRENDÖ NW, NE, SW, SE
WITH AN APPENDIX ON GEOPHYSICAL
ASPECTS BY J. D. CORNWELL

STOCKHOLM 1970

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BESKRIVNING TILL BERGGRUNDSKARTBLADEN TÄRENDÖ NV, NO, SV, SO

Kartbladet 28 L Tärendö består av 4 delblad (NV, NO, SV och SO) i skalan 1:50 000, som tillsammans täcker ett område av 2 500 km^2 i Övre Norrland. Den beskrivning, som nu föreligger, behandlar enbart berggrunden (ej kvartära fenomen) och bygger huvudsakligen på geologiskt fältarbete utfört 1963–1967 i SGU:s regi (malmbyrån). I kartframställningen och i beskrivningen har hänsyn tagits till tidigare publicerade arbeten av bl. a. P. Geijer, O. Ödman och T. Eriksson (se separat litteraturlista). Opublicerat originalmaterial från Ödmans och T. Erikssons arbeten i SGU:s arkiv har ägnats speciellt intresse. Dessutom har geofysiska mätningar på marken (malmbyrån) och från luften (geofysiska avdelningen) varit av stor betydelse och är redovisade i ett särskilt appendix av J. D. Cornwell.

Bergarterna består till över 60 % av granit, granodiorit och kvartsdiorit, återstående 40 % av sediment, vulkaniska bergarter och gabbro. De vulkaniska bergarterna är huvudsakligen grönstenar av olika slag; sedimenten består av kvartsiter och skiffrar. Tack vare diskordansskiktningar som förekommer i olika led av bergartsserien kan en stratigrafisk lagerföljd byggas upp (fig. 2). Den består av 4 huvudenheter (grupper):

4. Rissavaarakvartsiten. Yngst.
3. Kalixälvgruppen (pelitiska skiffrar, grönstenar).
2. Pahakurkiogruppen (kvartsiter och glimmerskiffrar).
1. Veikkavaara grönstensgrupp. Äldst.

Namnen är nya och tagna från platser på bladet där bergarterna i fråga är bäst blottade. En tänkbar korrelation med Kirunabladets stratigrafi (Offerberg 1967) visas i fig. 17.

Svårplacerad i ovannämnda stratigrafi är det tidigare kända konglomeratet vid berget Haukkalaki (Tärendö SO). Enligt T. Eriksson (1954) skulle detta konglomerat vila på ett äldre bergartskomplex. Den nuvarande karteringen och sammanställningen lämnar inget stöd för påståendet. Snarare är konglomeratet ett led i ovannämnda lagerföljd, även om underlaget, en andesit-porfyr, skiljer sig från de övriga bergarterna inom fältet.

Ett antal gabbrokroppar finns på bladet och den största av dessa är den vid Tärendö, här kallad Tärendögabbron. Formen och storleken på denna skiljer sig starkt från tidigare uppfattningar mest beroende på nytillkomna flygmagnetiska data. Vid en plats strax väster om Tärendö samhälle har gabbron en distinkt bandning men någon större mineraldifferentiation saknas. I stort är gabbron diskordant mot sedimenten och vulkaniterna samt har i olika grad blivit påverkad av senare graniter. Den har varit föremål för speciella geofysiska tolkningsförsök av J. D. Cornwell (se appendix) i vilka gravimetriska data också har kommit till användning. De andra gabbrokropparna på bladet är av betydligt mindre storlek och för det mesta dåligt blottade. Isohuhta-gabbron är blottad på ett ställe och Koinujoki-gabbron inte alls. I båda fallen har de flygmagnetiska kartorna varit av stor betydelse för ritningen av de geologiska gränserna.

Ett fåtal basiska gångar är kända. De härstammar från ett tidigt skede i områdets geologiska utveckling. Gångarna har troligtvis bildats i samband med eller strax efter gabbrons intrusion. En andesitporfyr norr och nordväst om Haukkalaki (Tärendö NO) är tolkad som intrusiv och är yngre än åtminstone Veikkavaara grönstensgrupp.

Såväl metasedimenten som gabbron har genomgått kraftig deformation i form av veckningar av regional omfattning (Oriasvaara-, Masugnsbyn- och Tärendö-synklinalerna, Kalixälvdomen samt Saittajärvi-antiklinalen) och förkastningar (t. ex. Kalixälvsförkastningen). Som en följd av fältets utpräglade tvärstruktur har veckaxlarna nordostliga eller nordvästliga riktningar, framförallt vid Oriasvaara mitt på bladet. Ett antal mindre förkastningar, oftast orienterade NO–SV eller NV–SO har också kunnat konstateras. I närheten av Tärendögabbron är en N–S-lig riktning ibland markant. Denna avvikelse tolkas som en lokal avlänkning av en NV-lig tektonisk riktning förorsakad av gabbrokroppen. Andra N–S-liga förkastningar uppträder i området söder om Lauttakoski. Förkastningstektoniken tycks ha ägt rum i samband med eller strax efter veckningen. Som framgår av kartan har Oriasvaara-synklinalen varit mest utsatt för förkastningar.

Bergarternas metamorfos är översiktligt behandlad dock med uppmärksamheten riktad mot de iögonfallande sillimanit- och andalusitbildningar som ofta karakteriserar pelitiska skiffrar i lagerserien (fig. 24–25). Mineralassociationerna talar för metamorfos under relativt hög temperatur och moderat tryck. Metamorfosen kan sammanlänkas med djupbergarternas uppkomst och särskilt Linagraniten har haft stor betydelse i detta sammanhang.

Metasomatiska effekter, med undantag av kalitillförsel i samband med granitisering av gabbror och sedimentseriens bergarter, består av skapolitisering, obetydlig turmalinisering samt skarnbildning (skarnjärnmalm vid Masugnsbyn).

Graniter och liknande bergarter upptar över hälften av kartbladets areal. Den dominerande typen är kalirik Linagranit, som har sin största utbredning i bladets västra och sydliga delar. Den uppträder ofta diskordant mot andra bergarter och är sålunda yngre än dessa.

De översiktliga flygmagnetiska mätningarna har bl. a. givit en ny bild av Linagranitens interna struktur. Magnetiska drag är vanliga på flera ställen och ibland påminner de om veckningar i metasedimenten. De är troligtvis relikta drag från en veckningsfas före granitens uppkomst. Smala, raka drag med låg magnetisk intensitet korsar granitområdena och är tolkade som förkastningar. I många fall kan även dessa anomalier vara relikta drag. Postgranitisk förkastning är känd bara vid Masugnsbyn, där pertitgranitens gräns mot söder är kraftigt breccierad och uppsprucken (hällar i övre ändan av Rautajoki Isokursu). Flera tidsskilda förkastningsfaser är dock sannolika. Vissa delar av Linagranitområdet saknar orienterade magnetiska drag och har relativt låg magnetisk intensitet. Dessa är tolkade som mer homogena graniter. Den länge kända pertitgraniten vid Kompelusvaara (1f–1g) är ett exempel.

En annan djupbergart är granodioriten vid Lovikka. Denna bildar en ganska väl avgränsad kropp i bergarter av Veikkavaara grönstenstyp. Någon åldersskillnad mellan granodioriten och Linagraniten går inte att påvisa genom sedvanlig geologisk kartering. Andra djupbergarter däremot, såsom pertitmonzoniten vid Viiksivaara (9h) och kvartsdioriten i närheten av Petäjävaara gabbron och öst om Martinvaara (0b), kan tänkas vara av äldre ursprung. De är att hänföra till Haparandaseriens bergarter (Ödman 1957). I vissa fall (Martinvaara) skärs kvartsdioriten av smala granitgångar av Linatyp.

Pegmatiter förekommer ganska allmänt i samband med Linagraniten som ofta är pegmatitisk vad kornstorleken beträffar. Pegmatitgångar förekommer ganska allmänt i pelitiska och semi-pelitiska bergarter. Bredast och mest iögonfallande är pegmatiterna vid Masugnsbyn ("pelarna" se Geijer, 1931, fig. 2) och på berget Oriasvaara (5f–6f). Den senare är orienterad vinkelrätt mot veckaxelriktningen (Oriasvaara-synklinalen).

Områdets geologiska utveckling är följande: Avsättning av de suprakrustala bergarterna med Veikkavaara grönstensgrupp som första etapp. Därefter följer intrusion av gabbro och av ett fåtal basiska gångar. Berggrunden veckas regionalt och Haparandaseriens bergarter bildas. Linagranitserien bildas och i samband därmed uppstår en omfattande metamorfos av suprakrustalbergarter följd av post-granitiska förkastningar. Därefter följer en lång erosionsperiod tills glaciala sediment avsätts i kvartär tid.

Endast två radiometriska åldersbestämningar finns på hela bladet. Det ena (Welin och Blomquist, 1966) är för uraninitkorn i skarnjärnmalmen vid Masugnsbyn, där en ålder av 1845 m. y. har erhållits. Den andra är för den kända, intilliggande pertitgraniten, som visar sig vara betydligt yngre, nämligen 1540 m. y. För den senare bestämningen har Rb–Sr whole rock metoden använts (personligt meddelande från Dr Eric Welin).

Fyndigheter av eventuellt ekonomiskt intresse finns upptagna i tabellen, fig. 32. Flera av dessa undersöks för närvarande och i avvaktan på resultaten begränsar sig författaren till en redovisning av fyndigheternas placering i det regionala sammanhanget. Järnmalmerna (Masugnsbyn och Junosuando) ligger stratigrafiskt högt upp i Veikkavaaragrönstensgrupp eller i övergången till den överliggande Pahakurkiogruppen. Inga nya järnmalmsförekomster har upptäckts trots intensiv letning över kartbladen inom denna stratigrafiska nivå. Andra metaller i form av mycket svaga kopparkis-svavelkisimpregnationer finns här och där i grönstenarna, men saknar allt ekonomiskt intresse. Dolomiterna vid Masugnsbyn ligger ungefär i samma stratigrafiska nivå som järnmalmerna och är förmodligen av sedimentärt ursprung. Dolomitens form (ruta 9d) är ritad med hjälp av såväl geologiska som gravimetriska data. Täljstenen vid Tärendöälv är känd sedan en längre tid, men är ännu ofullständigt undersökt. Den förekommer tillsammans med gabbro-diabaser, vilka intruderar bergarter tillhörande Veikkavaara grönstensgrupp. Täljstenen representerar möjligen en hydrotermisk omvandling av ett ultrabasiskt led. Svagt grafitförande skiffrar förekommer i övre delen av Veikkavaara grönstensgrupp, vilket kunnat konstateras med hjälp av elektromagnetiska mätningar samt ett flertal diamantborrhål (t ex Suinavaara) och i dagbrott (Nybrännan). Kvartsiten på Rissavaara är tolkad som en rest av sedimentär kvartsit i granit.

Som tidigare påpekats har geofysiska mätningar varit av stor betydelse för upprättandet av den geologiska kartan. En redovisning över utförda arbeten finns i ett appendix skrivet av J. D. Cornwell. Materialet består av flygmagnetiska mätningar (4 st. geofysiska kartblad 1:50 000), diverse geofysiska markmätningar utförda åren 1946–1968 (fig. 36 och fig. 37) och mätning av täthet, magnetiska egenskaper i ett antal prover från 25 olika platser på bladet (fig. 38). Principfrågor beträffande flygmagnetiska mätningar i Norrbotten är behandlade av S. Werner i Kirunabladets beskrivning (J. Offerberg 1967). Det geofysiska bidraget till Tärendöbladet begränsar sig till en behandling av vissa geofysiska enheter, framförallt de starkt magnetiska som finns vid Tärendö by (Tärendögabbron), vid Masugnsbyn och vid Junosuando (magnetitförande järnmalmer). I tolkningsförsöken har markmätningar med gravimeter kommit till användning. Starka elektriskt ledande drag har lätt kunnat spåras med slingramsmetoden och tycks vara förorsakad av grafitförande skiffer i Veikkavaara grönstensgrupp.

DESCRIPTION OF THE GEOLOGICAL MAPS TÄRENDÖ NW, NE, SW, SE

INTRODUCTION

Tärendö is the name of a small village situated near the confluence of the Kalix and Tärendö rivers in the northern part of Norrbotten county. The map-sheet Tärendö (fig. 1), with an area of 2500 square kilometers, is sparsely inhabited, the only settlements of note being Masugnsbyn, Junosuando and Lovikka (Torneälv), Granhult, Vettasjärvi, Niilivaara in the wooded country to the west, and Kompelusvaara to the south. Scenically it is characterized by low, wooded hills, extensive bogs and broad rivers. Exposures of bed-rock form only 0.37 % of the total area of the map-sheet and hence the scope of purely geological methods of investigation is limited.

No previous description exists for the map-sheet but investigations have been carried out spasmodically over many years by a number of geologists. Their results are summarized on the geological map of Norrbotten published by Ödman (1957). Significant contributions have been made by Geijer (1931, 1958, 1966), Ödman (1939) and T. Eriksson

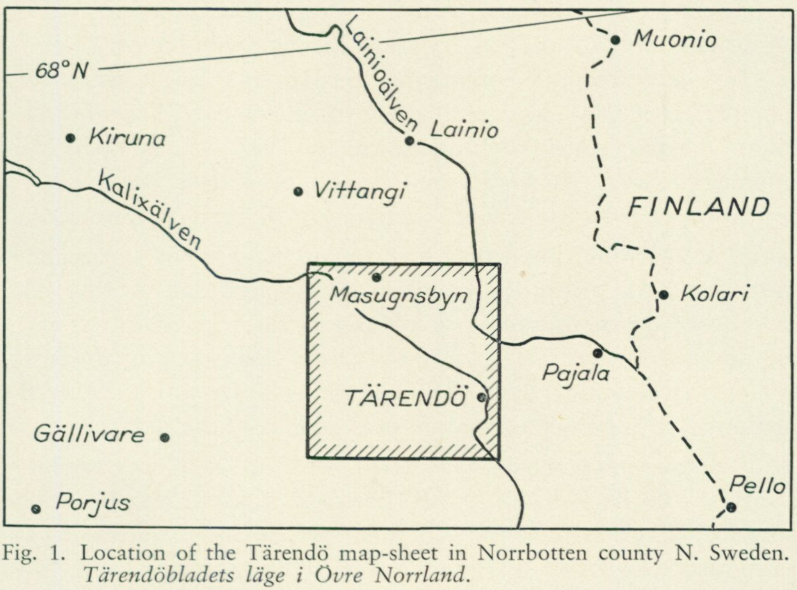

Fig. 1. Location of the Tärendö map-sheet in Norrbotten county N. Sweden.
Tärendöbladets läge i Övre Norrland.

(1954). In addition, the archives of the Geological Survey of Sweden contain valuable field data, notable contributors being O. Brotzen, M. Beyer and A. Theolin.

The rocks and structure of the sheet are thought to be entirely Precambrian in age though with two exceptions (Welin and Blomquist, 1966) no attempt has yet been made to verify this with the help of radiometric methods of dating. Granitic to dioritic rocks occupy more than 50 per cent of the total area while gabbroic intrusions and a thick sequence of layered rocks (metasediments, volcanics) make up the rest. Folding and faulting are important features being seen to best advantage in non-granitic rocks. The present topography is the result of prolonged erosion culminating in the glaciations of the Quaternary era. Interesting features include the Rautajokk (Isokursu) canyon at Masugnsbyn (Fromm, 1965 p. 135) and the glaci-fluvial sand delta at Tärendö marking the highest marine limit in late glacial times (op. cit. p. 21). A significant part of the dead-ice belt known in Swedish geological literature as 'Lainiobågen' also occurs on the sheet (G. Lundquist, 1943).

The present phase of investigations began in 1962 when aeromagnetic maps became available for the whole map-sheet. These confirmed the existence of many geological features but revealed the presence of many new ones. A re-examination of the outcrops was therefore necessary, all information being plotted on good quality photo maps (1:20 000). The four quarter-sheets comprising the Tärendö sheet were drawn on the basis of geological and geophysical evidence available to the Geological Survey of Sweden at the end of 1967. The Boliden Mining Company (Boliden AB) kindly put the results of their investigations at the disposal of the author. This cooperation is greatly appreciated.

Some of the more important features of the present survey include a more accurate delineation of gabbroic, granitic and dioritic bodies, a revision of the stratigraphic succession of the layered rocks, and the recognition of several major folds and faults. The scope of the publication is otherwise shown by the table of contents. Dr. J. D. Cornwell has contributed an appendix on geophysical aspects of the work.

Field investigations have been carried out in the summers 1962–67 by the author with the assistance of R. Larsson, H. Lindroos, B. Lundberg, I. Lundström, F. Ros, L. Rönnbäck, K.A. Sandahl and P. Stacey. A. Theolin also assisted significantly by his knowledge of the area gained during the course of earlier investigations conducted by Professor O. Ödman, Dr T. Eriksson and others. The author also had the benefit of discussions with Dr A. Shaihk concerning the soapstone deposit at Lauttakoski. Dr F. Witschard kindly investigated some thin sections and made drawings, some of which are included as text figures in the present publication. To all these persons the author offers his sincere thanks.

STRATIGRAPHY

As indicated in the introduction a layered sequence of rocks consisting of quartzites, mica-schists and greenstones of various types forms an important element of the geology of the map-sheet. The succession given in Fig. 2 has been arrived at by piecing together information from scattered outcrops. It satisfies tectonic requirements (see profiles, Pl. 1) and is strengthened by observations of 'way up' structures such as cross-

Group		Formation	
Rissavaara Quartzite	4	Quartzite at Rissavaara	
Kalixälv Group ca 3000 m	3d	Semi-pelitic and pelitic schists, basic schists (?amphibolitic)	
	3c	Limestone	
	3b	Conglomerate at Saarikoski and Tiankikoski	
	3a	Amphibolitic schist	
Pahakurkio Group ca 3830 m	2d	Quartzite	ca 1800 m
	2c	Pelitic schist	ca 1000 m
	2b	Quartzite	ca 430 m
	2a	Pelitic schist, locally with quartzite	ca 600 m
Veikkavaara Greenstone Group ca 3600 m	1c	Basaltic greenstones with graphitic schists and carbonate horizons	ca 1500 m
	1b	Pelitic schist and quartzite (Suinavaara quartzite)	ca 100 m
	1a	Basaltic greenstones	2000 m
		?	

Fig. 2. The stratigraphic succession for the map-sheet 28L Tärendö.
Lagerföljden på bladet 28L Tärendö.

bedding at various places. No fossils or traces of fossils of any sort have been seen and the succession is therefore exclusively lithostratigraphic. Brief descriptions are given below of the various units, beginning with the oldest.

1. VEIKKAVAARA GREENSTONE GROUP

Rocks of this group are the oldest on the map-sheet and form a conspicuous V-shaped area between Masugnsbyn, Saittajärvi and Junosuando (NO and NV). From the profiles it is estimated that 2–3000 metres of layered rocks are present and the group therefore represents a major unit in the stratigraphy of the map-sheet.

The V-shaped distribution of the rocks was recognized by T. Eriksson (1954, Pl. 1) from geological mapping and the results of a few, limited ground geophysical surveys. He concluded, however, that sediments of the type quartzite, phyllite and conglomerate occupied the centre of this V, a view which cannot be sustained in the light of the aeromagnetic evidence now available. Sediments of this type (conglomerate excepted) do occur north of Suinavaara, to the NNW of Lauttakoski (NO 8g) but are apparently a minor element of the group as a whole. They serve, however, to divide it into upper and lower parts. Greenstones of the lower part are exposed at one place on the map-sheet only, namely along the Tärendöälv, north of Suinavaara. They are here dark green, fairly finegrained, massive rocks (?lavas) and occur immediately below the quartzite. From the aeromagnetic maps they clearly have a continuation to the west and north-west but no outcrops are known.

The quartzite, here called the Suinavaara quartzite to distinguish it from others on the map-sheet, is exposed on the banks of the Tärendöälv, north of Suinavaara. It is jointed and otherwise tectonized but its primary feldspathic character can still be discerned. Its thickness is considered to be from 20 to 50 metres. Some phyllitic rocks also seem to belong to about the same horizon or possibly slightly above it. One outcrop of quartzite is in contact with carbonate but it is not known whether the latter is a primary, sedimentary feature or not. Special interest attaches to these rocks since they are also reported from the Vittangi sheet to the NW by B. Eriksson (personal communication) and have about the same stratigraphic position within a greenstone group there.

More is known about the rocks above the Suinavaara quartzite. At

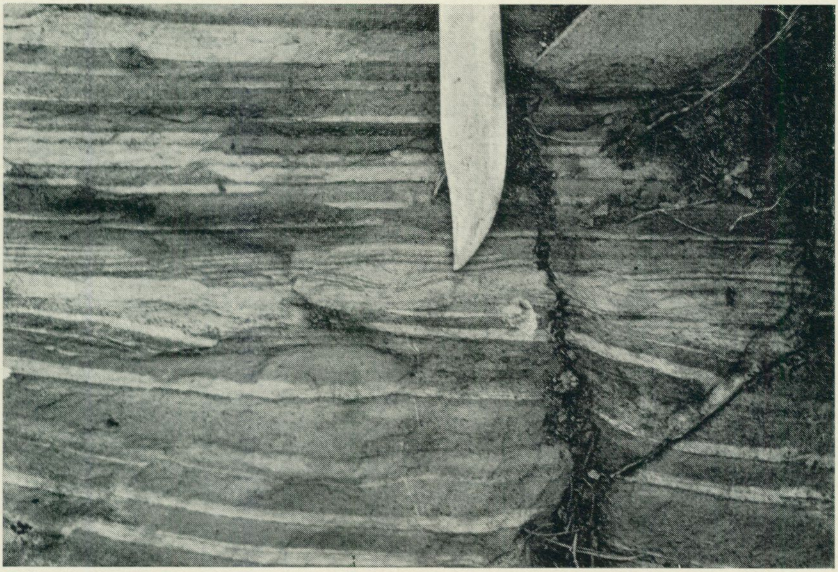

Fig. 3. Cross-bedding in the Veikkavaara Greenstone Group, Suinavaara (square 8g). Knife blade gives scale.

Diskordansskiktning i Veikkavaara grönstensgrupp, Suinavaara (ruta 8g). Kniven anger skalan.

Suinavaara itself a variety of greenstones is present. These include light green, fine-grained tuffitic varieties as well as coarser grained hornblende-rich types more reminiscent of lavas (metamorphosed). Indeed the area is worth closer petrologic study. An interesting feature is the presence at one place of sedimentary structures (crossbedding) which indicate that younger beds occur in the direction of dip and are not, therefore, inverted (figs. 3–4). Pelitic* or phyllitic horizons here as elsewhere are rarely exposed but geophysical measurements suggest that at least one horizon of graphite-bearing schist is present. In fact dark, graphitic schists seem to characterize the upper part of the Group.

A few small outcrops 3 km to the east in the direction of Salmijärvi probably occupy about the same stratigraphical position with respect to the quartzite. The rock here is a fine-grained greenstone with a weak

* The term *pelitic* is here used adjectively for rocks originally thought to be fine-grained and argillaceous but now having a metamorphic mineral assemblage. The author thus follows Tyrrell (Geological Magazine, 1921 Vol. 58, p. 501) and a large number of other Anglo-Saxon authors in this usage.

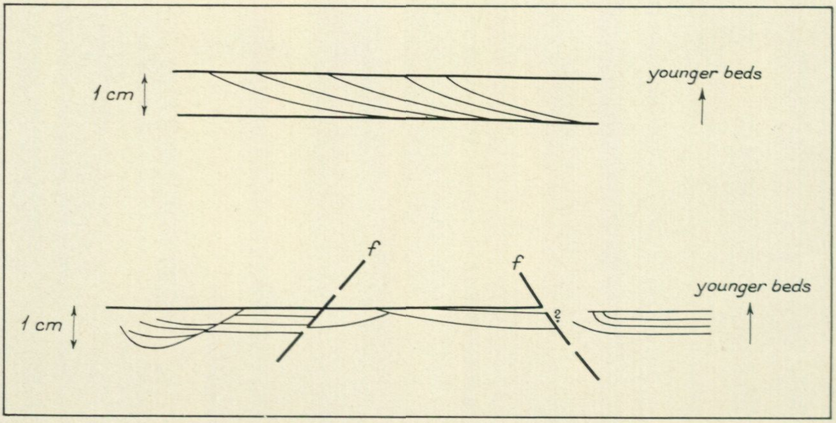

Fig. 4. Sketch of minor cross-bedding features in the Veikkavaara Greenstone Group, Suinavaara (square 8g). See fig. 3.

Schematisk bild av små diskordantskiktningar i Veikkavaara grönstensgrupp, Suinavaara (ruta 8g). Se fig. 3.

but distinct primary banding. Coarser clastic layers are occasionally interbedded. The rock may be described as a tuffitic greenstone with basaltic affinities. Rather similar rocks are found (see analyses A1, A2 in figs. 34–35) in drill-cores immediately west of the iron-ore zone at *Junosuando* (Tornefors deposit) (NO 9h). Here the fragmental character is very marked and the rocks are interpreted as agglomeratic greenstones. They lie at a slightly higher stratigraphical level than those at Suinavaara and Salmijärvi. Graphitic schist occurs west and stratigraphically below these greenstones (drill-hole under the Torneälv). Continuations of these beds, are thought to occur to the east, in the vicinity of the Lainioälv but are much granitized.

Several outcrops occur on the hill *Vinsavaara* (NO 7f) between Lauttakoski and Saittajärvi. The beds lie about 500 m below the top of the formation and dip to the SE. They consist of clastic sediments, the bulk of the material being volcanic and probably locally derived. Pebbles of schist, often up to 7 cm in length and well rounded, are present and may be somewhat magnetic. Dark grey pelitic schists, also slightly magnetic, overlie the clastic rocks.

The uppermost part of the formation is best known from exposures on and around the hill *Veikkavaara* (NV 9d, 8e). Here the rocks are

Fig. 5. Well-bedded basaltic tuffs of the Veikkavaara Greenstone Group, Veikkavaara (square 9d).

Skiktade basaltiska tuffer tillhörande Veikkavaara grönstensgrupp, Veikkavaara (ruta 9d).

collectively termed greenstones because of their characteristic greenish appearance. A few persistent layers of dark, often graphitic schist occur too and are well exposed in a small quarry situated 4 km ESE of Masugnsbyn. Otherwise they are rarely exposed but their presence and location are well known as a result of ground electromagnetic surveys carried out by the Geological Survey of Sweden in 1949. Between Masugnsbyn and Saittarova two main conductive horizons are interpreted as graphitic schist and appear to be in general concordant with the greenstones or with magnetic sheets interpreted as greenstones. An interesting feature which emerges after combining magnetic and electromagnetic data is the progressive thickening of the uppermost greenstone unit northwestwards towards Masugnsbyn. This is considered to be a primary depositional feature. The rocks between the graphitic horizons show a marked alternation of magnetic and less magnetic horizons. This is by no means obvious in the exposures and could not be related to

Fig. 6. Steeply dipping basaltic tuffs of the Veikkavaara Greenstone Group with minor tectonic disturbances, Veikkavaara (square 8e).

Skiktade basaltiska tuffer med tektoniska drag, Veikkavaara (ruta 8e).

distinct rock types. This may be partly due to recrystallization and tectonization of the rocks. On the other hand, careful search has brought to light numerous examples of primary, compositional banding allowing measurements of the strike and dip to be made (figs 5–6). These coincide closely with those expected from the aeromagnetic and ground magnetic surveys. Indeed, in some exposures the primary banding is further accentuated by the secondary growth of garnets or magnetite in distinct horizons. Clastic layers are more difficult to identify and are only known with certainty from one place south of Veikkavaara where the rock has a conglomeratic appearance. Quartz and feldspar grains with angular outlines occur in rocks from several places on the north slope of Veikkavaara.

Carbonate beds are not uncommon features of the Veikkavaara Greenstones. Indeed the uppermost unit of the group as a whole seems to consist of limestones, in part dolomitic. In Saittajärvi village local blocks of an impure carbonate rock occur close to the lake Ruokojärvi (See also M. Beyer, 1948 and map in the archives of the Geological Sur-

Fig. 7. Dark, steeply dipping bands of graphite-bearing dolomitic limestone (g) exposed in the dolomite quarry at Masugnsbyn (August 1964).

Mörka brantstående grafitförande lager (g) i dolomitbrottet vid Masugnsbyn (aug. 1964).

vey). Further northwest, thick carbonate formations are known from the upper reaches of the stream Hietajoki (NV 8e) where it has a thickness approaching 100 m. The well known Masugnsbyn dolomite, currently being exploited, seems to belong to the same horizon though its expanded thickness, at least in outcrop, may be partly explained by folding and mobilization. Calc-silicate bands are common while certain dark bands in the dolomite (exposed by quarrying operations in

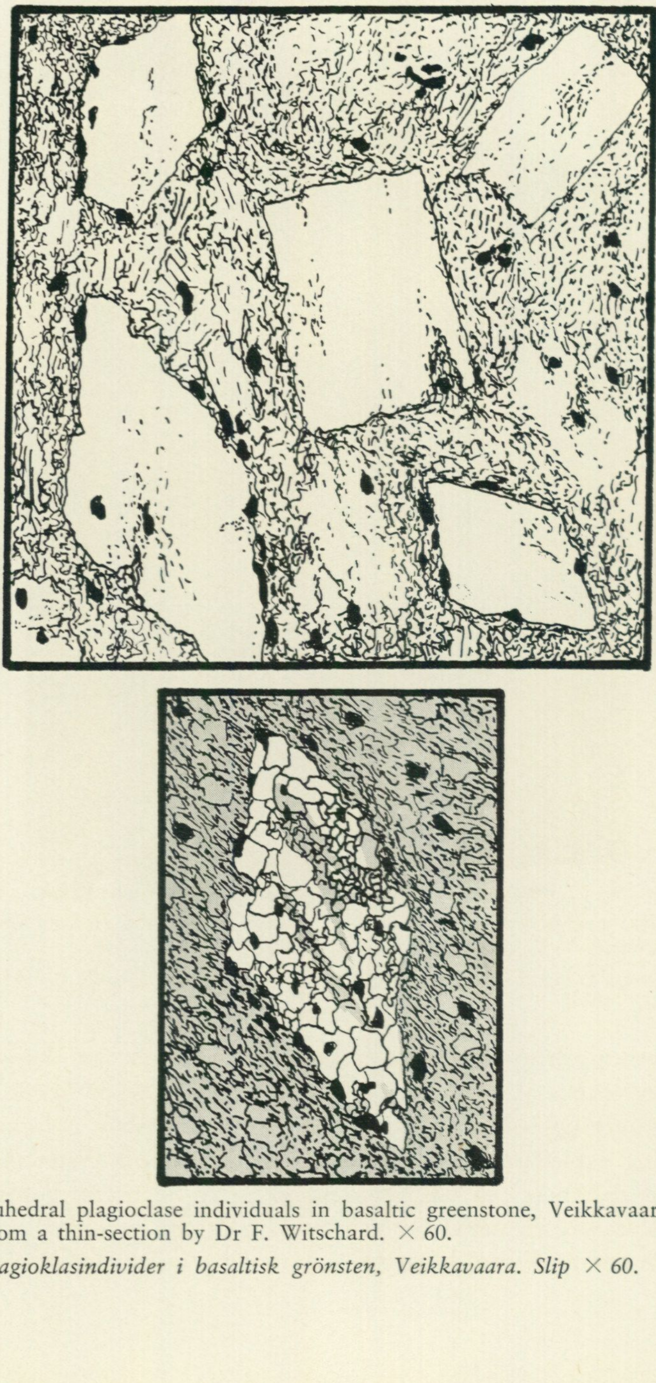

Fig. 8. Euhedral plagioclase individuals in basaltic greenstone, Veikkavaara. Drawn from a thin-section by Dr F. Witschard. × 60.

Plagioklasindivider i basaltisk grönsten, Veikkavaara. Slip × 60.

1964) are due to the presence of finely divided graphite (fig. 7). Pyrite also occurs as an impregnation in the dolomite. Limestone with calc-silicate bands was reported long ago by Fredholm (1886) from the southwest bank of the Tärendöälv (NO 7g), 2 km. downstream from Lauttakoski. This also seems to belong to the same stratigraphic horizon. Limestone reported from an outcrop close to the Tärendöälv, west of Suinavaara (NO 8g) must lie at a much lower level.

The nature and significance of the Veikkavaara Greenstones remains to be considered. From the descriptions and analyses given above it seems they can be described as sediments of basic to semi-basic composition. Their good stratification and the presence of certain persistent horizons of graphitic schist suggest deposition in water, probably the sea. Here opportunities existed for grading and re-working of the clastic material and for the precipitation of calcium, magnesium and iron compounds. The basic composition is therefore considered to reflect chemical as well as mechanical methods of sedimentation. It is possible that much of the material is pyroclastic (volcanic ash etc.) and originated in some area of basic volcanic activity. There are, however, no recognizable tuffitic fragments in thin sections examined to date, possibly due to destruction during reworking and/or later recrystallization. Nor has the author seen any obvious lava flow or structure which can be unequivocally interpreted as such. Certain massive-looking beds in the Veikkavaara area turn out to be intrusive bodies on closer examination. The porphyritic character of some of the rocks is occasionally due to the existence of much altered feldspars which still retain their euhedral character (fig. 8). Such rocks may be extrusive bodies but are probably local in extent.

2. PAHAKURKIO GROUP

This is the name given to quartzites and schists which overlie the Veikkavaara Greenstone Group. They are best exposed along the Kalixälv between Pahakurkio and Saarikoski (NV 6d–e) and in certain glacial melt-water channels such as the Syväjoki and Hietajoki, SSE of Masugnsbyn (NV 7e, 8e). Fredholm reported on them as early as 1886 (p. 19) and they were revisited by P. Geijer (1931, p. 66) who figured outcrops in the steep, canyon-like walls of the Syväjoki valley. A more detailed study of the outcrops was made by M. Beyer (1948) and the information incorporated on T. Eriksson's map of the Pajala field (1954, Pl. 1). The above outcrops are, in effect, type localities for the Group and from them an almost complete succession can be pieced together since their mutual relationships are known fairly accurately thanks to the aeromagnetic maps and to the structural interpretation. The vital feature is a correct determination of the order of stratigraphic succession and this can be established from the cross-bedding which is a not uncommon feature of some of the quartzitic members. Of course previous visitors, e. g. Geijer (1931, p. 68), Beyer (1948) noted the presence of cross-bedding too and even drew conclusions regarding the direction of 'younging'. Strangely enough this valuable information was never used in any systematic way by Eriksson or Ödman when compiling regional maps of the area. In the present investigation observations of this feature of sedimentation were made at numerous places and often several times within the limits of a single outcrop. No ambiguity was found as regards the direction of younging. The following stratigraphic succession is therefore presented with the greatest confidence.

Quartzite, 2 d
Andalusite and/or sillimanite schist, 2 c
Quartzite, 2 b
Greenschist (Syväjoki section)
Pelitic schist and quartzite, 2 a

The lowermost beds of the Pahakurkio Group are poorly exposed but there is no indication they are conglomeratic or that a marked discordance exists between them and the Veikkavaara Greenstones. It may, however, be recalled that the uppermost unit of the Greenstones thickens in the direction of Masugnsbyn and therefore a slight discordant relationship is evident on a regional scale between it and the lowermost formation of the Pahakurkio Group. There is no evidence that this discordance is an erosional feature.

The lowest beds exposed occur in the Rautajoki stream (NV 9d) and consist of mica-schist, quartz-mica schist and even quartzite with a little cross-bedding. The latter feature establishes that younger beds occur in a westerly direction and overlie the Veikkavaara Greenstones, here locally represented by the Masugnsbyn dolomite. Mica-schist follows and is in turn overlain by well bedded quartzites with good cross-bedding confirming the direction of younging. The quartzites seem to form a

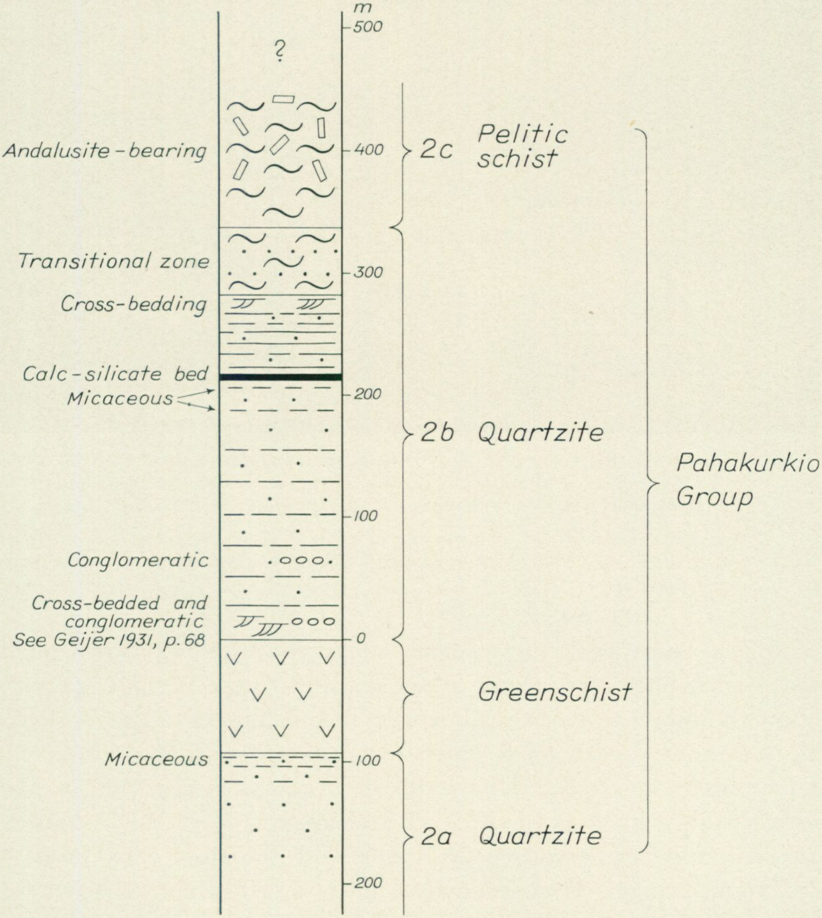

Fig. 9. Measured section of part of the Pahakurkio Group exposed in the Syväjoki stream (square 7e).

Sektion genom en del av Pahakurkiogruppen, Syväjoki (ruta 7e).

Fig. 10. Alternating quartzitic and pelitic schist marking the transition from formations 2b and 2c (Pahakurkio Group). Hietajoki stream section (square 8e), 8 km SE of Masugnsbyn. Hammer (lower right) gives the scale.

Växlande kvartsit och glimmerskiffer visande övergången mellan formationerna 2b och 2c (Pahakurkiogruppen). Hietajoki profil (ruta 8e). Hammaren anger skalan.

lithological entity probably wedging out to the south as shown on the map. Higher beds occur in the Syväjoki valley to the SE (NV 7e) where almost continuous exposures allow a detailed section to be drawn (fig. 9). The lowermost quartzite, is much recrystallized and few sedimentary structures can be discerned. Towards the top it is biotitic and in sharp contact with a greenschist. This rock is about 100 m thick schistose, scapolitized and apparently conformable with the other beds. From the aeromagnetic maps it seems to have a considerable lateral extent. Its primary character is unknown.

Well-bedded micaceous quartzites, 2b, overlie the greenschist. They commonly display cross-bedding, a feature further accentuated by the pebbly character of certain layers (See Eriksson 1954, fig. 12). In all cases the cross-bedding indicates younging of the beds to the west. Since, however, the bedding dips eastwards the beds are slightly overturned. Upwards, the quartzites pass into pelitic schists, often with large andalusite individuals. This takes place via a transition zone in which the thickness and frequency of the pelitic elements increases progressively. A typical example of rock from the transition zone is shown in fig. 10. The skarn rock shown in the section consists of quartz, feldspar, biotite, amphibole and epidote. It may represent a carbonate-bearing horizon in the sequence. The andalusite-bearing schists are of 2c type. They are, however, better exposed in a similar profile 4 km to the NW (NV 8e). Here the transition from quartzite to pelitic schist is well seen and many interesting features are shown by the quartzite, 2b. The angles of discordance between the sedimentary units are locally very large and at one place 'slum-rolls' of the type described by Ksiazkiewecz (1958) are seen. In contrast to exposures of the quartzite in the Syväjoki section pebbly, conglomeratic beds are virtually absent. Further study of the sedimentary features of this and other quartzites in the area is necessary before a better picture of the mode of sedimentation can be obtained.

The petrography of the clastic material is also of some interest. Pebbles observed by the author in quartzites exposed in the Syväjoki profile include quartz, quartzite and a dark rock possibly greenstone. No systematic study of the pebbles or of the dark bands often found together with the cross-bedding, has been undertaken. The latter are not significantly magnetic and in the few slides examined the 'heavy' minerals include rutile, tourmaline, zircon and ilmenite and apatite (fig. 11). Further investigations may throw some light on the provenance of the material.

The uppermost beds of the Group are well exposed along both banks of the Kalixälv between Pahakurkio and Saarikoski. Here the pelitic schists, 2c, seen in the westerly part of the Syväjoki section reappear and are overlain by a quartzite. Between the two, a transition zone about 10 m wide of alternating quartzitic and pelitic beds occurs. The pelitic members are crystalline schists and virtually no primary features remain. But because of the large, well-washed rock surfaces it is possible to discern a ribbing with a N–S strike and this coincides with the bedding of the quartzites above. It is therefore taken as an indication of bedding in the schists. The quartzite formation, 2d, which overlies the schists is extremely well-bedded and flat or gently dipping (fig. 12). Cross-bedding is rarely seen but when present indicates the succession of beds to be normal. A striking feature is the presence of excellent ripple-marks and rill-

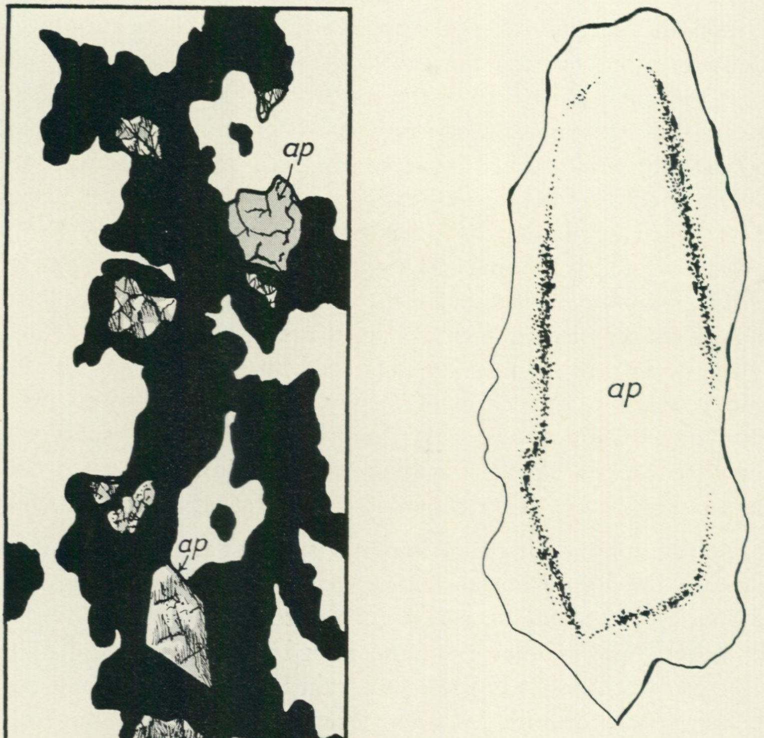

Fig. 11. Detrital apatite (ap) grains from a dark band in quartzite. Syväjoki profile. Drawn from a thin section by Dr F. Witschard.

Klastiska apatitkorn (ap) i ett mörkt skikt i kvartsit. Syväjokiprofilen.

Fig. 12. Flat-lying quartzites of the Pahakurkio Group (2d) exposed on the south side of the Kalixälv (square 6d).
Flatliggande kvartsiter (2d) tillhörande Pahakurkiogruppen vid Kalixälven (ruta 6d).

marks (cf Shrock, 1948, fig. 92) in some parts of the formation (figs 13–14). The contact with beds of the overlying group is not exposed but presumably occurs in the vicinity of Saarikoski. Downstream from Pahakurkio and lower in the succession, mica-schists and quartz-mica schists have been excellently described by Ödman (1939, pp. 78–79).

In conclusion, then, one can say that the Pahakurkio Group represents a radical change in the type of sedimentation as compared with the Veikkavaara greenstones. The absence of basal conglomerates seems to indicate that this did not begin with a marine transgression of classic type. Nor was there any marked erosion of the greenstones. On the contrary, the large quantity of clastic material, dominantly quartz and feldspar, introduced into the area seems to represent a continuation of the sedimentary process. The origin of this material is, however, unknown.

Fig. 13. Ripple-marked quartzite of the Pahakurkio Group (formation 2d) exposed in the north side of the Kalixälv (square 6d).

Böljeslagsmärken i kvartsit (2d) tillhörande Pahakurkiogruppen vid Kalixälven (ruta 6d).

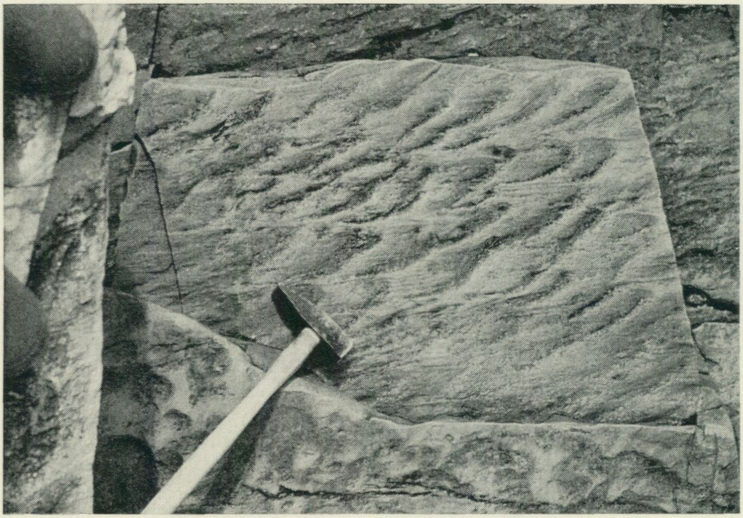

Fig. 14. Rill-marks in quartzite of the Pahakurkio Group (formation 2d) exposed on the north side of the Kalixälv (square 6d).

"Rill-marks" i kvartsit (2d) tillhörande Pahakurkiogruppen vid Kalixälven (ruta 6d).

Fig. 15. Conglomerate (3b) of the Kalixälv Group, Saarikoski (square 7d).
Konglomerat (3b) tillhörande Kalixälvgruppen, Saarikoski, (ruta 7d).

3. KALIXÄLV GROUP

Rocks belonging to this group occupy a zone of varying width west and south of the Pahakurkio Group. Outcrops are not too numerous but a few occur at Tiankikoski (NO 5f) and Saarikoski (NV 7d) on the Kalixälv and at scattered places west and southwest of the river. Long, continuous sections through the series do not exist and the nature of the rocks is incompletely known. Indeed, this major group of rocks, younger than the quartzites of the Pahakurkio Group, has not previously been recognized. Support for its existence rests largely on the evidence of the aeromagnetic maps, which reveal the presence of alternating magnetic and less magnetic sheets in contrast to the overall low magnetic intensity of the Pahakurkio Group. These sheets become increasingly difficult to follow west and south due, no doubt, to the increasing effects of granitization. Indeed the limits of the group are rather arbitrarily drawn in these directions. No satisfactory type locality is known.

The basal member of the group is not exposed but is taken to be a persistent magnetic sheet which crosses the Kalixälv at Saarikoski.

This is assumed to be some sort of greenstone (3a). The lowest exposed formation is a conglomerate (3b) with well rounded pebbles (fig. 15) which lies immediately above the magnetic horizon. The conglomerate is about 20 m thick and contains pebbles of quartzite and a dark basic rock. The quartzite can be matched with some of the coarser types of quartzite found in the Pahakurkio Group. The conglomerate passes upwards into a rather dark, fine-grained hornblende-bearing quartzite with distinct cross-bedding. The latter shows clearly that the beds young to the west and therefore overlie the Pahakurkio Group, a fact of great importance for unravelling the structure of the area.

No further exposures occur in a westerly direction but seven distinct magnetic sheets (3d), are clearly visible on the aeromagnetic maps. These are assumed to be beds of basic composition (basaltic sediments or basic lavas or the like) and are shown accordingly on the map (NV).

At Tiankikoski, approximately 13 km downstream from Saarikoski, a further conglomerate occurs. It is well known from the writings of Ödman (1939, pp 75–78) and T. Eriksson (1954, p. 25) who noted the well rounded nature of its pebbles and polymict character. Ödman identified a wide variety of pebbles including gabbro, syenite, granite, leptite and different sorts of quartzite. The conglomerate is here about 30 m thick and can be followed some distance from the river to the east. It dips steeply to the SSE and is apparently conformable with other formations. Assuming no inversion has taken place the succession at Tiankikoski is: –

Quartz-mica schist locally with gabbroic greenstone of intrusive origin, 3d
Conglomerate, 3b
Carbonatic greenstone and greenschist, 3a
?
Pahakurkio Group, 2a–d.

There is thus a certain similarity between the conglomerates as regards the nature of the pebbles, particularly the presence of quartzitic types in both, and associated beds. A direct physical connection between the two cannot be established by normal field mapping owing to lack of exposures but the aeromagnetic map suggests it exists. Unfortunately, the continuity of the beds is disturbed by a major fault close to Tiankikoski but allowing for displacement on this it seems, in the author's opinion, reasonable to equate the two conglomerates stratigraphically.

The beds above the Saarikoski conglomerate can also be followed on the aeromagnetic maps southwards and are similarly affected by the fault. Exposures of these are virtually non-existent to the north of the fault but to the south pelitic schists, often andalusite and/or sillimanite-bearing, occur at a few places, e. g. 6 km west of Männikönsaari, and are probably typical for the less magnetic layers of the group. Others with a more quartzose character are well exposed downstream from Tiankikoski. Unfortunately nothing is known about the rock type responsible for the magnetic sheets which characterize the group. Those in the upper part of the group are at best represented by biotite-magnetite granite-gneiss, a rock which gives little information about its primary nature. West and south-west, i. e. in the direction of younging of the rocks, granitization effects become more and more accentuated. It is therefore impossible to establish any natural upper stratigraphical limit for the group.

RISSAVAARA QUARTZIITE

Formations younger than the Kalixälv group are unknown with one possible exception, namely, the quartzite on Rissavaara (SV 2e). This is completely recrystallized and surrounded by granitic rocks. For tectonic reasons, however, it seems to be the youngest recognizable sedimentary rock on the map-sheet.

THE CONGLOMERATE AT HAUKKALAKI

One of the most puzzling features of the stratigraphy of the map-sheet is the conglomerate which makes up a significant part of the hill Haukkalaki (NO 6g). Some details have already been given by Ödman (1939, p. 80) and T. Eriksson (1954, pp 27–28). The best exposures occur on the northerly part of the hill (fig. 16) where the conglomerate is ill-sorted and contains boulders up to 35 cm in diameter. Southwards, the size and frequency of the fragmental material decreases and a bedding is discernible, sometimes accentuated by the parallel orientation of elongate pebbles. The strike is here NE and the dip 55–65 degrees to the SE. The pebble material consists of two main types, andesite porphyry and hornblende porphyry. The former can be matched exactly with outcrops 2 km north of Haukkalaki but the latter is not known from any outcrop.

Fig. 16. Conglomerate exposed on the north slope of the hill Haukkalaki (square 6g).
Konglomerat på Haukkalakis norra sluttning (ruta 6g).

Careful search has revealed the presence of a few small pebbles of quartzite, the source of which is unknown. The porphyry material, however, is most likely locally derived. Unfortunately, the contact between the conglomerate and the underlying beds (?porphyry) is not exposed but probably occurs immediately north of Haukkalaki.

A rather similar conglomerate occurs in exposures 5 km to the NNE, on the west bank of the Tärendöälv (NO 7g). It is here in contact with porphyry-type rocks but the attitude of the contact is indeterminable. The pebbles also have a porphyritic character though this is somewhat masked by later scapolitization. Between the two main outcrops one small outcrop is known, the rock here being slightly conglomeratic. At all three localities the magnetic intensity is low. The conglomerate is considered to occur as accumulations, probably in basins, on the eroded surface of the porphyritic rocks (see Pl. 1). It cannot be readily correlated with any of the stratigraphical units described above but is probably younger than the Veikkavaara Greenstone Group though possibly older than the Rissavaara Quartzite. The view of T. Eriksson (1954, p. 28) that the conglomerate marks a major unconformity between an older rock series, the porphyry-porphyrite series (= Svionian, Ödman 1957), and a younger Lapponian series (= Karelian, Ödman 1957) cannot be substantiated from evidence on the Tärendö sheet. Work in progress on the Pajala sheet to the east will, it is hoped, throw more light on this problem.

REGIONAL CORRELATION

The stratigraphic succession outlined above provides a more satisfactory basis for correlation with other areas in northern Norrbotten. Comparison with the succession recently worked out for the Kiruna sheet (Offerberg, 1967) is relevant in this respect. The correlation shown in Fig. 17 is entirely lithostratigraphic and probably only a rough approximation. Work in progress on intervening map-sheets may call for revision in the future but the essential element, namely, equation of the Veikkavaara Greenstone Group with the Greenstones of Kiruna type, seems indisputable. Apart from lithologic and petrologic similarities both are characterized by the presence of horizons of graphitic schist.

29J Kiruna	28L Tärendö
Upper Hauki Group (Vakko)	Rissavaara Quartzite
Paittajärvi Greenstones	–
Kiruna Porphyries	Kalixälv Group
Kurravaara Conglomerate	Pahakurkio Group
Greenstones of Kiruna type	Veikkavaara Greenstone Group
——— Major unconformity ———	?
Older Granite	

Fig. 17. Possible correlation of the main litho-stratigraphic units (groups) of map-sheets 29J Kiruna (Offerberg, 1967) and Tärendö.

Korrelation av 29J Kiruna- och Tärendöbladens större litostratigrafiska enheter.

The discordance which separates the Greenstones of Kiruna type from the basement of older granite cannot be recognized on the Tärendö sheet. On the other hand the Pahakurkio Group seems to have its natural equivalent in the Kurravaara conglomerate which apart from clastic rocks is also represented by mica-schists. A highly significant distinction between the two map-sheets is the absence of stratified porphyry on the Tärendö sheet. Tentatively it is proposed to equate the Kiruna porphyries with the Kalixälv Group.

Finally, the Rissavaara quartzite is considered to be younger than all other layered rocks on the Tärendö sheet and hence occupies a stratigraphic position equivalent to the well known Upper Hauki (Vakko) rocks. The latter are thought to be older than the Lina granite (Geijer, 1931, p. 22) which is also the case with the quartzite at Rissavaara.

BASIC-INTERMEDIATE INTRUSIVE ROCKS

GABBRO

A striking feature of the aeromagnetic maps is the light they throw on the distribution of the gabbroic rocks. Known bodies can be more accurately defined and new ones discovered.

The largest and most well known is the *Tärendö gabbro* (Geijer, 1931, pp 88–89 and T. Eriksson, 1954, p. 32), possibly due to the number of exposures, most of which are readily accessible from the roads. The main body is about 22 km long and orientated NE–SW. A narrow prolongation continues southwards on the adjacent sheet (27L NO). It has an outcrop width of 5–6 km and unites three separate bodies shown on Eriksson's and Ödman's (1957, Pl. 1) maps into a single body.

In outcrop the rocks are usually somewhat weathered but are clearly seen to be medium to coarse-grained and massive. No systematic petrographic study has been undertaken but in the few thin sections examined the chief minerals consist of andesinic-labradoritic plagioclase, clinopyroxene and possibly some orthopyroxene. Apatite is common among the accessories and Geijer (1931, p. 88) reported the presence of a coloured, pleochroic variety from a sample collected by Fredholm.

A chemical analysis (A3 in figs 34–35) of unusually fresh rock from a temporary exposure in a road-cutting near the south-west end of the body showed a normal gabbroic composition.

The massive character of the gabbro makes prediction of its extent in covered ground difficult without the aid of geophysical data. One interesting exception to this rule occurs in outcrops 2.5 km west of the bridge over the Kalixälv at Tärendö. Here a faint but distinct layering is discernible, the strike being N60E and the dip 20 degrees to the SSE.

This is in keeping with the elongation of the gabbro established by geophysical evidence. A dip of 20 degrees here is also in apparent agreement with a model worked out for the gabbro on the basis of gravimeter measurements (See Appendix). It does not, however, necessarily reflect the dip of the lower and upper contacts.

Outcrops of the gabbro rarely show any marked structural direction but the aeromagnetic map indicates the existence of strong faulting. Breaks in the regularity of the NE trending contact can best be explained as off-sets brought about by faulting. The presumed faults can be followed some way into the gabbro proper where they are commonly marked by narrow zones with lower magnetic intensity. The gabbro as a whole seems to be almost entirely surrounded by granite, the latter being distinctly younger in age.

Hence the present contacts represent the limit of granite invasion and do not necessarily coincide with the original limits of the body. Indeed it seems as if the granitic material penetrated the gabbro extensively along lines of faulting. This is particularly clear around Tärendö village. In other words, the general shape of the body is probably substantially unchanged though its overall dimensions are somewhat less. The interpreted form of the gabbro is shown in fig. 41 in the Appendix.

The aeromagnetic map suggests the presence of a syncline within the gabbro itself. The almost N–S axis passes close to Saarisuvanto (SO 1i).

The relation of the gabbro to the layered rocks is little known. However, a narrow, folded zone of magnetic gneisses assigned to the Kalixälv Group approaches the gabbro from the NW. The angular relationship which exists may be interpreted as a discordant intrusive contact on the part of the gabbro.

A large area SE of the Tärendö gabbro is characterized by fairly high magnetic intensities. Outcrops are sparse and it is difficult to know how to interpret the geophysical evidence (no gravimetric data exist.). One outcrop close to the road 6 km SSE of Tärendö consists of gabbro while another a little further south together with a number of locally derived blocks, is basic gneiss with porphyroblasts of K-feldspar. Outcrops on the hill Mestosvaara are of granite but others near the road immediately to the west consist of pyroxene, biotite, apatite as well as quartz and abundant K-feldspar, particularly microcline. This rock, from its field and microscopic appearance, is looked upon as gra-

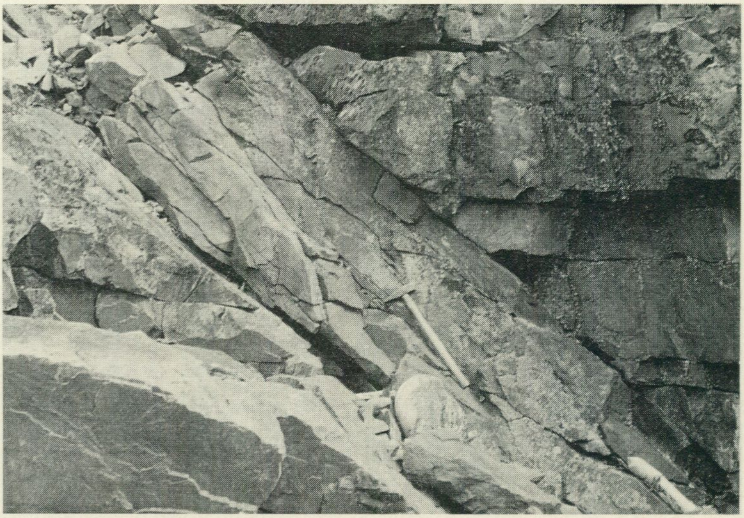

Fig. 18. Diabase dyke cutting flat-lying quartzites of the Pahakurkio Group. Exposure on the north side of the Kalixälv (square 6d).

Diabasgång genomsättande flackliggande kvartsiter tillhörande Pahakurkio-gruppen. Kalixälvens norra sida (ruta 6d).

nitized gabbro and is probably typical for many rocks within this area. It is considered therefore that the original rock was probably gabbro and possibly continuous with the Tärendö gabbro described above. As a result of extensive granite invasion and replacement it became detached from the latter, at least at the present level of erosion. Bodies of massive granite, such as that making up the bulk of Mestosvaara (SO 0i), were emplaced within it and granitization of the host gabbro took place to various degrees. A similar explanation is offered for a triangular area of magnetic rocks 4 km SSW of Kompelusvaara (SO 0f, 0g) but there are no known outcrops to permit confirmation of this.

The *Isohuhta gabbro* (SO 1f, 2f) has not previously been represented on any geological map. It gives rise to a distinct magnetic anomaly on the aeromagnetic map and one outcrop was found confirming the presence of gabbro. It is about 5 km long and between one and two km wide. The surrounding rocks are probably granitic in composition.

The *Koinujoki (?) gabbro* (SV 4d, NV 5d) was also previously unknown. It is, however, a sizeable body with a length of 7 km and a width varying between 1 and 2 km. No outcrops are known to exist and for this reason doubt remains whether it is in fact a gabbro at all. By analogy with the known bodies and from the general appearance of the magnetic anomaly, a gabbroic rock seems to offer the best explanation. It is almost certainly surrounded by granitic rocks.

The *Mäntykero gabbro* (NV 9e, 9f) is also a fairly large body whose limits are determined mainly from the aeromagnetic maps. A few outcrops occur, notably near Mäntykero itself, thus confirming the presence of gabbro. The body is considered to have an abrupt, discordant relationship with greenstones to the SE and SW and is in contact with granite to the NNW and NE. As such it is considerably smaller than supposed by Eriksson (1954). No gravimetric interpretation is available.

The *Petäjävaara gabbro* (NO 9i, 9j) is known from exposures along the Lainioälv, north of its confluence with the Torneälv. It is a hypersthene-gabbro with some clinopyroxene, biotite and a little quartz (3 per cent according to a volumetric analysis of Ödman, 1957, p. 104). But other, less basic rocks of syenitic or dioritic composition also occur marginal to the gabbro and probably account for the difficulty experienced in determining the limits of the body from the aeromagnetic maps alone. The form shown on the map is therefore an approximation. Two smaller magnetic bodies, thought to be gabbro (no outcrops), occur in the basic gneisses to the south.

MINOR BASIC AND ULTRABASIC INTRUSIVES

In the course of routine geological investigations a number of small intrusive bodies with a basic composition have been encountered. Though quantitatively very minor elements of the geology their petrographic character and relation to other rocks are of some interest.

Between Pahakurkio and Saarikoski exposures of quartzite are cut by a number of dyke-like bodies (NV 6d). These strike northeasterly and dip at about 45 degrees to the SE (fig. 18). Six separate bodies were found in exposures on the north side of the river over a horizontal distance of 160 metres. An interesting feature is that they show, in various degrees of intensity, a foliation roughly parallel with their walls. I. Lundström and K.-A. Sandahl studied these dykes more closely at the request of the author and found, at one place, the foliation to make an angle with the wall of the dyke. They also reported granite veining, the individual veins having a core of amphibole and biotite. There was no apparant baking of the quartzite close to the dykes.

A thin section of one of the more weakly folded dykes shows it to consist of tabular crystals of andesine, apparently primary, with a sub-parallel orientation, biotite with numerous pleochroic haloes around zircon, and hornblende, the larger crystals of which are distinctly poikiloblastic. Quartz is also a small but significant component, as is titanite. The foliated character is considered to reflect partly a primary, sub-parallel orientation of the plagioclase and partly recrystallization at a later date under the influence of tectonism.

New exposures made in connection with road improvements at the western end of the main Tärendö gabbro body were examined by the author in 1963 and 1964. The locality is close to the road to Gällivare (SO 1h), 18 km from Tärendö. Here two sub-vertical dykes 20 and 40 cm thick cut the gabbro. They are dark and fine-grained but a few slender, lath-like plagioclase (An_{30}) individuals with a sub-parallel orientation occur. The groundmass is largely epidotic.

A diabase dyke in the skarn/iron-ore zone at Masugnsbyn has previously been noted by Geijer (1929, p. 28). It is about 2.5 m wide and separated from the nearby granite by a narrow selvage of biotite skarn. It is apparently steeply inclined and essentially parallel to the granite contact. In thin section it shows a distinct sub-ophitic texture though significant alteration of the minerals has taken place. The plagioclase, for example, is sericitized, the pyroxene altered to hornblende, and a little scapolite developed. These features suggest the dyke is older than the skarn-forming processes and possibly older than the granite.

Minor intrusives of basic character are associated with the Veikkavaara Greenstones. On Veikkavaara itself they are exposed in a number of outcrops but not sufficiently well for their limits to be followed in detail. To all appearances they seem to be concordant or semi-concordant with the banded greenstones. All have undergone recrystallization in various degrees, hornblende being the most common secondary mineral. Some show distinct foliation which effectively masks primary textural features. In the absence of any evidence to the contrary these rocks are considered to be metadiabases of intrusive origin.

On the northern slope of Veikkavaara (NV 9d) a larger body with an outcrop width of nearly 300 m is exposed. It is termed gabbro-diabase

Fig. 19. Olivine occurring as brown-weathering ovoids (dark in picture) in an ultrabasic rock (light coloured in picture). Veikkavaara (square 9d). Coin 2.5 cm in diam.

Olivinindivider (mörka fläckar) i en ultrabasit (ljus). Veikkavaara (ruta 9d). Myntets diam. är 2,5 cm.

on account of its mineral texture and is apparently slightly discordant to the layering of the greenstones. Its western margin is marked by a dark, schistose rock with numerous brown-weathering ovoids (fig. 19) up to a centimetre in length. The latter have their long axes orientated parallel with the schistosity. In thin section they are seen to be olivines embedded in a matrix of tremolite (fig. 20). The olivine is surrounded by a narrow alteration zone consisting of iddingsite (closet to the olivine) and fibrous chrysotile. There is also a crude schistosity marked by parallel lines of opaque minerals, mainly magnetite, which are conformable with and pass into the schistosity of the rock as a whole. The olivine is therefore believed to be earlier than the development of the schistosity and the rock is thought to represent an ultrabasic facies to the gabbro-diabase. The tremolite is considered to be a secondary, i. e. metamorphic, mineral.

None of the intrusive bodies in this area seem to disturb significantly the continuity of the stratigraphy (see aeromagnetic maps) thus further

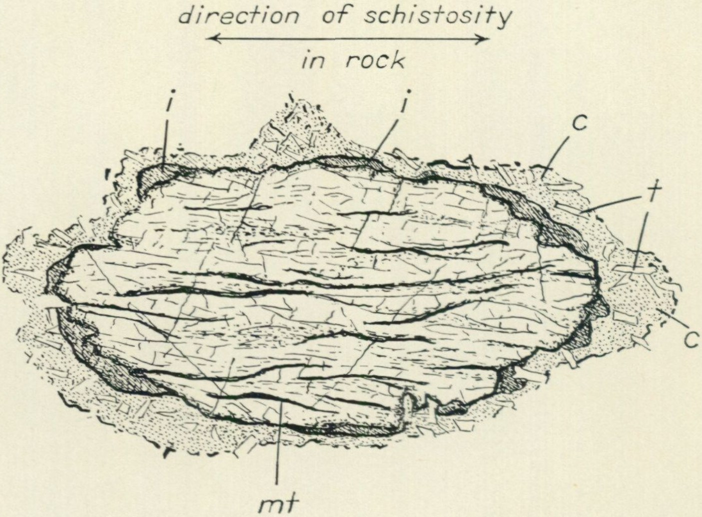

Fig. 20. Olivine marginally altered to iddingsite (i) and chrysotile (c). Tremolite (t) is also common in this zone and forms a major component of the matrix (the latter not shown in the text figure). The dark veins of magnetite (mt) in the olivine core are orientated in the same plane as the schistosity. Drawn from a thin section by Dr F. Witschard. × 5.5.

Omvandlad olivinkristall. Iddingsit (i), krysolit (c) och tremotlit (t). × 5,5.

emphasizing their concordant character. An interesting feature, however, is that they coincide with zones of low magnetic intensity. Whether this is a general characteristic or not is unknown. It is also appropriate to mention here that meta- and gabbro-diabases with similar characteristics are known from greenstone formations on the nearby Lainio and Vittangi map-sheets.

The diabases are considered to have been intruded shortly after the deposition of the sediments now constituting the Veikkavaara Greenstone Group and possibly represent near-surface intrusives related to some phase of contemporary volcanism.

Gabbro-diabasic rocks are also exposed close to the Tärendö River, NW of Lauttakoski (NO 8g). To the east of the river they seem to dip easterly at 50 degrees, are discordant to aluminous schists of the Veikkavaara Greenstone Group and are locally cordierite-bearing. On the west side of the river a rock of metabasic type, locally much altered by hydrothermal agencies, is exposed. It seems to be cut by granodiorite. A soapstone (= *täljsten* in Swedish) deposit is present on the east side of the river and may represent a highly altered ultrabasic differentiate of the gabbro-diabasic suite.

ANDESITE-PORPHYRY

Andesite-porphyry occupies a significant area north and NE of the hill Haukkalaki (NO 6g, 7g, 7h) where it is known from a few exposures and from blocks of local origin. It is typically massive (excluding later recrystallization and shearing effects at a few places) and is characterized by the presence of small tabular crystals of plagioclase 1–2 mm in length. In certain weathered surfaces the porphyritic character is especially well seen, the grey-white plagioclase individuals contrasting with the darker matrix. In thin section the rock is seen to consist of subhedral plagioclase individuals with an andesinic composition (An_{40-45}), hornblende and biotite. The matrix is normally fine-grained with quartz, a little microcline, plagioclase, titanite and epidote. Quartz never occurs porphyritically but is always confined to the matrix. The analysis (A4 in figs 34–35) shows a typical andesite composition except, perhaps for a little excess potash and quartz, possibly due to incipient granitization effects in the analyzed sample. The rock differs both macroscopically and microscopically from all other rocks on the map-sheet. A few rounded inclusions have been found, one resembling amphibolitic gneiss.

On the aeromagnetic maps, the porphyry is characterized by irregular levels of magnetic intensity without any consistent pattern which might denote layering. In general, it seems to be discordant to other rocks of the area and is considered by the present author to represent an intrusion in the Veikkavaara Greenstone Group pre-dating the main regional metamorphism and granite emplacement. It may, however, post-date all the layered rocks with the possible exception of the Rissavaara quartzite.

This interpretation differs radically from that offered by Eriksson (1954) who considered it to be part of an older sequence of rocks collectively termed the porphyry-porphyrite series and subsequently referred to the Svinonian (= Svecofennian) cycle by Ödman (1957). Such rocks would have to be older than the Veikkavaara Greenstones and to be exposed in the Haukkalaki-Naisvuoma region a fault with a vertical displacement of over 1000 m would be required. It is overlain by the Haukkalaki conglomerate which, unfortunately, cannot be readily correlated with any other formation.

GRANITIC AND DIORITIC ROCKS

Rocks of granitic and sub-granitic character occupy more than 60 % of the map-sheet. Their general distribution and petrologic features were first outlined by Geijer (1931) and subsequently incorporated, with modifications, in the map of the Pajala field (Eriksson, 1954) and of Norrbotten county (Ödman, 1957). Work carried out in connection with the present map-sheet description has not been specifically concentrated on these rocks since they are not known to be significantly ore-bearing but the aeromagnetic maps contain many features which improve our knowledge of their distribution and their relationships to each other and to non-granitic rocks. A better basis is, therefore, provided for future genetic, petrologic and geochronologic studies.

The rocks described above have one feature in common, namely, they are all younger than the supracrustal rocks and are probably younger than the gabbros. Nothing is yet known about their radiometric age and only a little about their relative age relationships. There are, however, indications that two phases of emplacement exist, an earlier one corresponding to the Haparanda Series of Ödman (1957, p. 65), and a later one to the well known Lina granite series (See legend to map-sheets). They are described accordingly.

1. THE HAPARANDA SERIES

Quartz-diorite occurs approximately 3 km east of Martinvaara (SV 0a, 0b). It is typically massive, cut by aplitic veins and distinct from the surrounding Lina-type granite from which it was first distinguished by Ödman (1957, Pl. 1). The present investigations show, however, that its form differs from that supposed by Ödman occurring in two parallel zones with a northerly trend. A thin section shows the main minerals to be biotite, hornblende, plagioclase and quartz with microcline, titanite and epidote in minor amounts. The rock is apparently older than the Lina granite which surrounds it and thus in mode of occurrence and petrography belongs to the Haparanda Series of Ödman, a group of earlier (? Karelian) intrusives. Though occupying only a small part of the map-sheet its presence is thus of considerable interest. A similar rock occurs to the north near Pikku Karravaara (SV 2a) and as relicts in Lina granite on Kesasvaara (SV 3a). A rather similar rock is thought to occur 6 km ENE of Junosuando (9i) in association with the Petäjävaara gabbro (F. Witschard, Lainio sheet 29 L).

Outcrops along the Lainio älv show this gabbro to be flanked by dioritic rocks. In the field there seems every reason to assume they are contamination products arising from the influence of granitic material on the pre-existing gabbro. Both quartz and microcline are significant elements together with pyroxene and hornblende. An analysis given by Ödman is relevant in this respect (1957, p. 127, tables 3 and 9). The use of the term syenite for this rock seems unwarranted though types with a higher proportion of alkali feldspar may well occur in this environment. The presence of such 'hybrid' rocks may explain the difficulty of drawing the limits of the gabbro in this area merely from the aeromagnetic maps. The time of formation of these dioritic rocks is uncertain but it is here referred to the earlier phase of emplacement (Haparanda series) by inference from work done a short distance to the north on the Lainio sheet (F. Witschard).

Perthite monzonite occurs on Viksvaara north of Junosuando (NO 9h) where it is typically massive. In thin section it is seen to contain equal amounts of plagioclase and potash feldspar and about 5 % hypersthene (F. Witschard, personal communication). Aeromagnetic maps indicate the presence of a well defined body only the southern part of which is present on the Tärendö sheet. Here greenstones are warped around it suggesting a forcible, dilatory mode of emplacement. It is probably synkinematic.

2. THE LINA GRANITE SERIES

By far the most extensive rock on the map-sheet is *granite of the Lina type.* This occurs widely in northern Norrbotten, is characteristically potassic (microcline-bearing) and younger than the gabbroic bodies and supracrustal rocks. An excellent review of its status has recently been given by Geijer (1966, pp 473–482) to which reference may be made. In the present investigation attention has been concentrated not so much on the petrography but on its internal structure and relationships to other rocks.

As regards internal structure the granite is by no means homogeneous. Magnetic sheets, admittedly with low intensity, can be easily traced within the granite area and are considered to represent relicts of pre-granitic formations. On Tärendö NV these sheets show marked parallellism with layered formations to the east. Further south, on Tärendö SV, the picture is more confused though relict folds can be detected as, for example, in the Rissavaara area. Quartzite of sedimentary origin is exposed here and is relict in the granite. Normally, however, the only indication of the magnetic sheets in outcrop is a weak foliation due to parallel orientation of dark minerals in otherwise granitic rock. To the west the granite appears to have fewer magnetic sheets and is therefore more homogeneous or 'isotropic'. This is confirmed from a study of the outcrops, some of which are very large and typically occur on high ground e. g. Ristivaara and Kuusipää. Indeed the general topographic elevation is appreciably higher than is the case for non-granitic areas to the east.

Further features of the internal structure include areas with lower magnetic intensity and weaker orientation, even random orientation, of the magnetic sheets (SV). It is assumed these represent areas of homogeneous granite and a form of discordance is traceable between them and their surroundings.

Distinct, more or less circumscribed bodies of granite occur in association with the metasediments. A good example is the Jakkumus-Tarrilainen body (NV 8c, 9c) briefly described by Geijer (1929, pp 11–12). This is now known to show cross-cutting relations to the schists and has the appearance of a pluton.

To the SSE, in the central part of the map-sheet, more complicated relationships exist between granite and non-granitic rocks. Extensive gneissification is evident in many outcrops with the development of mica and potassium feldspar. Schistose and granitic components are frequently closely associated, the rock then having the characteristics of a migmatite granite. Good examples occur SW and NE of Oriasvaara. Pegmatites are also common in this milieu.

On a regional scale supracrustal and gabbroic rocks in all stages of gneissification and granitization exist at several places within the granite. Examples include the quartzite at Rissavaara (2d, 2e), the sinuous zone of schist north of Onttovaara (4g, 4h, 3h) and schist of varying character at Jukkasvaara (5h, 6i), Nuolivaara (6i, 6j) and Hirvarova (4i, 4j, 5j). An attempt has been made to separate these from the granite though in this milieu and where exposures are scarce the limits are difficult to draw merely on the basis of aeromagnetic data. A subjective element inevitably enters into the interpretation.

In the triangle Masugnsbyn–Saittajärvi–Junosuando other bodies of granite probably exist judging from the aeromagnetic maps. Exposures, however, are very few and their existence can rarely be checked. One exception is a small body about 3 km NW of the hill Suinavaara (NO 8g). Outcrops occur close to the Tärendöälv and the rock in thin section is seen to consist largely of oligoclase in euhedral grains and with or without quartz. Microcline is conspicuous by its absence but other minerals present in small quantities include biotite, carbonate, muscovite and titanite. The rock is granodioritic and cannot be readily referred to the Lina granite series but like the latter seems to post-date the metasediments in the vicinity. A few small granite outcrops were found south of Veikkavaara (NV 8e) and probably form part of a lens-like body concordant with the stratigraphy.

Pegmatites are commonly associated with the Lina granite in Norrbotten and this is also the case for the Tärendö sheet where they form vein-like bodies of varying size. They normally occur in the non-granitic rocks and have essentially the same mineralogy as the Lina granite though black tourmaline is frequently an additional constituent. Even the granite is coarse-grained and may be described as pegmatitic in some areas as, for example, north of Isohuhta (SO).

An interesting body of pegmatite crops out on the hill *Oriasvaara,* between Masugnsbyn and Tärendö (NO 5f, 6f). Mapping carried out by P. F. Stacey showed it to be an irregular-shaped body elongated NW–SE. As such it is markedly discordant to the schistosity and bedding but at right angles to the fold-axis of the Oriasvaara syncline. It is probably intruded along an *ac* joint associated with this fold. It shows no marked zoning, the quartz, for example, occurring as irregular bodies throughout.

Another well-known pegmatite area is in the upper part of the Rautajoki stream, 1.5 km SSW of Masugnsbyn where several distinct bodies have been eroded out of the schists in which they occur (Geijer, 1929,

p. 6 and fig. 2). They are essentially concordant with the bedding and schistosity, show no well defined zoning, and are without economic interest.

Pegmatite veins are exposed at various places along the Kalixälv between Saarikoski and Tiankikoski. One of these has a N–S strike, unrelated to any known structure in the surrounding schists. It is about 1 m thick, vertical and unzoned. This pegmatite and others in the area lie within the limits of the Kalixälv dome which probably has a core of granite. In general it seems as if the pegmatites are most common in schistose, often pelitic rocks within or marginal to the Lina granite.

Perthite granite (Analysis A8, figs 34–35) occurs in a well defined body close to the village of Masugnsbyn (NV 9d, 9e). It shows both concordant and discordant relationships to the layered rocks and its south-east trending contact in the Rautajoki canyon is a faulted one. It is characterized (Geijer 1929, pp 12–24) by the perthitic character of its feldspar (microcline and albite) and in this respects as well as in field appearance is totally different to the Lina granite. It has a well marked albitic margin (analysis A9, figs 34–35) according to Geijer. Geophysical measurements (gravimetric and magnetic) recently carried out give us a much better picture of the granite east of the well known outcrops in the immediate vicinity of Masugnsbyn village. The gravimetric data indicate the granite to be less than 1 km in thickness (see Appendix). A recently completed age determination using the Rb-Sr whole rock method gave 1540 m. y. which is, of course, typical for the widespread Lina granite (personal communication from Dr Eric Welin).

*Kompelusvaar*a (SO 1f, 1g). It is readily distinguished from the Lina type granite on account of its large, often bluish, quartz individuals and reddish potash feldspar. A thin section shows the feldspar to be microcline microperthite and the quartz to be an aggregate of individuals, all of which show evidence of strain. Titanite, chloritized biotite and zircon are present in minor amounts only. This rock has long been distinguished from other granites (Geijer, 1931, Tavla 1) on account of its characteristic appearance. Rather similar rock occurs northeast of Kompelusvaara in the direction of Selkävaara (SO 2h). The exact limits of the rock cannot be determined by normal geological mapping owing to lack of outcrops but the aeromagnetic maps indicate the existence of a more or less circumscribed body in the vicinity of Kompelusvaara. This is shown accordingly on the map but its relation in time to the other granitic rocks is unknown.

Granodiorite. A body of significant dimensions occurs north, east and south-east of Lovikka (NO 6i–j, 7h–j). It is known from a number of exposures and local blocks, and everywhere has a distinctly massive and homogeneous appearance. The uniformity is sometimes relieved by the presence of rounded ovoids of dark basic rock (hornblende- and biotite-bearing) a few centimetres across. In the Siikajoki area (6j, north of Anttis), narrow zones of steeply dipping schist with a NW or NNW strike can sometimes be discerned and these coincide with the long axis of the granodiorite body, which is also one of the main tectonic directions of the map-sheet. In general, the body is characterized by rather low levels of magnetic intensity but its limits to the NE and SW are marked by sharper gradients to higher levels. To the NW, towards Junosuando, it is apparently in discordant contact with the Veikkavaara Greenstones and therefore post-dates them. Its relation in time to the other granitic and gneissic rocks is unknown. The possibility exists that it is older than the Lina granite.

In thin section it consists of well developed plagioclase crystals of oligoclasic to andesinic composition. These form two thirds or more of the total feldspar content which otherwise consists of microcline. There is also a significant amount of quartz (up to 20 per cent) which takes the rock out of the field of diorite. Biotite and hornblende also occur in significant amounts. The rock, furthermore, has a typical granodioritic composition (Analyses 5 and 7, figs 34–35).

The granodiorite described above was previously referred to as syenite. Geijer (1931), for example, outlined a large body of plagioclase-perthite syenite between Kurkkio (map-sheet 29L Lainio) and Palokorva on the Torneälv. This rock is supposed to have rhomb- or rectangular-shaped plagioclase crystals with distinct zoning, the outer alkalic rim being perthitic. Quartz is virtually absent and the content of mafic minerals low. This is clearly a different rock both mineralogically and chemically to the granodiorite described above. Zoning is present in an outcrop close to the Siikajoki but no perthitic rim is present. Quartz is also more abundant. Eriksson (1954) preferred the name syenite for these rocks, a name which was accepted by Ödman when compiling the geological map of Norrbotten. The ratio of plagioclase to alkali feldspar and the quartz content, however, clearly indicate the rock is not a syenite.

Other syenitic rocks. Both Eriksson (1954) and Ödman (1957) use the term syenite for rocks lying outside the limits of the granodiorite as defined above. Relevant outcrops are those near Nuolivaara (NO 6j) to the south-west. Here the rocks are massive and one type superficially resembles syenite from classic syenite areas such as southern Malawi (Nyasaland). In thin section it is seen to consist of pyroxene partially altered to hornblende, biotite and opaque minerals. These are surrounded by plagioclase and microcline in the ratio 2 to 1. A little quartz is also present. The rock is clearly a diorite and is in contact with a darker, finer grained rock reminiscent of microgabbro. It consists of andesine, clinopyroxene and biotite, the latter with a poikilitic relationship to the other minerals. These rocks probably form part of an elongate body slightly discordant to the surrounding gneisses. Another body with similar discordant relationship is thought to occur 5 km west of the Nuolivaara body (aeromagnetic data) but no exposures exist. Recently (1968), roadmaking WNW of Anttis exposed coarse-grained gabbro with some later microclinization and scapolitization. This is part of yet another basic intrusive and hardly merits the name syenite.

Syenitic rocks were identified in the vicinity of Tärendö by Geijer (1931, pl. 1) who referred them to his lime-alkali syenite group. According to Geijer *(op. cit.* pp 89–90) diopsidic augite, hornblende and biotite occur together with oligoclase, microcline and quartz (up to 15 per cent). Other minerals include titanite and apatite and the total volume of mafic minerals lies between 10 and 22 per cent. The aeromagnetic maps help us to delineate the gabbro much better and it seems clear that the supposed syenitic rocks lie close to it. Unfortunately, exposures are too few to allow any detailed picture to be obtained. In principle, however, any syenitic types which occur are probably contamination products *in situ* arising from the reaction of granite with gabbro rather than magmatic differentiates of syenitic composition.

TECTONICS

When aeromagnetic maps of the Tärendö sheet became available it soon became apparent that several hitherto unsuspected structures of regional importance were present. A re-examination of the geological evidence was clearly necessary paying particular attention to ”way-up” features in the sediments, to the measurement of minor tectonic features, and to a careful separation of primary bedding from schistosity and foliation. The various structural elements, both major and minor, are shown on the map of the area and in supporting profiles (Plate 1). Strictly sedimentary structures are described in the stratigraphical section of this paper. Subsequent deformations, represented by folds and associated faults, are normally orientated NW or NE, common directions for the geology of the Precambrian of Norrbotten as may be seen from Ödman's map (1957).

The main tectonic features include the Kalixälv dome (map-sheet NV), Masugnsbyn syncline (NV, NO), Saittajärvi anticline (NV, NO), a fold-fault complex at Lauttakoski (NO), the Junosuando syncline (NO) and Oriasvaara syncline with the associated Kalixälv fault (NO, NV). Other features of regional tectonic significance include the Tärendö fault complex (SO, NO), a syncline in the Tärendö gabbro (SO 2i), pre-granitic (relict) structures in granitic areas, and post-granitic faults at Masugnsbyn (NV).

Kalixälv dome (NV). This is a conspicuous feature of the geology between Saarikoski and Tiankikoski on the Kalixälv. Good outcrops occur along this section of the river and have been visited by a number of geologists. The most recent work was carried out by M. Beyer in 1948 and his results are incorporated in Eriksson's map of the Pajala field (1954) and subsequently in Ödman's map of Norrbotten county (1957, Pl. 1). The dome structure has, however, not previously been recognized.

As may be seen from the map the long axis of the dome has a NW trend and lies slightly SW of the Kalixälv. The exposures which occur along the river are of the greatest importance for establishing the existence of a dome. In the present investigation great care has been taken to distinguish between primary bedding, schistosity and foliation though this is often difficult due to the presence of porphyroblastic minerals and granitization effects. The dip of the beds is low to moderate but increases outwards from the centre of the dome (profiles I and IV on plate 1). A few observations of crossbedding in the quartzites indicate younging of the beds outwards (and upwards) from the centre of the dome.

Masugnsbyn syncline (NV, NO). This is a long narrow structure extending from the village of Masugnsbyn southeastwards in the direction of the hill Oriasvaara. It is also known to extend northwards on to the neighbouring sheet (29L Lainio) where the fold closure is readily apparent on magnetic maps. The fold axis in the vicinity of Masugnsbyn plunges to the south.

The existence of such a marked fold is by no means clear from normal geological mapping but its presence can be confidently postulated since a syncline is necessary to connect two anticlinal areas, namely the Kalixälv dome and the Saittajärvi anticline (see below). The fold-axis is probably gently undulating. The structure loses its identity to the south and is probably cut off by a fault, the Kalixälv fault.

Saittajärvi anticline (NV, NO). This structure occupies a prominent position in the northern half of the map-sheet where its form is conveniently displayed by the Veikkavaara Greenstone Group. The latter has a V-shaped outcrop reflecting the N–S orientation of the fold-axis and southerly plunge. There is no evidence that extensive areas of sediment (quartzite, phyllite and conglomerate) occupy the central parts of the structures as supposed by Eriksson (1954, pl. 1). The SW-facing limb of the fold is remarkably straight and its continuation only broken by a few lesser faults. The beds have a steep or vertical dip and may even be overturned to the SW. Crossbedding in quartzites in the Syväjoki section clearly indicates a younging to the SW though the dip of the beds is to the NE.

The SE-facing limb is poorly exposed and more difficult to interpret. Between Saittajärvi and Lauttakoski, however, the aeromagnetic maps indicate a fairly constant strike. This is confirmed from exposures on the hill Vinsavaara where dips of 40–60 degrees to the SE are seen. The direction of 'younging' is also supposed to be to the SE. Continuity of the strike is only broken by the *Saittajärvi fault* and by some of the N–S faults mentioned in connection with the Oriasvaara syncline.

Between Lauttakoski and Junosuando the strike is far less regular due to folding on NW–SE axes (NO 8g, 8h). A synclinal fold is postulated for the Suinavaara area and an anticline in the vicinity of Salmijärvi. In both cases the plunge of the fold-axes is to the SE. Observations of 'way-

Fig. 21. Brecciated and carbonate-veined greenstone in blocks of local origin close to the Kalixälv fault, Tiankikoski (square 6f).
Lokala block av breccierad och karbonatådrad grönsten vid Tiankikoski (ruta 6f) i Kalixälven.

up' structures are limited to one locality on Suinavaara (figs 3–4) where 'younging' of the beds to the east is evident. This is also the direction of dip and the beds are therefore not inverted. Strong faulting with a WNW trend occurs between Lovikka and Lauttakoski and further complicates the picture. SE and east of Salmijärvi a number of magnetic horizons, presumably greenstones, show deviations from the regional trend and seem to be arranged in the form of a syncline with a NNW plunging fold axis. The eastern limb is much replaced by granite. The structure is clearly complementary to the Saittajärvi anticline as is the Oriasvaara syncline. It is proposed to call it the *Junosuando syncline*.

Oriasvaara syncline (NV, NO). A synclinal structure has been deduced for an area towards the centre of the map-sheet where the hill Oriasvaara is the most conspicuous topographic feature. The structure has not been previously recognized.

The regularity of the fold is broken by faults but, in general, the fold axis plunges SW causing the structure to open out in that direction. It

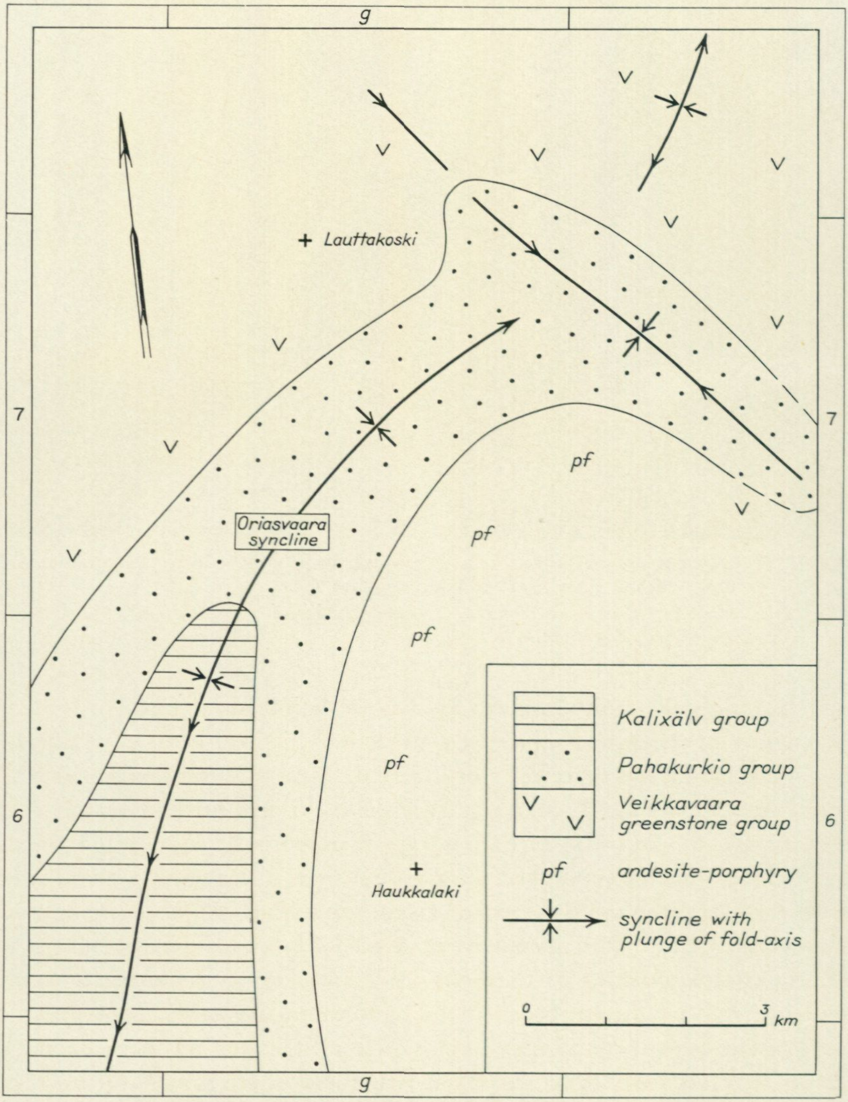

Fig. 22. The Oriasvaara syncline, faulting omitted.
Oriasvaarasynklinalen (förkastningarna är ej medtagna).

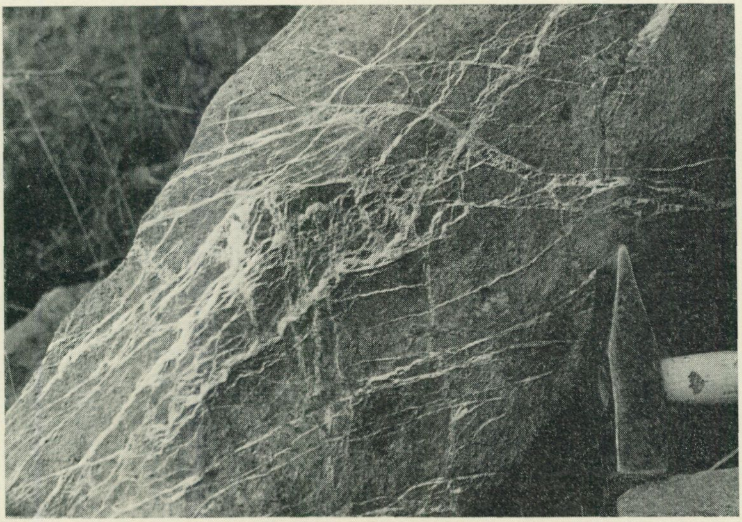

Fig. 23. Scapolite-veining in local blocks of andesite-porphyry near fault line. 1.4 km north of Haukkalaki (square 6g).
Skapolitådring i andesitporfyr (lokala block) vid en förkastning 1.4 km norr om Haukkalaki (ruta 6g).

is bounded to the north and northwest by the *Kalixälv fault* with a downthrow to the SE and is therefore in tectonic contact with both the Kalixälv dome and the Masugnsbyn syncline. This fault is marked by brecciation and carbonate veining in rocks close to the Kalixälv (fig. 21) and by intense jointing 1 km NW of Oriasvaara (NO 6f). Its eastern limb is partly replaced by granite or is in faulted contact with other rocks. Exposures are unfortunately too few for the structure to be mapped in detail but several lesser folds with the same axial directions seem to be present within the main structure. Some indications of these are seen in exposures along the Kalixälv at Tiankikoski and on the aeromagnetic maps. A local reversal of the plunge of the fold axis is seen at one place. Towards the northeast (NO 6g) there is a more pronounced reversal of plunge so that a quartzite formation has a boat-shaped, i. e. synclinal, form. Pelitic schists, stratigraphically below the quartzite, show small-scale drag-folding, the folds, in profile, indicating the presence of a syncline to the NW. This syncline is considered to be the axial continuation of the Oriasvaara syncline. Towards the north-east, in the vicinity of the Tärendöälv, the structure becomes involved in strong transverse folds and faults with the WNW or NW direction. A simplified picture of the fold relationships, faults omitted, is shown in fig. 22. This is admittedly somewhat speculative and probably oversimplified but is presented to explain the author's interpretation of this complicated structure.

The regularity of the syncline is further disturbed by a number of N–S trending faults. These pass from the eastern limb of the syncline across its axial zone and onwards in the general direction of Lauttakoski. One of them can be observed directly in exposures 2.5 km NE of Naisvuoma and numerous local blocks of porphyry occur in the vicinity with intricate scapolite veining (fig. 23).

In the Onttovaara area (SO 4g, 4h, 3h) to the south-east a distinct zone of magnetic rocks occurs in an otherwise granitic area. These rocks supposedly belong to the Pahakurkio group and are folded into an anticline and a syncline, complementary to the Oriasvaara syncline.

Tärendö gabbro fault complex (SO). Gabbroic rocks have long been known to occur in the vicinity of Tärendö and SW of it. The aeromagnetic maps show clearly that not only are they more extensive than previously supposed but they are also much disturbed by faulting. On the basis of the aeromagnetic data Cornwell (1964, p. 155, fig. 5) carried out a preliminary interpretation using the abrupt termination of magnetic sheets as evidence of faulting. These features are easily seen along the margins of the gabbro as well as within it. Unfortunately, no outcrops are known on any of these supposed lines of faulting, the latter being characterized by lower levels of magnetic intensity. This is also true for continuations of the fault lines into granitic areas. The faults are clearly part of a regional structural pattern and should be judged accordingly.Thus in the main body of the gabbro they often have a N–S trend but outside it assume a NW–SE direction which is one of the dominant tectonic directions (fold-axes) on the map-sheet. It seems therefore as if the N–S trend is a refracting effect due to the presence of gabbro. An exception to this is the most westerly fault of the complex, the *Narkausjoki fault,* (SO 1h, 1g) which coincides with the western boundary of the gabbro. It can be followed 10 km or more to the NNW into granitic rocks curving gently from N 5 W in the south to N 35 W further north. Its relation to the gabbro in time is, however, unknown. It may be later than the gabbro but may equally well be younger in which case it could have acted as a channelway for the magma.

Tärendö syncline (SO). In connection with the description of the Tärendö gabbro the existence of a syncline north of Saarisuvanto was mentioned. Here the magnetic sheets dip towards each other in the manner of a syncline according to the geophysical interpretation. This structure has a northerly or NNE trending foldaxis. To the north, and outside the limits of the gabbro, relict structures in the granite may also be part of a syncline with a NNE trending fold axis, the Tärendö syncline. From the map therefore it is apparent that the gabbro lies somewhat discordantly in the axial zone of the Tärendö syncline but its own synclinal structure north of Saarisuvanto may belong to the same fold phase. If so the gabbro is older than both the folding and faulting.

Structures in granitic rock. The structures so far described occur for the most part in non-granitic rocks but sometimes continue into areas of granite. The latter are in fact far from homogeneous or isotropic as regards their magnetic properties: weak magnetic sheets can be traced without difficulty on the aeromagnetic maps and in a few cases the direction of dip can be ascertained from a study of the flight profiles. Some of the sheets show a progressive change in strike which immediately suggests the presence of relict folding. The Rissavaara quartzite may actually lie within the core of such a fold, in this case an anticline (SV). The folds are, however, nebulous and further speculation about them is pointless at the present time.

Study of the aeromagnetic maps reveals the presence of narrow zones with low magnetic intensity. These extend for considerable distances through granitic areas, are straight or gently curving and are flanked by areas with somewhat higher magnetic intensity. The significance of these zones is often obscure but it is a matter of experience that magnetic sheets, presumably representing primary, pre-granitic bedding, often terminate abruptly against them suggesting they are fault lines. Some confirmation of this is seen between Lovikka and Lauttakoski where such a zone is continuous with faulting affecting greenstones of the SE-facing limb of the Saittajärvi anticline. Similarly the Saittajärvi fault is in line with such a zone to the SE in the direction of the Tärendö gabbro.

In the western granite area the elongated lake Kääntöjärvi (NV 7b, 7c) coincides with the course of such a zone but cannot be related to any fault in non-granitic rocks. Its NW trend, however, conforms to one of the two main tectonic directions on the map-sheet. A further feature occurs north and south of Granhult (SV 1b, 2c, 3c). It has a more N–S trend, is concave to the west and traceable for 20 km. Magnetic sheets clearly terminate against it at many places suggesting the presence of a fault. It shows no direct connection with a fault in a non-granitic area but a slight possibility exists that it represents a continuation of the Kalixälv fault.

Though the above features are best explained as faults nothing can be deduced about the dip of the fault planes or the direction of movement. The outstanding problem is their relation to the granite in time. Many are conceivably pre-granitic and are therefore to be interpreted as relict structures. Alternatively, they may be post-granitic in which case brecciation or mylonitization of the rocks is to be expected. Little evidence of such effects is seen but lack of suitable outcrops makes further study of the problem by conventional geological methods impossible.

Post-granitic faulting. The only post-granitic fault known for certain follows the upper part of the Rautajoki canyon (NV 9d) SE of Masugnsbyn where the margin of the perthite granite is mylonitized and jointed in a complicated way. Actinolite is developed on joint planes and feldspar sericitized. Other post-granitic faults probably occur but are not exposed Work on the Lainio sheet to the north shows deformation of the granites there to be common.

Conclusions regarding tectonics. Deformation on the map-sheet is represented by folds and faults having NE or NW trends. The structures intersect therefore at high angles, a good example being the Oriasvaara syncline which lies athwart both the Kalixälv dome and the Masugnsbyn syncline. The Saittajärvi anticline can be considered the result of synclinal folding on each of its limbs, the NE-trending Oriasvaara syncline and the NW-trending Masugnsbyn syncline being the operative elements. The N–S strike of the fold axis is then to be regarded as a vector direction in the stress pattern. In this respect it is interesting that minor fold-axes and lineations formed by the intersection of bedding and schistosity planes, parallel the axis of the Masugnsbyn syncline rather than the Saittajärvi anticline (NV 8e). Faults with a N–S trend also occur but this direction seems to be due to special conditions, namely, the presence of massive rocks causing deviation from the normal NW or NE trends. Examples are the Tärendö fault complex (NW trend) and faults at Naisvuoma (NE trend). Much of the faulting seems to post-date the folding but it is not known how much is pre- and how much post-granitic.

The tectonic interpretation offered for the map-sheet clearly opens the door for speculation about the time relationships of the two directions of folding and laboratory studies of the type described by Ghosh and Ramberg in a paper on 'Buckling experiments on intersecting fold patterns' are obviously relevant in this respect. The problem is, however, one of general interest for the Precambrian geology of Norrbotten and will not be further explored here.

METAMORPHISM

Metamorphic textures and mineral associations are found in all non-granitic rocks of the area. This is not surprising since granite surrounds and most likely underlies them at no great depth. The metamorphism described below is therefore regional and some idea of its nature can be obtained from the petrographic descriptions of Geijer (1931) and Ödman (1939). As indicated in the stratigraphic section primary features such as conglomerate, porphyritic texture and cross-bedding in clastic sediments can be seen at several places but the rocks invariably show unmistakeable signs of metamorphism. Other rocks are more extensively altered and primary structures consequently more difficult to find. The metamorphic features of some of the major rock groups are presented below.

Quartzo-feldspathic rocks are represented by the quartzites of the Pahakurkio Group, the Suinavaara Quartzite, certain beds in the lower part of the Kalixälv Group and the Rissavaara Qaurtzite. No systematic petrographic study of these rocks has been carried out but existing knowledge indicates the presence of both metamorphic minerals and textures. The effects of regional metamorphism are conveniently shown by quartzites of the Pahakurkio group exposed in the Syväjoki stream section. These consist mainly of quartz and feldspar with a varying amount of mica, mainly biotite. The feldspar consists of microcline and plagioclase of acid-intermediate composition. In hand specimens and at low magnification the light-coloured minerals appear clastic and give the rock a granular texture. At higher magnifications the grain boundaries are often highly irregular or suture-like and the texture crystalloblastic. There is, however, no significant enlargement of the size of the grains. Grains of rutile, zircon and tourmaline seem to have retained their rounded, detrital forms. A typical thin-section of the rocks is that figured by Geijer

Fig. 24. Porphyroblasts of andalusite in pelitic schist (formation 2c), Pahakurkio, Kalixälv (square 6d).
Andalusitskiffer (formation 2c) vid Pahakurkio, Kalixälv (ruta 6d).

Fig. 25. Porphyroblasts of andalusite in pelitic schist (formation 2c), Hietajoki (square 8e).
Andalusitskiffer (formation 2c), Hietajoki (ruta 8e).

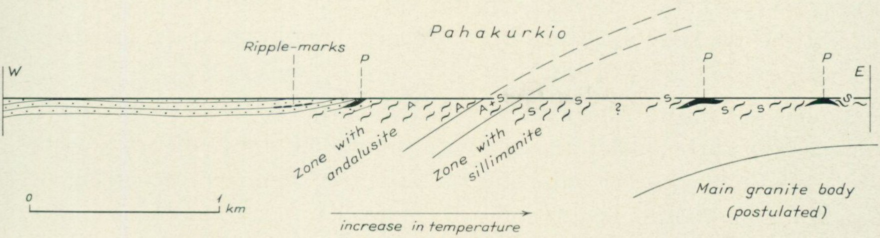

Fig. 26. Profile (see map-sheet 28 L NV, squares 6d–e) exposed along the Kalixälv at Pahakurkio showing metamorphic zoning in pelitic schists of the Pahakurkio Group.

Metamorfa zoner i pelitisk skiffer (Pahakurkiogruppen) vid Pahakurkio, Kalixälven. (Profilens läge se kartblad 28 L NV 6d–e).

(1931, p. 69, fig. 30). White spots occur in some fine-grained, micaceous horizons, the rock resembling *fleckschiefer*. Biotite is absent from these spots in contrast to the matrix and possibly represents some form of metamorphic differentiation. Epidote, or more often clinozoisite occurs in small amounts in all the thin sections, usually together with biotite. Other secondary minerals include muscovite, scapolite and hornblende. No garnets are known to occur. The rocks may therefore be termed quartz-microcline-plagioclase-biotite-muscovite schists and can be assigned to the amphibolite facies or the almandine-amphibolite facies, staurolite-almandine sub-facies (Turner and Verhoogen, 1960). In this sub-facies epidote may occur with biotite and intermediate plagioclase.

Pelitic rocks form important units of the Pahakurkio and Kalixälv groups. In the case of the former, good exposures occur in the Syväjoki (NV 7e) and Hietajoki (NV 8e) sections, along the Kalixälv near Pahakurkio (NV 6d, 6e), NNV of Naisvuoma (NO 6g) and 2 km SW of Mukkavuoma (NO 7h). In all outcrops the rocks show evidence of significant thermal metamorphism. Those NNW of Naisvuoma are typically knotted schists, the knots being mineral aggregates rather than one distinct metamorphic mineral. Normally the rocks elsewhere are highly schistose and consist of biotite, a little muscovite, quartz and small, almost accessory amounts of alkali feldspar. Characteristic for many of the rocks is the presence of andalusite, often as centimetre large individuals, the rock then resembling *knotenschiefer* (figs 24–25). Zircons are common in the biotite and are surrounded by dark haloes. Chemically the rock has an excess of silica but is poor in potash, hence the absence of microcline. The presence of the andalusite normally denotes contact metamorphism and in the case of the Syväjoki and Hietajoki exposures may indicate the existence of granite at no great depth.

Similar andalusite schists are exposed along the Kalixälv immediately west of Pahakurkio. They are separated from dome-like bodies of granite (thickness unknown) by sillimanite schists, the sillimanite occurring in bundles up to 4 cm in length and with a parallel or sub-parallel arrangement. Between the andalusite and sillimanite is an intermediate zone in which andalusite and sillimanite occur together. There is thus a zoning of the metamorphic minerals on granite in the classic manner of progressive metamorphism (fig. 26). In thin section the andalusite is clearly secondary and usually contains a large number of inclusions of quartz, feldspar and biotite. Sillimanite on the other hand, has clearly grown at the expense of the biotite in the manner described by Tozer (1955) and occurs as bundles of slender sillimanite needles (fibrolite) and as distinct crystals in quartz, feldspar and even in muscovite. The sillimanite schists may also contain skeletal crystals of andalusite but these are not easily identified in hand specimens.

A similar suite of metamorphic minerals is found in schists of the Kalixälv Group exposed on the hill Vittikovaara (NV 5e). Sillimanite is found together with quartz, intermediate plagioclase, biotite and some muscovite. At one locality a little cordierite is present, at another some andalusite. These rocks are clearly in medium to high grades of metamorphism and the mineral associations indicate the amphibolite facies of Eskola. Andalusite, however, is normally developed under conditions of contact metamorphism and together with the other minerals indicates the hornblende-hornfels facies, a refinement of the amphibolite facies introduced by Turner and Verhoogen (1960). It is, however, known to have a regional distribution too (Read, 1952). The mineral association has closer affinities with the Buchan type of metamorphism (Read, 1952, Hietanen, 1967, pp 192–193) rather than with the Barrovian type, the absence of kyanite being significant in this respect. This in turn indicates the existence of relatively high temperatures and low to moderate pressures in accordance with its assignment to the hornblende-hornfels facies of contact metamorphism.

Basic and semi-basic rocks (excluding gabbro) make up much of the Veikkavaara Greenstones and probably a significant part of the Kalixälv

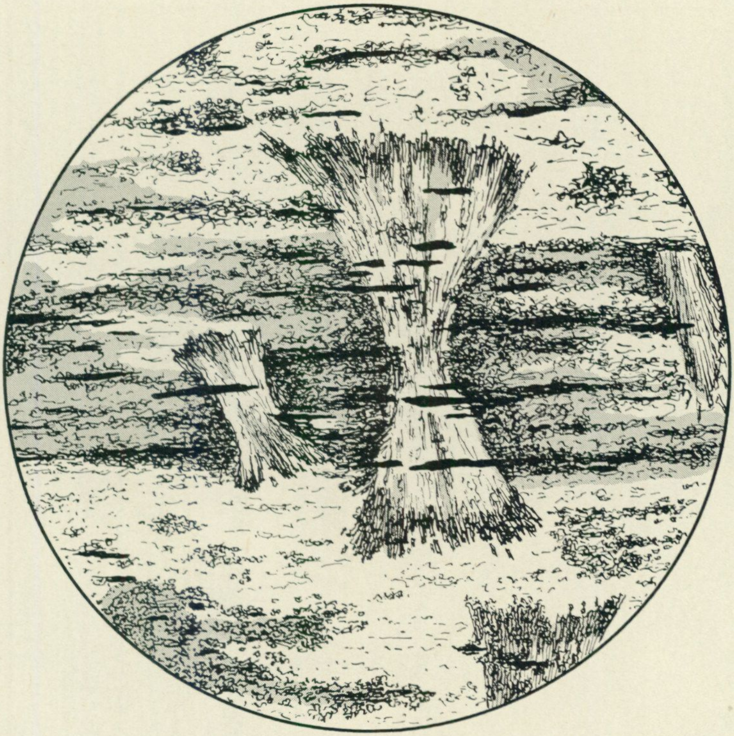

Fig. 27. Actinolite bundles arranged transverse to the schistosity in basaltic greenstone, Suinavaara (square 8g). Drawn from a thin section by Dr F. Witschard. × 60.

Aktinolitkärvar orienterade vinkelrätt mot skiffrigheten. Basaltisk grönsten, Suinavaara (ruta 8g). × 60.

Group. Since the latter is poorly exposed attention is here concentrated on the former.

In the stratigraphic section it was argued that the Veikkavaara Greenstones are largely made up of sediments with a basic composition but some basic intrusive bodies are known to exist locally, e. g. Veikkavaara. All the rocks are metamorphosed, the basic material being now represented by amphibole which in turn gives the rocks their dark, greenish colour, hence the term 'greenstones'. The proportion of amphibole to other minerals is usually between 50 and 70 per cent.

The amphibole is often common green hornblende with normal pleo-

Fig. 28. Almandine in greenstone. Veikkavaara (square 9d). Drawn by Dr F. Witschard. × 60. hb – hornblendic reaction zone.
Almandingranat i grönstenar, Veikkavaara (ruta 9d), hb = hornblände. × 60.

chroic features. However, a pale-coloured, non-pleochroic variety is also quite common. This has a lower maximum extinction angle (22 degrees) and is often in elongated crystals reminiscent of actinolite. It may be present in the same rock slice as common hornblende. A further variety, possibly intermediate between the two is characterized by having both pleochroic and non-pleochroic areas. Actinolite is also known from the Suinavaara and Salmijärvi areas (NO 8g), a beautiful radiating form being present in a specimen from the former (fig 27). It is not known if

Fig. 29. Garnetiferous bands in basaltic greenstone. Veikkavaara (square 9d). The coin is 2.5 cm in diam.

Granatförande skikt i basaltisk grönsten. Veikkavaara (ruta 9d). Myntet är 2,5 cm i diam.

the optical differences of the amphiboles have any significance as regards the grade or facies of metamorphism. They may merely represent differences in the availability of alumina and iron but this aspect needs more attention. Quartz is present in nearly all rocks but mainly in the banded, non-intrusive types, and is usually strained. The feldspar is exclusively plagioclase of variable composition in the range An_{10-50}. Determinations are, however, often difficult due to the smallness of the crystals. Almandine garnet is found together with hornblende in a sample from Veikkavaara (fig. 28) and has also been observed in layers, probably representing more aluminous horizons in the sequence (fig. 29). Epidote is normally absent but when present occurs in veins cutting the schistosity and is therefore of later origin. Albite is also absent. Thus the composition of the plagioclase and the presence of hornblende together with almandine suggest the rocks are in the almandine-amphibolite facies of regional metamorphism. The actinolitic varieties noted from the Suinavaara and Salmijärvi areas may represent slightly lower grades of metamorphism, possibly a retrogressive effect, though this aspect also needs more attention. The characteristic mineral assemblages of the greenschist facies, are unknown. *Carbonates* are quantitatively of minor importance in the stratigraphic succession and invariably much recrystallized. Impure bands with calc-silicate minerals are commonly present but neither these nor the carbonates proper have been studied from a metamorphic point of view.

The above remarks give some idea of the degree and type of metamorphism shown by the more important layered rocks of the map-sheet. The study is by no means exhaustive but the mineral associations present are quite normal and estimates of the metamorphic facies can be made with some confidence. Using the terminology of Turner and Verhoogen (1960) nearly all the rocks belong to the almandine-amphibolite facies of regional metamorphism or, in the case of the andalusite-bearing schists, to the hornblende-hornfels facies of contact metamorphism. Regional differences in facies are not readily discernible but this may be partly a function of inadequate exposure of the rocks. Further microscope work and a wider range of rock samples from known exposures may reveal additional mineral associations though not such as to change radically the facies determined in the present investigation.

The metamorphism is supposedly related to the widespread emplacement of deep-seated rocks, in particular to the Lina granite series.

METASOMATISM

Mineral association and textures indicative of metasomatism are widespread within the map-sheet. They include potassium enrichment, plagioclase formation, scapolitization, tourmalinization and iron-magnesia metasomatism.

The most important of these, quantitatively speaking, involves the *addition of potassium* to the rock. This is normally identified by the growth of secondary, potassium-bearing minerals such as muscovite and microcline. The phenomenon has been noted in pelites and semi-pelites of the Pahakurkio and Kalixälv groups, the rock rapidly assuming a gneissic character. Good examples are seen in exposures at Tiankikoski on the Kalixälv (see Ödman, 1939, pp 78–79) and eastwards towards Oriasvaara. Basic or semi-basic rocks such as those of the Kalixälv Group may also show the porphyroblastic development of the potash feldspar and muscovite but commonly the metamorphic hornblende is replaced by biotite and any excess iron forms magnetite. The rock is then a biotite-muscovite-microcline-magnetite gneiss and is probably responsible for some of the parallel N–S magnetic sheets of the Kalixälv Group west and south of Saarikoski. The rock is thus intermediate between identifiable supracrustals (layered formations) and granite. In the extreme SE corner of the map-sheet (SO 0h–j, 1j, 2j) gabbroic rocks are probably greatly affected by potassium enrichment. In one of the two known exposures the rock is characterized by the presence of large microcline augen.

Scapolitization affects certain layered formations in the area, the scapolite occurring as small, light-coloured, rounded crystals or crystal aggregates 0.5–2.0 mm in diameter. The rock affected, commonly greenstone or greenschist, then has a characteristically spotted appearance. In thin section the scapolite is seen to have ragged outlines and a large number of disoriented inclusions of minerals such as hornblende, biotite, quartz and feldspar. It may also occur as veinlets and is clearly post-metamorphic in origin. Good examples are known from Veikkavaara and from drill-cores of the Tornefors (Junosuando) iron-ore deposit (NO 9h). The exposure of Haukkalaki conglomerate close to the Tärendöälv (NO 7g) is also heavily scapolitized, the matrix being most affected. Thin sections of a dark basic rock exposed on Hirvirova (SO 4j) also contain, rather surprisingly, scapolite in thin veinlets. In all cases it seems to be a post-metamorphic mineral.

An interesting case is a greenstone of the Pahakurkio Group exposed in the Syväjoki section (NV 7e). Scapolitization affects the western margin of the greenstone (cf Geijer, 1931, pp 69–70), the rock being distinctly schistose with biotite and quartz as the most important minerals. Scapolite and a little microcline occur as porphyroblasts. They are probably of about the same age though in one case microcline is included in scapolite. Inclusions are very abundant in the scapolite and consist mainly of quartz and biotite. Occasionally a pale greenish mineral is also seen. A further interesting feature is the presence of a few euhedral crystals of hornblende which seem to have an almost poikilitic relationship to the scapolite and in one case to microcline. However, the relationships (fig. 30) probably indicate that scapolite is the latest mineral, the hornblende being primarily metamorphic.

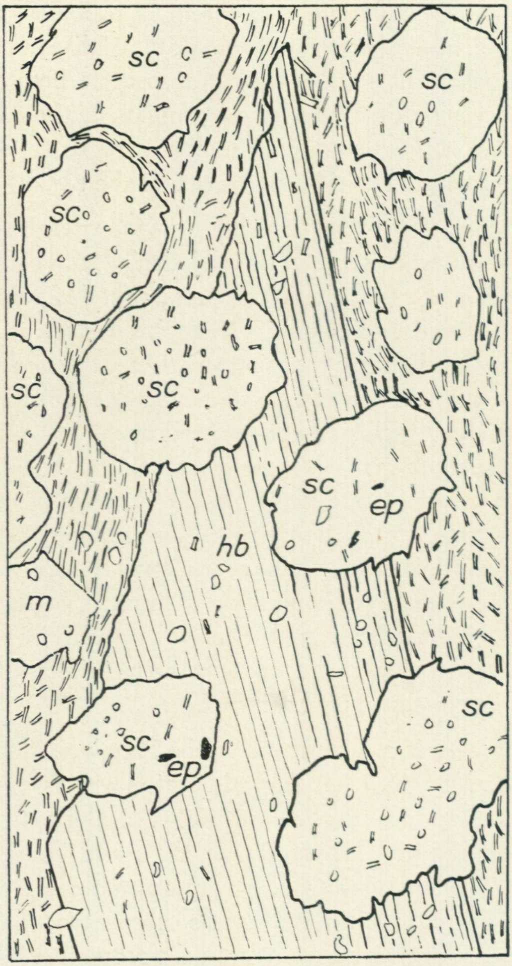

Fig. 30. Scapolite (sc) with inclusions of epidote (ep) replacing hornblende (hb) in amphibolitic greenstone. Syväjoki stream section × 30. m – microcline.

Skapolit (sc) ersättande hornblände (hb); ep = epidot, m = mikroklin. Syväjoki. × 30.

Fig. 31. Scapolitization (lighter area) of greenstone. Veikkavaara (square 9d).
Skapolitisering (blekare område i bildens centrala del) av grönsten. Veikkavaara (ruta 9d).

A further type of scapolitization affects greenstones exposed on the north-facing slope of Veikkavaara (NV 9d). Here the rock is bleached in a rather irregular way with loss of banding and parallel mineral orientation (fig. 31). In thin section it is seen to contain abundant scapolite, often as skeletal crystals. Grain boundaries are by no means sharp and the mineral is difficult to recognize in hand specimens and outcrops. It may, therefore, be more common than supposed.

It must be emphasized that scapolitization is quantitatively of minor importance but is nevertheless widespread, at least within the non-granitic rocks.

Unfortunately, nothing is known about the exact chemical composition of the scapolites but it is probable CO_2 or Cl or both were added to the rock and the formation of scapolite thereby facilitated. This is almost certainly a post-metamorphic event.

Secondary plagioclase is characteristic of certain greenstones exposed on Suinavaara (NO 8g). It occurs as irregular bodies with diffuse boundaries and is apparently post-metamorphic in age. It was thought to be scapolite in the field but X-ray diffraction studies kindly carried out at the request of the author by Dr Malcolm McNamara, formerly of the Geological Survey of Sweden, showed it to be indisputably plagioclase with a composition of An_{50} or more. The mineral may also be more widespread than is realized but its identification in the field is a major problem. At the moment it has mineralogical interest only.

Tourmalinization of greenstones has been noted in a few thin sections of greenstones from the Veikkavaara and Masugnsbyn areas. The tourmaline is developed as brown, euhedral crystals with weak zoning. It presumably denotes a slight addition of boron to the rock. Similarly, a dark tourmaline of secondary origin is present in a quartzite from the Syväjoki profile (NV 7e).

Iron-magnesia metasomatism. A remarkable development of skarn minerals is found in association with iron-ore at Masugnsbyn (NV 9d). Drill-cores show an intimate association of magnetite (and occasionally iron sulphides) with skarn minerals in a steeply dipping zone 70–100 m wide. Magnesian minerals such as diopside, tremolite-actinolite and phlogopite are common in the skarn, and serpentine and chondrodite have also been reported. Geijer (1929, p. 34) considered the whole mineral paragenesis to be contact metasomatic, the nearby perthitic granite being the source of the metals. A metasomatic origin was further indicated by the presence of fluorine in certain skarn minerals (Geijer, 1960). Frietsch (1966, p. 174) has recently argued that iron and metals necessary for the formation of the skarn existed in the layered rocks of the area and the existing association is due to the effects of regional metamorphism in connection with the emplacement of the Lina granite. A metasomatic addition of substances from the granite is therefore not necessary. The present author is to some extent in agreement with both authors. It is undeniable that iron was concentrated in sediments belonging to the uppermost part of the Veikkavaara Greenstone Group and that dolomitic layers are also present in this part of the succession. Indeed, all the chemical elements exist for development of skarn with the possible exception of fluorine. The elemental differentiation which now exists into iron-rich layers on the one hand and skarn on the other seems to require some form of metasomatic transfer, even if only over short distances. The cause of this transfer is however, another problem. At first glance the nearby perthite granite would seem to be responsible but a recent determination of its age by radiometric means shows it to be about 1540 m. y. whereas the skarn is much older, at least 1845 m. y. according to a determination on uraninite from chondrodite in the skarn (Welin and Blomquist, 1966).

GEOLOGICAL EVOLUTION

In previous pages repeated mention has been made of the time relationships of various geological events. Together these constitute the geological evolution of the area and are summarized in this short chapter.

1. The oldest recognizable event is deposition of a thick sequence of sediments and extrusive rocks. These indicate volcanic activity dominantly of basaltic type (Veikkavaara Greenstones) interrupted by periods of normal sedimentation (aluminous shale, graphite shale) or by the introduction of clastic material (quartzites of the Pahakurkio Group, Rissavaara Quartzite).

2. Intrusion of gabbro accompanied or closely followed by intrusion of basic dykes.

3. Folding on NW or NE axes or on both. The emplacement of the quartz-diorite, perthite monzonite (Haparanda Series) may belong to this time.

4. Faulting, possibly a continuation of 3.

5. Emplacement of Lina-type granite (±1550 m. y. in other parts of Norrbotten according Dr Eric Welin) and the perthite granite at Masugnsbyn (recently dated at 1540 m. y. by Welin). Much of the regional metamorphism probably belongs to this period but not necessarily the formation of skarn: uraninite from chondrodite skarn at Masugnsbyn is much older (1845 m. y.) and hence the formation of the skarn itself is at

least of this age. An interesting geological observation in this connection is veining of skarns by quartz-diorite of the Haparanda granite series on the Lannavaara sheet to the north (Frietsch, 1967). This also indicates a considerable time-gap between the formation of the skarn and emplacement of the deep-seated rocks.

6. Post-granitic faulting.

7. A prolonged period of erosion lasting to the present time and only represented, to the best of our knowledge, by deposition of glacial sediments in the Quaternary.

This attempt to summarize the geological evolution is almost certainly an oversimplification and a number of problems remain for further study. These concern particularly the folding and faulting. It is not clear, for example, whether folding occurred in one or more phases. Nor is the relation of the faulting to the granite established in all cases though this may be largely due to lack of exposures. The time relationships of the Lina granite, perthite granite, perthite monzonite and granodiorite are poorly known and without better exposures cannot be established by conventional geological methods. The application of radiometric methods of age determination is, however, a possible way of attacking these problems.

ECONOMIC ASPECTS

Rocks and minerals of economic interest occur at several places on the map-sheet (fig. 32).

Name	Nature of-deposit	Map square	References
Masugnsbyn	Iron-ore (magnetite)	9d	Geijer 1929, Ödman 1957, Frietsch 1966
Junosuando (Tornefors)	Iron-ore (magnetite)	9h	Eriksson 1954, Ödman 1957, p. 115
Masugnsbyn	Dolomite	9d	Ödman 1957 p. 122
Lauttakoski	Soapstone	8g	Fredholm 1886 p. 31, Shaikh
Suinavaaragruvan	Graphite	8g	(in preparation)
Nybrännan	Graphite	9e	Ödman 1957 p. 121
Rissavaara	Quartzite	2e	Ödman 1957 Pl. 1

Fig. 32. List of deposits of possible economic interest on the Tärendö map-sheet.
Fyndigheter av eventuellt ekonomiskt intresse på bladet 28L Tärendö.

All the above occurrences were known previous to the present investigations. Several are currently being re-investigated by the Survey (SGU), the object being to gain more information about their extent, tonnage and grade. Little can, therefore, be added to that given in the published reports listed above but some remarks about their geological setting are of interest.

The iron-ore zone at *Masugnsbyn* is well known thanks to the work of Geijer (1929). It has a N–S strike and is apparently concordant with the stratigraphy, features which are confirmed by recent aeromagnetic and ground surveys. Only its southern part is present on the Tärendö sheet and here skarn minerals are very conspicuous, hence its classification as a skarn iron-ore. Northwards (Lainio sheet 29L), however, it has more the character of a sedimentary iron-ore. Stratigraphically the ore zone occurs in the uppermost part of the Veikkavaara Greenstone Group. Furthermore, the formational units above and below show a tendency to thicken in the Masugnsbyn area which can be interpreted as indicating the existence of a more accentuated basin of deposition.

In the *Junosuando* area a narrow zone of magnetite iron-ore with associated skarn minerals was discovered several years ago (T. Eriksson 1954 p. 24). The present investigations show that it too is concordant with the stratigraphy and must lie in the upper part of the Veikkavaara Greenstone Group.

The upper part of the Veikkavaara Greenstone Group has thus special interest from the point of view of iron-ore concentration, a fact which has not been overlooked in the present phase of prospecting.

At both Masugnsbyn and Junosuando *carbonat*e occurs close to the iron-ore zone. At Masugnsbyn it is distinctly dolomitic with an outcrop width of 250 m or more. This unusually great thickness may be explained in varous ways, as a primary condition of sedimentation, as a result of isoclinal folding, or due to mobilization and diapiric upward movement of a carbonate formation. A sedimentary origin for the carbonate seems inescapable and represents a phase of chemical sedimentation in the uppermost part of the Veikkavaara Greenstone Group. Some sharp folds, homoaxial with other folds in the area, have been observed in the quarry face but their amplitudes are difficult to estimate. Dark, steeply dipping bands of graphite-bearing dolomite also occur occasionally (fig. 7). The NW trending fault displacing the dolomite is possibly a continuation of

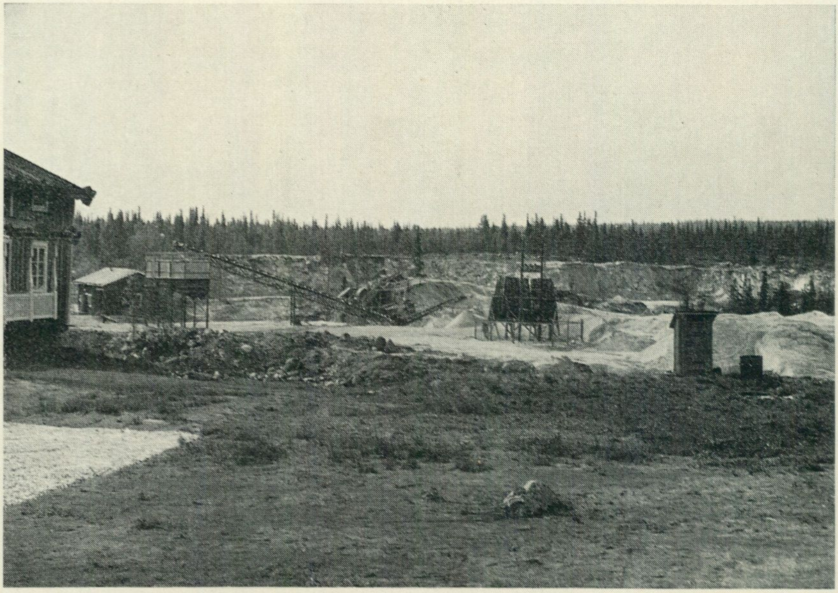

Fig. 33. Masugnsbyn dolomite quarry in 1966, looking south.
Dolomitbrottet vid Masugnsbyn i augusti 1966.

a zone of brecciation affecting perthite granite in the Rautajoki Isokursu (canyon). The existence of the fault is also supported by gravimetric measurements.

Exploitation of the dolomite has proceeded rapidly in recent years by relatively simple quarrying methods (fig. 33). It is in fact the only deposit on the map-sheet currently being exploited.

The occurrence of *soapstone* (= täljsten) close to the Tärendöälv, 3.5 km NNW of Lauttakoski has long been known (Fredholm 1886 p. 31). It appears to occupy a narrow zone in gabbro-diabasic rocks intruded into the Veikkavaara Greenstones. By analogy with similar deposits elsewhere in the world it probably represent the hydrothermal alteration of basic or ultrabasic rocks, types which are by no means uncommon in the Greenstones. The results of recent investigations by SGU will be reported in a forthcoming publication by Dr A. Shaikh.

Graphitic schists are important members of the upper part of the Veikkavaara Greenstone Group. Though rarely exposed their presence can be easily detected by electromagnetic methods either on the ground or from the air. The distribution shown on the geological maps is probably not complete but it shows clearly their stratigraphic mode of occurrence. Drill-cores show the rock to be dark and schistose with variable amounts of graphite. Special interest has been shown in these schists at two places, namely, close to the Tärendöälv, NW of Lauttakoski (Suinavaaragruvan) and at Nybrännan. No exploitation is in progress at the time of writing (1968).

Ödman (1957 Pl. 1) was the first to include the *quartzitic rocks at Rissavaara* on a geological map. Much of the material, particularly that in boulders of local origin, is to all appearances a pure, white quartzitic rock. It probably occurs as separate wedge-like bodies with an E–W strike and enclosed by granite. Structural considerations indicate that it belongs to a higher stratigraphic level than any other layered rock on the map-sheet.

Sulphidic minerals occur at several places but not, as far as is now known in economic quantities. The Masugnsbyn dolomite, for example, sometimes has a weak pyrite impregnation, seriously reducing its value as an ornamental stone. Pyrite and chalcopyrite impregnations occur in greenstones just north of Oriasvaara and at various places in the Veikkavaara Greenstone Group. Chalcocite, bornite and chalcopyrite occur in several narrow quartz veins (up to 4 cm thick) on the hill *Maunuvaara,* about 5 km SW of Saarikoski (Geijer, 1918, pp 84–86). Old workings, now much overgrown, show the host rock to be granite and dark dioritic gneiss. Azurite and malachite are sometimes conspicuous on joint surfaces.

No new deposits, metallic or non-metallic, have so far been found in the course of the present investigations. Nevertheless, the geological conditions are not unfavourable: faulting is common whilst granitic and subgranitic rocks are in contact with a wide range of other rocks. The gabbros are commonly magnetic but there is no evidence that significant concentrations of ore minerals are present. Indeed as a group they show little petrographic differentiation and indisputable layering is found at one place only.

	A 1	A 2	A 3	A 4
Publ.	New	New	New	New
Analyst	B. Åkerlund	B. Åkerlund	G. Svedenbäck	B. Åkerlund
Sample	156.97–161.32	72.60–75.73	PP 103 1964	BL 14C 1967
Rock	Basaltic Greenstone	Basaltic Greenstone	Gabbro	Andesite porphyry
Locality	Tornefors Bh 1	Tornefors Bh 7	Narkausjoki	Naisvuoma
Square	9h	9h	1h	6g
SiO_2	48.2	48.4	51.6	62.0
TiO_2	1.03	0,89	1.31	0.63
Al_2O_3	15.3	10.7	17.8	14.7
Fe_2O_3	4.9	2.0	10.1*	3.2
FeO	7.2	9.7	–	3.4
MnO	0.15	0.15	0.15	0.09
MgO	8.0	14.2	6.7	2.6
CaO	8.0	4.0	8.3	4.3
BaO	0.03	0.04	0.01	0.11
Na_2O	4.3	2.2	2.0	3.2
K_2O	1.5	4.3	0.9	5.0
P_2O_5	0.12	0.10	–	–
H_2O $> 105°$	1.3	2.0	–	1.2
H_2O $< 105°$	0.13	0.14	–	–
F	0.02	0.03	–	–
CO_2	0.10	0.06	–	0.1
S	0.30	0.21	–	–
Total	100.58	99.12	99.87	100,53

* Total Fe

Fig. 34. Chemical analyses in weight %.

A 5	A 6	A 7	A 8	A 9
New B. Åkerlund PP 107 1964	Ödman 1957 A. Aaremäe	Ödman 1957 A. Aaremäe	Geijer 1929 A. Bygdén	Geijer 1929 A. Bygdén
Granodiorite	Syenite	Quartz syenite	Perthite granite	Albite granite
Palokorva	Tornefors Bh 5	Siikajoki	Masugnsbyn	Masugnsbyn
8i	9h	6i	9d	9d
62.0	60.18	63.37	74.41	77.47
0.52	0.46	0.48	0.38	0.33
16.6	18.45	16.48	13.36	13.50
2.2	1.51	2.08	0.60	0.14
2.4	2.69	2.84	0.24	0.07
0.05	0.05	0.04	0.04	–
2.0	1.98	1.62	0.43	–
4.2	4.92	3.60	0.57	0.12
0.17	0.14	0.10	0.04	–
4.8	5.69	4.46	4.79	7.88
3.4	2.55	3.35	4.80	0.10
–	0.20	0.32	–	–
0.9	0.92	0.92	0.29	0.26
0.24	0.07	0.14	–	–
0.05	0.03	0.07	–	–
–	–	–	–	–
0.01	0.07	0.08	–	–
99.55	99.91	99.95	99.95	99.87

Fig. 34. Kemiska analyser i vikts-%.

	A 1	A 2	A 3	A 4	A 5	A 6	A 7	A 8	A 9
Q	23.0	20.5	23.0	41.1	41.3	38.7	44.2	53.8	56.7
L	39.5	31.5	39.5	42.3	46.7	49.9	45.7	43.3	42.5
M	36.6	47.2	36.6	16.1	11.7	10.7	9.2	2.6	0.2
C+Hz	–	–	–	–	–	–	–	–	0.4
Ru+Cp	0.9	0.8	0.9	0.5	0.3	0.7	0.9	0.3	0.2
π	0.27	0.13	0.27	0.16	0.18	0.20	0.20	0.01	0.01
γ	0.17	0.81	0.17	0.20	0.19	0.16	0.03	0.23	0.0
k	0.19	0.57	0.24	0.50	0.32	0.23	0.33	0.40	0.01
mg	0.55	0.68	0.56	0.42	0.45	0.46	0.38	0.50	–
ω	0.38	0.16	–	0.46	0.46	0.32	0.40	0.73	0.67
si	108.5	104.4	130.3	215.4	222.4	202.4	239.8	425.8	486.7
qz	– 37.5	– 37.6	+4.7	+27.8	+24.8	+5.6	+41.8	149.8	193.5
al	20.3	13.6	26.5	30.1	35.1	36.6	36.8	45.0	49.8
fm	48.9	66.7	44.6	31.7	24.1	21.4	23.9	7.6	1.1
c	19.3	9.2	22.5	16.3	16.4	17.8	14.8	3.4	0.8
alk	11.5	10.5	6.4	21.9	24.4	24.2	24.5	44.0	48.3
ti	1.8	1.4	2.4	1.7	1.3	1.2	1.4	1.7	1.5
p	0.1	0.1	–	–	–	0.2	0.5	–	–
Cata-equivalent norms									
Q	–	–	9.3	11.5	9.1	3.8	13.3	24.6	28.4
Or	9.0	25.7	5.5	30.3	20.5	15.1	20.3	28.4	0.5
Ab	32.5	19.0	18.5	29.2	43.5	51.0	40.7	43.2	69.9
Ne	3.8	0.6	–	–	–	–	–	–	–
An	18.0	6.8	37.8	11.0	13.8	17.0	15.1	0.7	0.5
Wo	8.5	5.1	1.7	4.3	2.9	2.3	0.4	0.8	–
En	–	–	18.9	7.2	5.6	5.5	4.5	1.3	–
Hy	–	–	–	2.1	1.6	2.7	2.3	–	–
Fo	16.6	29.7	–	–	–	–	–	–	–
Fa	4.9	9.6	–	–	–	–	–	–	–
Mt	5.1	2.1	7.4	3.4	2.4	1.6	2.2	–	–
Hm	–	–	–	–	–	–	–	0.5	0.1
Ilm	1.4	1.2	0.9	1.0	0.6	0.6	0.6	–	–
Ap	0.2	0.2	–	–	–	0.4	0.6	–	–

Fig. 35. QLM, Niggli values, cate-equivalent norms for the analyses in fig. 34.
QLM, Niggli-värden och kata-ekvivalentsnormer for analyserna i fig. 34.

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APPENDIX: GEOPHYSICAL INVESTIGATIONS ON THE MAP-SHEET TÄRENDÖ 28L

by

J. D. Cornwell

CONTENTS

INTRODUCTION

An investigation of certain geophysical features of the Tärendö sheet has been carried out simultaneously with the geological investigations. This short appendix includes specific data on the physical properties of certain selected rocks as well as interpretations of geophysical anomalies present on the aeromagnetic maps. The results of earlier ground surveys carried out by the Geological Survey of Sweden (SGU) have also been taken into consideration. It is intended to complement the foregoing geological description by P. Padget.

The basis for the present work on the Tärendö map is the 1:50,000 scale aeromagnetic map made in 1961. As with other aeromagnetic maps made by the Geological Survey of Sweden (SGU) in Norrbotten the intensity readings of the total magnetic field have been corrected for secular variation so that the values are those which would have been recorded if the measurements had been made in June 1960 ("Zero time"). The base value (0 on aeromagnetic map) is 48,000 gammas and the normal field is taken as 51,500 gammas. As the fluxgate magnetometer was flown at a height of only 30 m one obtains a very detailed magnetic picture and this has been used extensively in the drawing of the geological map. The aeromagnetic mapping methods and application of results have been discussed in detail by Werner (1963, 1967) and need not be repeated here.

Quarter map-sheet	Locality	Object	Area of measurement (km^2)	Method	Year
NV	Masugnsbyn	Iron ore	26.60	M, G.	1965
NV/NO	Saittajärvi	Graphite/sulphides	7.17	Slingram (3.6 kc/s, 40 m)	1946
NO	Oriasvaara	Graphite/sulphides	0.42	Slingram (18 kc/s, 40 m)	1966
NO	Leppäjoki	Magnetic indication	1.28	M, G.	1968
NO	Junosuando	Magnetic indications	76.5	M (Tiberg Balance)	1946
NO	Tornefors	Iron ore	0.92	M (Tiberg Balance)	1946
	Tornefors	Iron ore	0.92	G	1966
NO	Lauttakoski	Soapstone	3.0	M	1967

M = Magnetic (vertical component), G = Gravity.

Fig. 36. Ground geophysical surveys carried out by SGU on the Tärendö map-sheet. Measurements were also made with a Tiberg magnetic balance in 1949 over small areas at Lovikka and Peninsaari.
Markmätningar utförda av SGU på bladet Tärendö. År 1949 utfördes även mätningar med Tibergsvåg inom mindre områden vid Lovikka och Peninsaari.

Site no.	Site	Co-ord-inates	Rock type	Density gm/cm³	Magnetization	
					ϰ	J
1	Masugnsbyn	673 973	Perthite granite	2.60	1.89	0.17
2	Isokursu	690 975	Perthite granite	2.60	0.85	0.09
3	Masugnsbyn	672 975	Perthite granite	2.62	–	–
4	Masugnsbyn	674 974	Perthite granite	2.62	1.55	0.14
5	Masugnsbyn	675 974	Perthite granite	2.61	1.71	0.11
6	Masugnsbyn	675 973	Perthite granite	2.62	1.09	0.08
7	Narkausjoki	787 659	Granite	2.63	1.29	0.19
8	Kompelusvaara	824 549	Migmatite granite	2.70	4.48	0.65
9	Vähäjärvel	978 636	Migmatite granite	2.73	5.53	3.64
10	Kompelusvaara	859 562	Granite dyke	2.63	0.45	0.44
11	Palokorva	925 923	Syenite (Ödman 1957)	2.71	1.85	0.19
12	Tärendö	986 629	Syenite (Ödman 1957)	2.71	3.69	2.91
13	Anttis	927 812	Syenite (Ödman 1957)	2.84	5.59	2.05
14	Tärendö	964 683	Gabbro	3.02	6.60	3.89
15	Narkausjoki	859 562	Gabbro	2.94	5.79	8.20
16	Narkausjoki	868 593	Gabbro	2.95	8.43	14.22
17	Rakkulavaara	880 586	Gabbro	2.94	11.87	10.43
18	Saarisuvanto	898 574	Gabbro	2.98	4.88	10.60
19	Syväjoki	714 923	Banded greenstone	2.98	0.07	0.01
20	Nybrännan	702 961	Greenstone	2.94	0.06	<0.01
21	Masugnsbyn	671 975	Magnetite ore	4.30	353.00	317.00
22	Masugnsbyn	670 974	Dolomite	2.86	<0.01	<0.01
23	Syväjoki	706 913	Quartzite	2.72	0.05	1.34
24	Syväjoki	706 912	Andalusite schist	2.79	0.01	<0.01
25	Nybrännan	701 961	Graphitic shale	2.62	0.07	0.41

Fig. 38. Mean densities and magnetic properties of rocks from sites on the Tärendö map-sheet.

Several of the magnetic indications on the aeromagnetic maps have been followed up with detailed ground measurements with gravimeters and vertical component magnetometers. These measurements were made along rectangular systems of staked lines at intervals of 10 m, 20 m or 40 m with the magnetometer and 40 m or 80 m with the gravimeter, and it has been possible to incorporate the preliminary results of these surveys in this description.

A summary of the detailed ground measurements carried out by SGU is given in fig. 36 and the areas involved are shown in fig. 37. (In map-folder.)

As can be seen several of these areas were investigated previous to the present programme of systematic examination of the iron-ore resources of Norrbotten. The gravimeter measurements along the roads (fig. 37) are part of a regional survey intended to tie up the isolated detailed surveys and to provide information of regional structures.

Included in the final section are data on the density, susceptibility and rema-

Q-value	Directions		Scatter		Total magnetization			No. of samples	
	D°	I°	α°	K	D°T	I°T	Intensity	n	N
0.18	233	+65	–	–	345	+81	1.11	1	4
0.21	351	+59	–	–	359	+74	0.52	1	3
–	–	–	–	–	–	–	–	2	2
0.18	340	+68	–	–	358	+76	0.95	1	1
0.13	117	+41	–	–	29	+79	0.96	1	3
0.14	317	+47	–	–	349	+75	0.63	1	3
0.30	121	+87	33	15	5	+80	0.98	3	3
0.29	57	+50	24	12	26	+74	2.82	5	5
1.31	320	+45	41	6	326	+56	5.55	4	4
1.94	333	+51	10	90	341	+61	0.84	4	4
0.21	123	+80	30	10	15	+79	1.12	4	4
1.58	323	+31	9	118	329	+50	4.36	4	4
0.73	273	+80	–	–	349	+79	4.37	2	4
1.18	337	+41	11	126	342	+59	6.88	3	3
2.83	318	+52	8	65	324	+57	10.75	6	6
3.37	357	+38	7	300	357	+47	17.74	3	3
1.76	334	+46	–	–	326	+58	15.70	2	2
4.35	348	+45	–	500	349	+52	12.52	3	5
0.18	–	–	–	–	–	–	–	4	4
<0.10	–	–	–	–	–	–	–	2	2
1.80	186	+73	23	5	180	+84	426.00	10	10
–	–	–	–	–	–	–	–	5	5
58.20	347	+48	–	–	347	+49	1.34	2	3
0.40	–	–	–	–	–	–	–	2	2
11.61	166	+80	9	29	147	+82	0.44	10	10

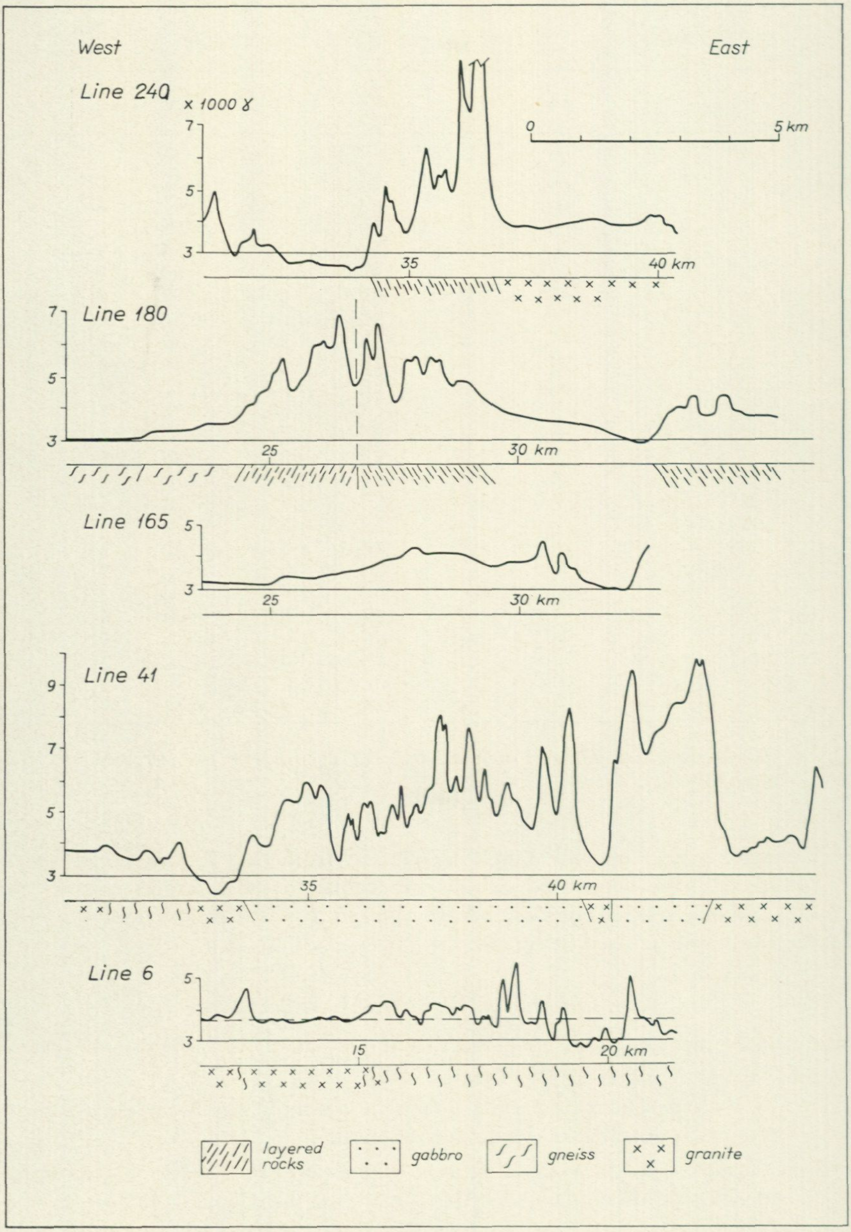
Genomsnittliga tätheter och magnetiska egenskaper för bergarter på Tärendöbladet.

nent magnetization of rock samples collected from the Tärendö map sheet. These results have been used, where applicable, in the interpretation of the gravity and magnetic anomalies and are referred to in the following description by the site numbers used in fig. 38.

REGIONAL GEOPHYSICAL FEATURES

Study of the aeromagnetic maps reveals immediately the presence of several major features of geophysical interest. These are:

1. The V-shaped area of parallel magnetic sheets in the area Masugnsbyn-Saittajärvi-Lauttakoski (Saittajärvi anticline).
2. A strong N to NNW-trending magnetic zone in the vicinity of Masugnsbyn (Masugnsbyn magnetite iron-ore).
3. A marked magnetic zone 1 km in length at Junosuando (Tornefors magnetite iron-ore).


West
East
Line 240
x 1000 γ
0
5 km
35
40 km
Line 180
25
30 km
Line 165
25
30 km
Line 41
35
40 km
Line 6
15
20 km
layered rocks
gabbro
gneiss
granite

4. A broad, NE-trending zone with high magnetic values in the vicinity of Tärendö (Tärendö gabbro).
5. Low magnetic values over a large part of the map-sheet (granite and related rocks) but with a) a number of narrow, often discontinuous magnetic zones (relict layered rocks), b) irregular-shaped strongly magnetic bodies (gabbro).

1. *The V-shaped area Masugnsbyn-Saittajärvi-Lauttakoski* consists of several sheets with a high magnetic intensity alternating with others with very low intensity. Examples of the former type have not been sampled but samples from sites 19 and 20 with susceptibilities of 7×10^{-5} gauss/oersted are examples of the non-magnetic type. Horizons also occur with highly conductive properties and these represent graphite-bearing schists. An electromagnetic survey with 3.6 kc/s slingram apparatus traced such a horizon for 14 km from the Nybrännan quarry to Saittajärvi (fig. 37). Samples from the Nybrännan quarry have a low density and low susceptibility but show the high Q-values commonly found for pyrrhotite-bearing rocks (site 25). These horizons occur elsewhere in the area and have been readily detected by airborne electromagnetic surveying (private communication from Boliden AB). The magnetic sheets, which are commonly discontinuous, are thought to represent greenstones of basic composition. The sharp change in trend direction of the magnetic sheets in the vicinity of Saittajärvi is considered to represent a fold structure. The sheets on the SE flank of this fold cause gentle magnetic gradients to the SE (fig. 39, profile 180) and it seems from this that the structure is an anticline plunging southwards. The broad area with slightly higher anomalies which occurs S of the nose of the fold is probably due to the presence of buried greenstone. The NE trend of the magnetic sheets is broken at Lauttakoski and is interpreted as being due to a fault with a NW trend.

2. *The NNW trending magnetic anomaly close to Masugnsbyn* continues northwards on to the adjacent map-sheet 29L Lainio. It has recently (1965) been investigated by detailed magnetic and gravimetric surveys and in 1967 a new systematic drilling programme was started. The anomaly coincides with the well known Masugnsbyn skarn iron-ore deposit (Geijer 1929).

On the Tärendö sheet the magnetic anomaly has an amplitude of up to 35,000 gammas above the low values over the granite to the east and sediments to the west. With the better resolution of the ground measurements the ore is

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Fig. 39. Airborne magnetometer profiles over some of the geological features on the Tärendö map-sheet. The line numbers range between 0 (southern edge of map-sheet) and 250 (northern edge of the sheet) and the fix-points on each profile are measured in km from the western edge of the sheet. Possible rock types are shown by the appropriate symbols.

Utvalda flygmagnetiska profiler över Tärendöbladet. Linjerna ligger mellan 0 (kartbladets S kant) och 250 (kartbladets N kant). Fixpunkterna har mätts för varje profil i km från bladets V kant.

seen to be split into two and sometimes three magnetic horizons within a 70 m wide zone. A pronounced double negative anomaly clearly visible half-way along the ore zone on the magnetic map coincides with a pinching-out of the main positive anomaly. It is believed to be due to truncation of the ore at an interpreted depth of about 120 m, probably by an extension of the perthite granite to the E. The magnetite ore was sampled (site 21, fig. 38) at the old mine in Masugnsbyn and the magnetization found to be unusual in that the remanence is relatively strong and not coincident with the direction of the induced field. These features are probably due to alterations brought about by weathering and primitive methods of mining the ore.

A Bouguer anomaly map shows a local anomaly of 3 milligals over the iron-ore and associated skarn minerals. It is flanked by gravity lows, thus facilitating calculation of the mass excess. The clearly developed gravity low immediately E of the magnetic ore zone is obviously due to a body of perthite granite discordant to denser rocks (greenstones) to the S and N. An estimate of the depth extent of the granite can be made by taking a vertical cylinder with a radius of two km and a density of 2.61 gm/cm^3 (fig. 43) as a model. Along one profile the granite gives a minimum of 9 milligals relative to the background level over the denser greenstones to the N and S. If these greenstones have a similar density to those observed at sites 19 and 20 (2.96 gm/cm^3) the cylinder would have to extend from the surface to a depth of 0.75 km to give the 9 milligals anomaly.

A small gravity high W of the S end of the magnetic anomaly coincides with the relatively dense dolomite exposed in the quarry at Masugnsbyn. The high does not extend far to the S, possibly due to replacement of the dolomite by limestone or some other light rock.

3. The marked *magnetic zone at Junosuando* (Tornefors iron-ore) was discovered in 1949 by a magnetic survey with a Tiberg balance (Eriksson 1954). It is clearly indicated on the aeromagnetic map by a N–S anomaly of 24,000 gammas. It was further investigated by a gravity survey in 1966 and a maximum local anomaly of 1.1 milligals revealed. This is consistent with the low iron content observed in the drill-cores. The small gravity high due to the ore is difficult to separate on the gravity map from the large anomaly arising from the greenstone sequence W of the ore horizon. The problem of estimating the tonnage of a skarn ore in a similar environment at Kaunisvaara has been described by Werner (1965). To the N and S of the Tornefors ore several other large anomalies appear on the aeromagnetic map, probably due to small concentrations of ore similar to Tornefors. Most of these were included in the extensive magnetic ground survey made with a Tiberg Balance in 1949 (See text to fig. 36).

4. The broad, NE-trending zone of *magnetic anomalies in the vicinity of Tärendö* is the main feature of the Tärendö SE map-sheet. On the aeromagnetic map an irregular arrangement of elongated high and low anomalies is evident, the former sometimes reaching 9,000 gammas above the magnetic level to the NW. These values and arrangement of the sheets suggest the rock

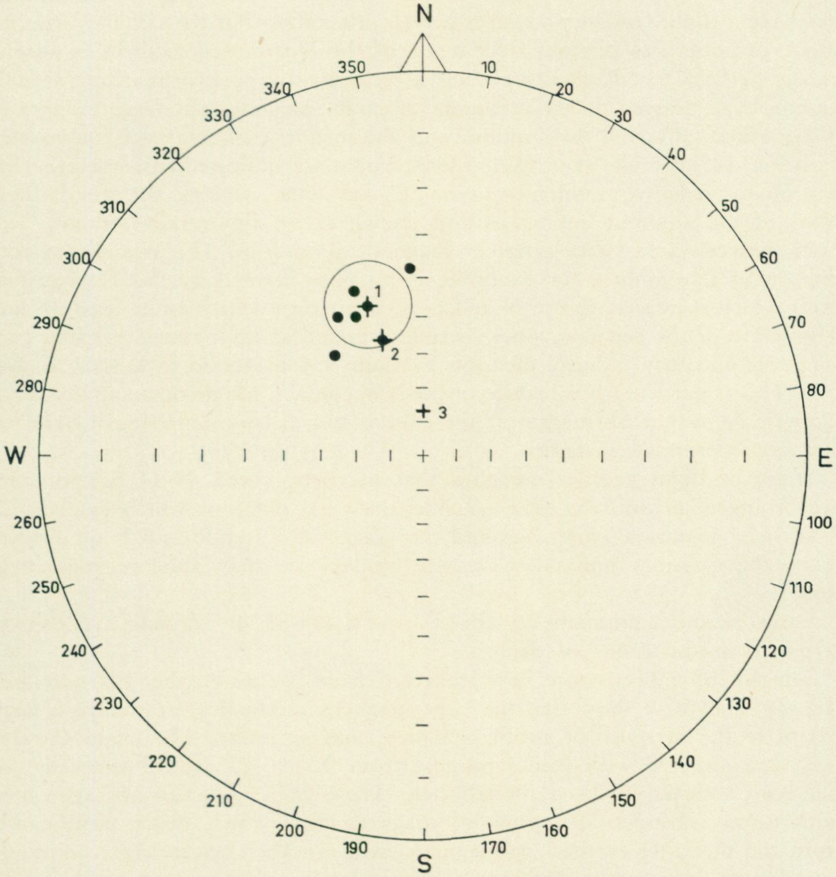

Fig. 40. Stereogram showing the directions of remanent magnetization for 5 sites on the Tärendö gabbro. Their mean and circle of confidence, 1. The mean direction of the total magnetization, 2. The direction of the geomagnetic field, 3.

Stereogram visande riktningarna för remanent magnetisering vid 5 platser på Tärendögabbron. 1 = genomsnittsvärdet med konfidenscirkel, 2 = genomsnittlig riktning för den totala magnetiseringen, 3 = det geomagnetiska fältets riktning.

is a gabbro, and this is further supported by gravimetric measurements made along the roads. Geological observations on isolated outcrops confirm the presence of gabbro in this area (the Tärendö gabbro). The trends of the anomalies have a slight tendency towards a N–S orientation but the circular arrangement, of anomalies obvious over many of the Norrbotten gabbros is absent, except perhaps S of Rovaniemi where a semi-circular positive reaching +8,000 gammas can be seen on the aeromagnetic map. An unusually large number of discordances affecting the continuity of the magnetic anomalies is interpreted as being due to faults (Cornwell 1964). These are indicated in some cases by continuous negative anomalies up to 0.5 km wide crossing the trend directions of the adjacent anomalies and elsewhere by abnormally straight contacts between areas with different magnetic properties. The straight western margin of the gabbro, for example, is possibly defined by the Narkausjoki fault which continues to the N and S, giving a total length of at least 30 km. The width of the negative zones (here interpreted as fault zones) is often considerable and may indicate invasion by some less magnetic rock such as granite. This is particularly a feature of the NW contact. Magnetic anomaly trends likewise define the SE margin of the gabbro but discontinuities exist here too and are interpreted as faults.

Study of flight profiles indicates that magnetic sheets N of Saarisuvanto are arranged in the form of a syncline, the axial plane of which extends for 9 km (see geological map). Around the village of Tärendö and E of the Kalixälv the magnetic anomalies become weaker and may indicate migmatization.

Large magnetic anomalies 5 km NE and 8 km SE of Tärendö are also interpreted as intrusions of gabbro.

Samples of gabbro have been collected from 5 sites in the Tärendö area (fig. 38) and these show that the large magnetic anomalies are due to a large extent to the presence of strong remanent magnetization. The mean Q-value is 2.52, compared with values ranging from 0.1 to 0.5 typical generally for the Pre-Cambrian rocks of Norrbotten. These high Q-values are associated with tightly grouped directions of magnetization which differ significantly from the direction of the geomagnetic field, another feature not commonly found with Norrbotten rocks, and consequently interpretation of the magnetic profiles cannot be based simply on the induced magnetization (fig. 40). Similar directions of magnetization and high Q-values were also measured for samples from a granite dyke in the gabbro (10), migmatite granite (9) and syenite (12). The last two sites lie close to the gabbro and suggest that the magnetization in the area has been influenced by metamorphism or the nearly simultaneous formation of the syenite, migmatite and gabbro but the reason why the remanence should have been preserved here and not in presumably contemporaneous rocks elsewhere is not known. It is of interest to note that the mean direction of the remanent magnetization of the Tärendö gabbro (339°+45°) is similar to that of the Ylivieska gabbro (340°+42°) in Finland (Puranen 1960).

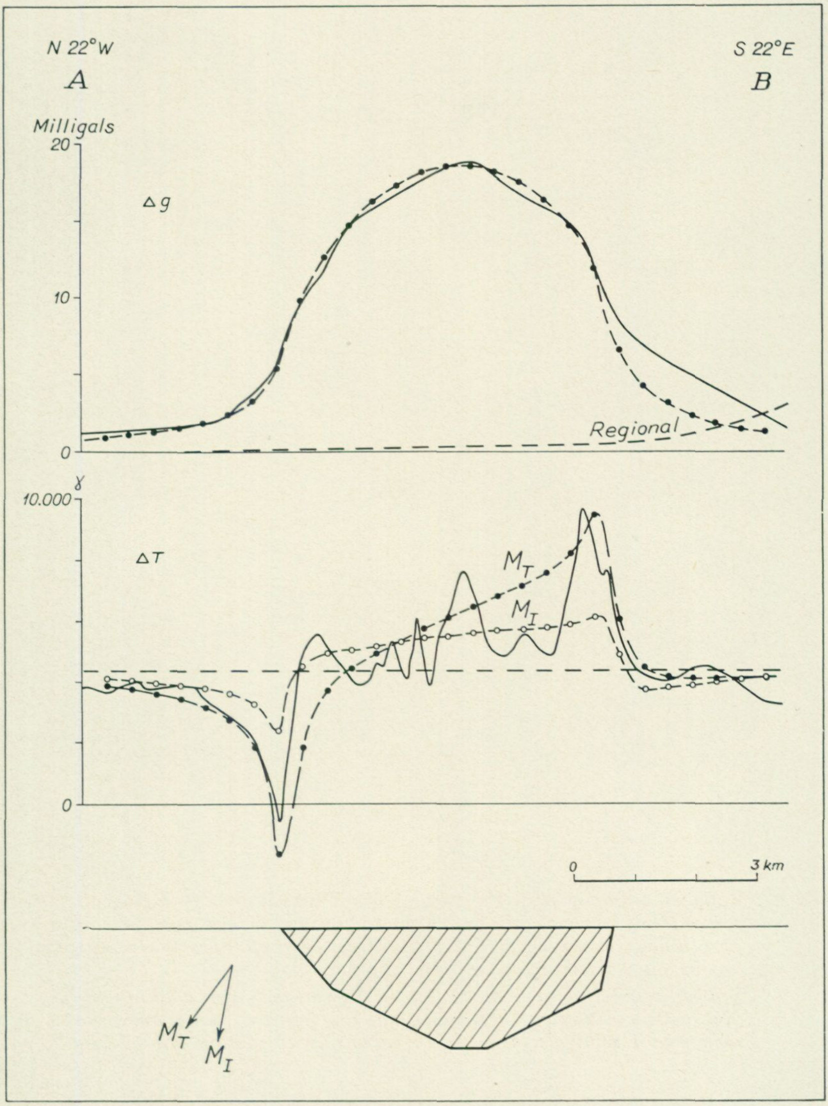

Fig. 41. Gravity (Δg) and total field magnetic (ΔT)profiles along line AB in fig. 42. Dashed curves show theoretical profiles for model in lower part of text-figure. Δ T curves are shown for both magnetization contrast based on sample determinations (M_T) and for induced magnetization alone (M_I).

Gravimetrisk (Δg) och totalfält-magnetisk (ΔT) profil längs linjen AB i fig. 42. Streckade kurvor visar teoretiskt beräknade profiler för modellen längst ner i figuren. ΔT-kurvor visas för såväl den magnetiseringskontrast som uppmätts på bergartsprov (M_T) som för enbart inducerad magnetisering (M_I).

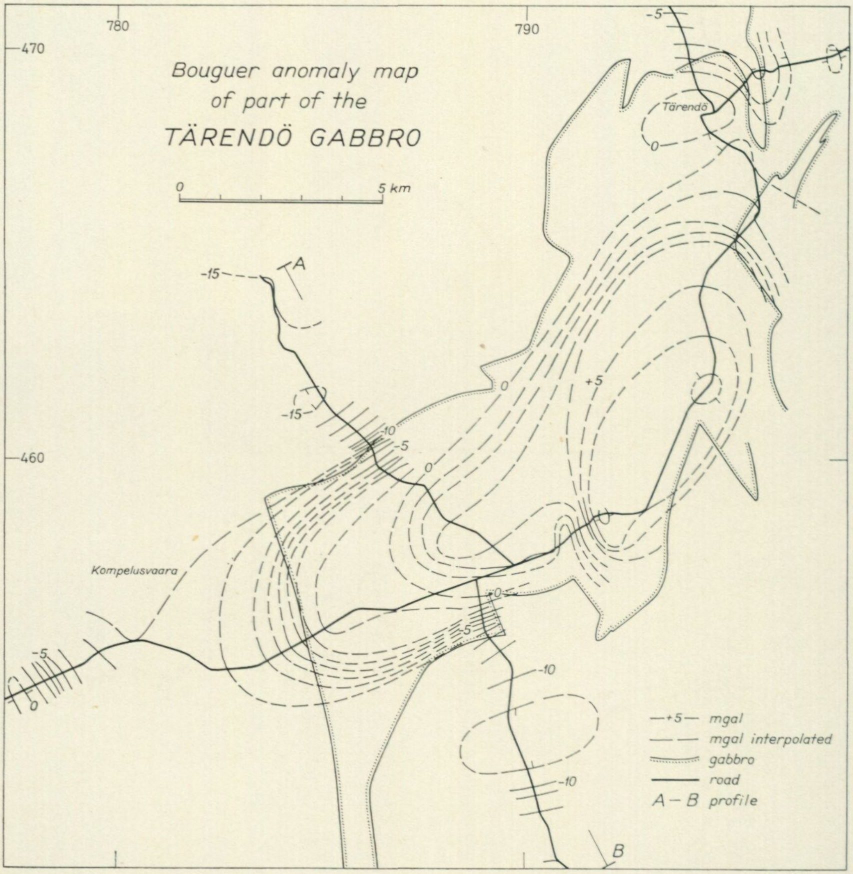

Fig. 42. Bouguer anomaly map for part of the Tärendö gabbro based on measurements along roads shown by the thick, full lines. The curves have been drawn at 1 milligal intervals and are shown as dashed lines where extrapolated. No terrain corrections have been applied.

Bouger-anomalikarta över en del av Tärendögabbron. Mätningarna gjordes längs vägar (kraftiga, heldragna linjer i figuren). Anomalikurvorna är ritade med 1 milligals intervall. Ingen terrängkorrektion har pålagts.

The aeromagnetic maps provide information on the form of the gabbro body at depth and, in particular, the presence of the large negative anomalies flanking the north-western and western margins of the intrusion suggest that these contacts with the granite dip under the gabbro, to the SE and E respectively (Cornwell 1964) (fig. 41). Very well marked negative anomalies, probably resulting from sloping contacts, appear at the margins of the two anomalies near the eastern edge of the map (Isohuhta gabbro) and in fact are quite common features of Norrbotten gabbro anomalies.

It is interesting to note the effect of the remanent magnetization on the magnetic anomalies over the gabbro for their amplitudes in several places exceed the minimum value of 58,000 gammas thought to justify further ground investigations elsewhere in Norrbotten. The maximum site magnetization recorded was 1.8×10^{-2} gauss at site 16 (fig. 38) but the magnetite content is here estimated to be only 3 vol. %. The maximum anomaly such a magnetization can give is 11,000 gammas (total field 62,500 gammas) and if it occurs as a vertical zone 100 m wide the anomaly would decrease to 6,500 gammas (58,000 gammas) at a height of 40 m. A somewhat wider zone would be necessary to produce the anomalies of 59,000–60,000 gammas recorded on the aeromagnetic map in places but an explanation is still theoretically possible without increasing the magnetite content of the rocks to an economic level. The cases where such ambiguity exists in regard to the origin of large magnetic anomalies are fortunately rare.

An estimate of the depth extent of the gabbro can be made from the Bouguer anomaly map and fig. 42 is a preliminary map based on measurements along the roads. Because the gabbro is surrounded by acid rocks with much lower densities this map naturally shows a gravity high over the basic intrusion but it will be noticed that the maximum anomaly occurs at Saarisuvanto, coincident with a structure which has been interpreted as a syncline from the magnetic map. The small but sharp gravity low measured along the road just W of this maximum coincides with a narrow magnetic low and is believed to be due to a wedge of granite, perhaps 0.3 km deep, intruded along a fault line.

An interpretation of the profile AB in fig. 42 is shown in fig. 41 for the anomalies in the total force magnetic and gravity fields, based on a two-dimensional model and calculated using the computer programme ”D2 Form” written by L. Granar and K. Beskow (Internal report SGU). The density contrast of 0.34 gm/cm^3 used for the model assumes that the gabbro with a density of 2.96 gm/cm^3 (fig. 43) rests in granite with a density of 2.62 gm/cm^3, an average value for the Norrbotten granites and 0.01 gm/cm^3 less than the observed value for site 7.

Two theoretical curves for the total magnetic field anomaly are shown for the same model. The first (M_T in fig. 41) has been computed using the mean magnetization contrast and direction based on the sample determinations. The amplitude of the negative anomaly is obviously too large, perhaps due to a sampling bias or the effect of the granitization at the critical north-western margin of the gabbro. Reducing the curve to give the best fit indicates an average magnetization of 9.0×10^{-3}. M_I is for an induced magnetization and based on the mean susceptibility value of 7.5×10^{-3} gauss/oersted (see table, fig. 43).

Prior to computing the theoretical gravity curves for models such as that

Igneous body	Physical properties				Unit remanence vectors				True remanence vectors			Total magnetiz-ation			No. of sites	No. of samples	
	ϱ	$\varkappa$	J	Q	D_r°	I_r°	α°	K	D_R°	I_R°	M_R	D_T°	I_T°	M_T		n	N
Tärendö gabbro	2.96 $\pm$0.04	7.51 $\pm$2.76	9.47 $\pm$3.79	2.52	339	+45	11	50	341	+45	9.14	332	+54	12.54	5	17	17
Perthite granite at Masugnsbyn	2.61 $\pm$0.01	1.44 $\pm$0.44	0.12 $\pm$0.04	0.17	335	+78	39	5	320	+82	0.10	0	+78	0.83	5 (6)	5	15

Fig. 43. Mean magnetic properties and densities for two igneous bodies on the Tärendö map-sheet. For explanation see later under 'Magnetic property determinations'.

Magnetiska egenskaper och tätheter för två intrusivkroppar på Tärendöbladet.

shown in fig. 41 a preliminary estimate of the thickness of the gabbro was made by assuming that it had a rectangular cross-section with a width determined from the magnetic map. This method of interpretation based on the model of a rectangular block has been found useful in many cases and will be discussed in a future publication. If the contacts are not vertical additional preliminary information of their dip (δ) may be obtained from the following simple relationship applicable to outcropping fault-like structures:

$$\delta \text{ (radians)} = \frac{\Delta g_E}{2G \varrho t}$$

where Δg_E is the gravity anomaly directly on the contact, ϱ and t are the density contrast and maximum depth of the body and G is the gravitational constant.

If the gabbro is completely stopped at the Narkausjoki fault as is suggested above its thickness must decrease from the maximum of 2 km interpreted along profile AB, westwards towards the fault line to explain the corresponding gradient observed along the road. There is however a local gravity high on the road measurements centered 1 km E of the contact by the Narkausjoki stream. The full extent of this high is not known but it seems likely that it is due to a local deepening of the gabbro, possibly representing a northward extension of the narrow neck of gabbro which is so obvious on the magnetic map. The alignment of this peculiar 0.6 km wide feature along the Narkausjoki fault suggests that it could be one of the feeder channels for the gabbro.

5. *Low magnetic values* occur over large areas of the map-sheet. Sometimes these represent sediments or metasediments of quartzitic or pelitic character (geological observations), as for example, the parallel series of very long anomalies with amplitudes of several hundred gammas (fig. 38, sites 23 and 24) between Saittajärvi and Masugnsbyn. The western half of Tärendö NW shows only small variations around the normal magnetic field. There are, however, very weak, regularly orientated positive anomalies, or zones 0.5 to 1 km wide with low magnetic values. The latter are probably fault or crush-zones and occur on many other aeromagnetic maps. The positive anomalies are aligned parallel with well defined N–S anomalies belonging to the layered sequence of metasediments to the E. Geological observations indicate the presence of granite, sometimes with schistose relicts. Most of Tärendö SW is rather similar though the anomalies have a more complicated arrangement. Amplitudes rarely exceed 1,000 gammas and in the Koinuvaara area the magnetic values change by only 100–200 gammas over 5 km. Granite is the dominating rock type in this area.

From gravimetric work it is clear that lighter rocks surround the Tärendö gabbro. To the NW (Onttovaara) granite with a rather inhomogeneous magnetic appearance is present. To the W, i. e. W of the Narkausjoki fault, the Bouguer anomalies decrease only to – 8 milligals, 7 milligals higher than the value over the granite to the north of the gabbro. There are two main possible explanations for this: one is that the area between the fault and the gravity high at Kompelusvaara is occupied by a granite with a density of 2.62 gm/cm^3 but a thickness of only 0.6 km and underlain by gabbro, implying that the gravity high at Kompelusvaara is also due to gabbro. The second alternative is that the area is occupied by a considerably greater thickness of rocks with a higher density, resulting in a lower density contrast with the gabbro. The magnetic map of this area suggests the presence of metamorphic rocks and the samples from site 8 have a mean density of 2.70 gm/cm^3. This second alternative therefore seems more likely but the ambiguity could be settled when the Bouguer anomaly map of the transition area between the granite to the N of the gabbro and the rocks to the W becomes available.

The elliptical area with low magnetic values immediately E of Masugnsbyn (fig. 43) is treated above (p. 82) in connection with the magnetic anomaly at Masugnsbyn.

MAGNETIC ANOMALY TREND DIRECTIONS AND LEVELS

The magnetic anomalies on the aeromagnetic map reflect the main geological structures of the Tärendö area and certain directions, such as N–S and NW to SE, are obviously preferred. Fig. 44 is a compilation of the directions of all the positive anomalies on the magnetic map with the frequency measured in terms of anomaly lengths. The strongest peak occurs at N 35° W and there is a broad but minor peak at the complementary angle of N 50° E. Both these directions are clearly visible in the Saittajärvi fold but the N 35° W direction is also shown by the supracrustal rocks in the NE corner of the map-sheet. It is also a direction commonly taken by the weak anomalies occurring within the large granite massifs on many of the other map-sheets and is the dominant fault direction in northern Norrbotten. Within the Tärendö district however these weak anomalies within the granites and the adjacent metamorphic rocks on the two western map-sheets have directions giving rise to the narrow peak in the diagram centered at N 5° E.

The rarity of anomalies with E–W strike directions is obvious from fig. 44 and while it is true that this is not a common structural direction in Norrbotten the distribution is affected by the fact that the aeromagnetic surveys have been made with an E–W flight direction. This 'sampling error' is not due completely to the non-detection of the magnetic anomalies, for very few indications are less than 200 m wide, but could arise unintentionally during the preparation of the maps when the anomaly peaks on adjacent lines are connected so as to give the smallest displacement. The anomalies can be recorded in this way with the wrong strike direction. The probability of detecting the same magnetic horizon on more than one flight line naturally also decreases with the sine of the angle between the anomaly strike and the flight line directions.

There are many areas on the aeromagnetic maps where the magnetometer recorded rather constant anomaly values for distances of many kilometres (see

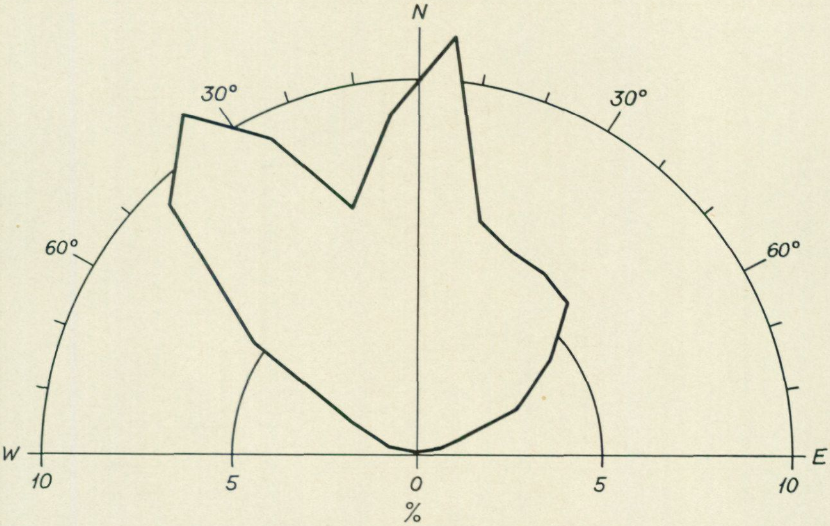

Fig. 44. Trend directions for the magnetic anomalies on the Tärendö map-sheet.
Trendriktningarna för de magnetiska anomalierna på Tärendöbladet.

Profile 6, fig. 39). Such readings typically occur over the large bodies of the youngest granite and the anomaly level recorded will depend upon the magnetization of the granite, its depth extent and to a lesser extent on the magnetization of the rocks forming the floor to the granite. Fig. 45 is a histogram of the anomaly levels recorded along 1,145 km of profile on the Tärendö map-sheet. It shows practically no levels of less than 2,900 gammas (50,900 gammas absolute value), a sudden increase to the peak at 3,500 gammas (51,500 gammas) and a gradual decrease to 4,000 gammas (52,000 gammas), the maximum value found over extended areas of granite. The 'normal value' for the map-sheet has been estimated (Werner 1967) to be 51,500 gammas and coincides with the most common anomaly level.

The anomaly level peak at 3,500 gammas can be regarded as reflecting the most common magnetization of the granites in combination with their most frequent depth extents. A general investigation of the younger granites has shown that their magnetizations (M_T) are well grouped about a value of 1.1×10^{-3} gauss with a direction coincident with the geomagnetic field. The many anomaly levels with values of between 3,500 and 3,800 gammas could be due to the effect of the numerous areas of relict metamorphic rocks contained within the granites.

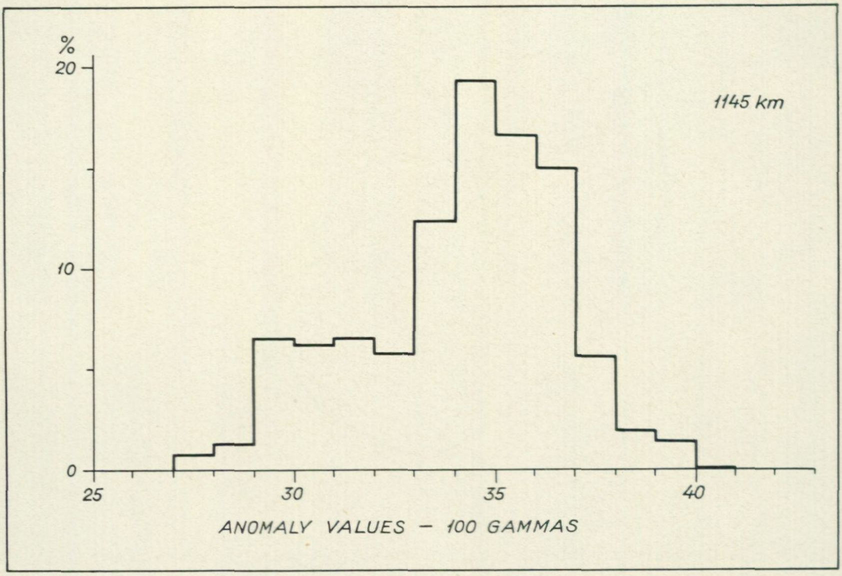

Fig. 45. Histogram of the total field magnetic anomaly observed along 1145 km of profile over granites on the Tärendö map-sheet.
Histogram över anomalinivåer för det magnetiska totalfältet längs 1145 profilkilometer över granitiska områden på Tärendöbladet.

MAGNETIC PROPERTY DETERMINATIONS

As an aid to the understanding and interpretation of the gravity and magnetic anomalies on the Tärendö map-sheet samples were collected from 25 sites for magnetic and density determinations and the results are summarized in Fig. 38. These measurements are part of a more extensive investigation of the Pre-Cambrian rocks of Norrbotten county. The density determinations were made using a normal balance and a fourprobe Oerstedmeter was adapted to measure the susceptibility and remanent magnetization of the hand samples in a field of 0.5 oersteds. An explanation of the results in the tables (figs. 38 and 43) follows:

Site. The co-ordinates of the sites are given to the nearest hundred metres following the system of Rikets Allmänna Kartverk but omitting the first two figures (the full co-ordinates of the SW corner of the Tärendö map-sheet are x = 17,500, y = 74,500).

The *density* is the saturated bulk density.

The *susceptibility* ($\varkappa$) *and remanent magnetization (J)* have units of 10^{-3} gauss/oersted and 10^{-3} gauss respectively (per cm^3).

The *Q-value* is the ratio of the remanent magnetization to the magnetization induced in a field of 0.5 oersteds.

The directions of magnetization are measured from geographical north and the inclination (I°) is regarded as positive if the N-seeking pole dips below the horizontal.

The *scatter of the directions* has been analyzed according to the method of Fisher (1953) in which K is an estimate of the precision and α is the half-angle of the cone of confidence which includes the true mean direction with a probability of 95 %. Every remanence vector is given unit weight in this analysis.

The *total magnetization* is the vector sum of the remanent magnetization and the magnetization induced in the local geomagnetic field. The intensity of the resultant has units of 10^{-3} gauss.

n is the number of orientated samples averaged to give the mean magnetic properties for the site and N is the total number of samples collected and averaged to give the mean site density.

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Place names used in the text

Anttis 6j
Granhult 2b
Haukkalaki 6g
Hietajoki 8e
Hirvirova 4j
Isohuhta 2f
Jakkumus 8c
Jukkasvaara 5h
Junosuando 9h
Kalixälven 6e, 5f, 4h, 2j, 0i
Kesasvaara 3a
Koinujoki 5d
Koinuvaara 4d
Kompelusvaara 1f
Kuusipää 3b
Kääntöjärvi 7b
Lauttakoski 7g
Leppäjoki 8f
Lovikka 7i
Martinvaara 0a
Masugnsbyn 9d
Maunuvaara 6c
Mestosvaara 0i
Mukkavuoma 7h
Männikönsaari 5g
Mäntykero 9f
Naisvuoma 6g
Narkausjoki 3f
Nilivaara 4a
Nuolivaara 6i–6j
Nybrännan 9e
Onttovaara 3h
Oriasvaara 5f
Pahakurkio 6d, 6e
Peninsaari 4j
Petäjävaara 9j
Pikku Karrav. 2a
Rakkulavaara 2g
Rautajoki (Isokursu) 9d
Rissavaara 2e
Ristivaara 4c
Rovaniemi 2j
Ruokajärvi 6f, 7f
Saarikoski 7d
Saarisvuanto 1i
Saittajärvi (Saittarova) 6f
Salmijärvi 8g
Selkävaara 2h
Siikajoki 7j
Suinavaara 8g
Suinavaaragruvan 8g
Syväjoki 7e
Tarrilainen 9c–9d
Tiankikoski 6f
Tornefors 8h
Torneälv 9h, 8h, 8i, 6i, 5i
Tärendö 3i
Tärendöälv 8f, 6h, 6i, 5j, 9g
Veikkavaara 8e
Vettasjärvi 8a
Viksvaara 9h
Vinsavaara 7g
Vittikovaara 5e

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