SVERIGES GEOLOGISKA UNDERSÖKNING
BERGGRUNDSGEOLOGISKA OCH GEOFYSISKA KARTBLAD
SKALA 1:50 000
Serie Af · Nr 9—12

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DESCRIPTION
OF THE GEOLOGICAL MAPS
LAINIO NV, NO, SV, SO

WITH AN APPENDIX BY P. NISKANEN
THE AEROMAGNETIC MAPS LAINIO NV, NO, SV, SO

BESKRIVNING TILL BERGGRUNDSKARTBLADEN
LAINIO NV, NO, SV, SO

STOCKHOLM 1970

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Kartorna godkända ur sekretessynpunkt för spridning.
Rikets allmänna kartverk 1970.12.2.

C. DAVIDSONS BOKTRYCKERI AB, VÄXJÖ 1970

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ABSTRACT

The description presents the results of geological investigations carried out in the years 1966–1969 in the map-sheet 29L Lainio (2,500 km^2), Norrbotten county, Northern Sweden. It is part of a systematic mapping programme of Norrbotten being conducted by the Ore Investigation Department of the Geological Survey of Sweden (SGU).

It is concerned entirely with a study of the Pre-Cambrian bedrock which is generally poorly exposed on account of extensive marshes and thick moraine deposits. Plutonic rocks, mainly granites and diorites prevail. They have been classified into five categories according to their compositions and modes of emplacement. Strongly recrystallized and granitized supracrustal rocks are also present and correlations with the map-sheets 29J Kiruna and 28L Tärendö have been attempted. The modes of emplacement, conditions of deposition, relations to tectonic deformation and age sequence are dealt with. A detailed investigation of post-granitic deformation has been made. The geological interpretation relies on aeromagnetic maps presented together with the geological maps. Geophysical investigations carried out by SGU on this map-sheet are described in an appendix by P. Niskanen.

GEOLOGISK ÖVERSIKT

Det geologiska kartbladet 29L Lainio är beläget inom Norrbottens län, där det täcker ett 50×50 km stort område cirka 10 mil nordöst om Gällivare. De geologiska och flygmagnetiska kartorna utges vardera i form av fyra, separata blad: 29L Lainio NV, NO, SV och SO i skala 1:50,000. De geologiska kartorna baseras på undersökningar utförda under åren 1966–1968.

Den nordöstra delen av kartbladet karaktäriseras av en bruten topografi där berggrunden är väl blottad. Därutöver täcks kartbladet huvudsakligen av vidsträckta myrmarker och lågland, inom vilka blottningar är sällsynta. En stor del av en mäktig dödisbildning, känd under namnet *Lainiobågen* (G. Lundqvist 1943), sträcker sig parallellt med Lainioälven mellan Junosuando och Lainio. Inom den del, som avlagringen täcker, har praktiskt taget inga berggrundsblottningar påträffats. De flygmagnetiska kartorna har varit till stor hjälp för den geologiska tolkningen av de hällfattiga områdena.

Förutom det material, som grundar sig på undersökningar utförda vid länskarteringen (Ödman 1957), föreligger endast några publikationer, vilka berör kartområdet. Äldre arbeten är av lokal natur och omfattar en beskrivning av järnmalmsfältet vid Masugnsbyn (Geijer 1929); en undersökning av de grafitförande skiffrarna vid Meraslinkka (J. Lundqvist 1952) samt en inventering av uranrika myrar inom ett område några kilometer nordväst om Masugnsbyn (Armands 1967).

A – GEOLOGI

Berggrunden inom kartbladet Lainio tillhör uteslutande urberget. Den utgörs huvudsakligen av djupbergarter med sur eller intermediär sammansättning, vilka ställvis omsluter större relikta partier eller mindre inneslutningar av äldre, veckade ytbergarter. Metamorfos av växlande styrka (grönskifferfacies – amfibolitfacies) har vanligen utplånat alla spår av primärstrukturer i de sedimentära och vulkaniskt-sedimentära bergarterna.

Det finns fortfarande många olösta problem när det gäller den geologiska korrelationen med andra kartblad. Berggrundens huvudelement inom den aktuella delen är emellertid jämförbara i sådan utsträckning, att en stratigrafisk korrelation mellan kartbladen Lainio och kartbladen Kiruna (29J) och Tärendö (28L) är möjlig att genomföra (Fig. 4). Inordnade i stratigrafisk följd kan följande huvudenheter urskiljas (Se Fig. 42.):

Djupbergarter
- Linagranitserien
- Porojokidiorit
- Pertitmonzonit
- Kangosdiorit
- Gabbror och diabaser

Ytbergarter
- Porfyrgruppen
- Ruutivaaragruppen
- Pahakurkiogruppen och Haaravaaragruppen
- Veikkavaara grönstensgrupp

Mer än 100 slipprov av djupbergarter med sur eller intermediär sammansättning har bestämts planimetriskt (point-counting) och bergarterna har klassificerats med avseende på relativa innehållet av kvarts, plagioklas och mikroklin. (Se diagrammet Fig. 3.)

Veikkavaara grönstensgrupp. Bergarterna i denna grupp är de äldsta, som påträffats inom kartområdet. Gruppen innehåller en komplex lagerföljd av grönstenar, lokalt grafitförande skiffrar och andra metasediment, delvis omvandlade till gnejser. Vid Sakarinpalo (0e) har natrium- och kiselsyrerika bergarter påträffats i association med olika effusiva grönstenar, basiska intrusiv och skiffrar. Ett konglomerat bestående av dioritbollar inneslutna i amfibolitiskt matrix är blottat vid Meraslinkka. Magnetitrika skarninlagringar och, i mindre utsträckning, dolomithorisonter påträffas i gruppens övre del.

Pahakurkiogruppen. Denna bergartsgrupp, som till övervägande del utgörs av kvartsrika metasediment, överlagrar Veikkavaara grönstensgrupp. De dominerande leden består av biotitförande skiffrar, vilka här och var innehåller smala men relativt uthålliga kvartshorisonter. Sillimanitförande skiffrar och gnejser är vanliga i den sydvästra delen av kartbladet. Vid Paloleuska (2a) framgår av välbevarade strömskiktningar i metasedimenten, att lagerserien är något överstjälpt. Metasedimenten (gnejser) gränsar till en tunn konglomerathorisont, vilket innehåller kvartsitbollar liggande i en kvartsitisk grundmassa.

Haaravaaragruppen. Talrika blottningar av bandade gnejser uppträder längs de branta älvstränderna i kartbladets nordöstra hörn. De flygmagnetiska kartorna visar att gnejserna ingår i en bergartskomplex, som huvudsakligen faller inom kartbladen Lannavaara (30L) och Huuki (29M). Sannolikt är gnejserna ekvivalenta med metasedimenten i Pahakurkiogruppen. Till skillnad mot dessa, intar emellertid gnejserna ett nästan horisontellt läge. Inga relikta, sedimentära drag har påträffats i den undersökta delen av komplexet, men länskartan över Norrbotten (Ödman 1957) visar att kvartsithorisonter uppträder i gnejsernas fortsättning mot norr och nordöst. Gnejsernas sammansättning är övervägande granitisk eller granodioritisk.

Ruutivaaragruppen. Denna bergartsgrupp överlagrar Pahakurkiogruppen. Den uppbyggs av en mäktig serie hornblände-plagioklasrika skiffrar och gnejser, vilka ställvis innehåller magnetitkoncentrationer samt impregnationer av olika skarnmineral. Bergarterna har tolkats som metamorfa, ursprungligen karbonathaltiga sediment. Typen har huvudsakligen påträffats inom kartbladets sydvästra del. Amfibolrika skiffrar och gnejser, vilka i hög grad påminner om föregående, har observerats i kartans norra del. Dessa bergarter har provisoriskt hänförts till Ruutivaaragruppen.

Porfyrgruppen. Porfyrerna nordväst om Laulajavaara har intermediär (monzonitisk) sammansättning och utgör de yngsta, kända suprakrustalbergarterna inom kartområdet. Deras kontaktförhållanden visar att de uppenbarligen är yngre än angränsande dioriter. Vissa observationer tyder på att de har bildats under en deformationsfas. *Porfyrer i Vivungiområdet.* Den stora och något rundade, komplexa, magnetiska anomali, som finns i Vivungi-området, har tolkats som en bassängstruktur innehållande porfyrer av olika typer. Då detta område saknar berggrundsblottningar har tre borrhål slagits, för att utreda de geologiska förhållandena. Magnetitrika porfyriter, diabaser, andesiter och en pyroklastisk, basisk bergart har påträffats. Tolkningen av detta område är emellertid fortfarande mycket osäker.

Gabbror och diabaser. Basiska intrusivbergarter syns delvis ha trängt in under den tid då Veikkavaara grönstensgrupp avlagrades (diabaser), delvis under en senare period, sannolikt i samband med tektonisk deformation (gabbror). De har utsatts för en omfattande metamorfos, vilken delvis har förstört deras ursprungligen ofitiska texturer.

Kangosdiorit. Denna bergartstyp påträffas i allmänhet i direkt anslutning till gabbror, vilket troligen är uttryck för ett närmare samband mellan dem. Texturen är hypidiomorf med subhedral plagioklas i en amfibolrik grundmassa. Kangosdioriten tillhör den av Ödman (1957) definierade Haparandaserien. Kontaktförhållandena i området nordväst om Laulajavaara samt nyligen utförda, ännu preliminära radiometriska åldersbestämningar från Haparandaområdet (Welin, i tryck) visar att dessa bergarter (alt. Kangosdiorit) sannolikt är äldre än Porfyrgruppen. (Se Fig. 42.)

Pertitmonzonit. Pertitmonzoniter är kvartsfria bergarter uppbyggda av pertit, amfibol, biotit, någon gång augit, mera sällan hypersten samt vidare ett flertal accessorier. Huvuddelen av de ingående mineralen visar tecken på instabilitet. Detta förhållande, samt bergarternas uppträdande gentemot omgivande ytbergarter tyder på, att de sannolikt bildats under en intensiv veckningsfas.

Porojokidiorit. Denna bergartstyp innehåller en förhållandevis stor mängd hybrida former, vilket beror på att den partiellt assimilerat olika ytbergarter. Den är ofta parallellstruerad och har sannolikt tillkommit under en deformationsfas. Porojokidioriten har i hög grad påverkats av den yngre Linagranitbildningen, vilket kommer till uttryck i en omfattande kalimetasomatisk omvandling. Mikrolin har nästan alltid senkristallina drag, och mineralet förtränger vanligen bergarternas plagioklas i stor utsträckning.

Linagranitserien. Linagranitserien sammansätts av Jyryjokigranit, Linagranit och pertitgranit, d. v. s. de tre yngsta djurbergarterna, som påträffats på Lainiobladet. *Jyryjokigraniten* är mer eller mindre parallellstruerad (relikt förskiffring) och visar glidande övergångar till å ena sidan Linagranit, å andra sidan gnejser tillhörande Haaravaara- eller Pahakurkiogrupperna. Den besitter andra petrografiska och kemiska karaktärer än Linagraniten, har troligen bildats vid omkristallisation av sediment med sur eller intermediär sammansättning. *Linagraniten* är relativt homogen och har en kvartsmonzonitisk medelsammansättning. En regionalt utbredd, sen pegmatitfas är associerad med granitbildningen, som visar intrusiva drag gentemot övriga bergarter. Emellertid förefaller den till stor del ha uppkommit vid en ganska lugn omkristallisering av sura sediment. *Pertitgraniten* har endast påträffats vid borrningar inom den norra delen av järnmalmsstråket vid Masugnsbyn. Den bildar ett tämligen homogent massiv, vilket är välblottat på Tärandöbladet i söder. Massivet omges av en tunn bård av albitgranit, vilken ofta har porfyrisk utbildning.

B – TEKTONIK

De flygmagnetiska kartorna har varit synnerligen värdefulla för utvärderingen av strukturerna inom kartområdet. Ytbergarternas strukturella huvudelement i den södra delen av kartbladet utgörs av en mäktig dom, vilken delvis faller inom kartbladet 28L Tärendö, delvis inom kartbladet 29L Lainio. I sin centrala del innehåller strukturen olika formationer tillhörande Veikkavaara grönstensgrupp. Norra delen av denna domstruktur är påverkad av ett vecksystem med i genomsnitt N–S-lig axialriktning (Se Fig. 38.). Den nordvästra delen av kartområdet karaktäriseras av en stor, avrundad struktur, vilken tolkats som en bassäng. Dennas huvudaxel har, liksom i föregående fall, N–S-lig strykning. Haaravaaragnejserna är, i motsats till vad som observerats i andra metasediment, relativt flackliggande. Den övriga delen av kartbladets suprakrustala berggrund har vanligen brant stupning och visar ibland tecken på intensiv veckning.

Föreliggande undersökning har även behandlat den postgranitiska stela deformationen inom kartområdet. Den utmärks av ett finmaskigt nät av förkastningar och krosszoner, med två huvudriktningar: NV–SO och NNO–SSV.

INTRODUCTION

The map-sheet 29L Lainio is an area of 50×50 km situated in Norrbotten, about 100 km to the north-east of Gällivare and 80 km to the east-south-east of Kiruna. The geological maps are presented as four separate sheets: north-west (NV), north-east (NO), south-west (SV) and south-east (SO). The scale is 1/50,000. Corresponding aeromagnetic maps are drawn at the same scale. The Lainio map-sheet is surrounded by the following map-sheets: to the south 28L Tärendö, to the west 29 K Vittangi, to the north 30L Lannavaara and to the east 29M Huuki.

Except for the north-east part of the map where many hills occur, the area is characterized by extensive marshes and lowlands and low, forest-covered hills. Marshes cover more than 700 km^2 of the map-sheet. Their

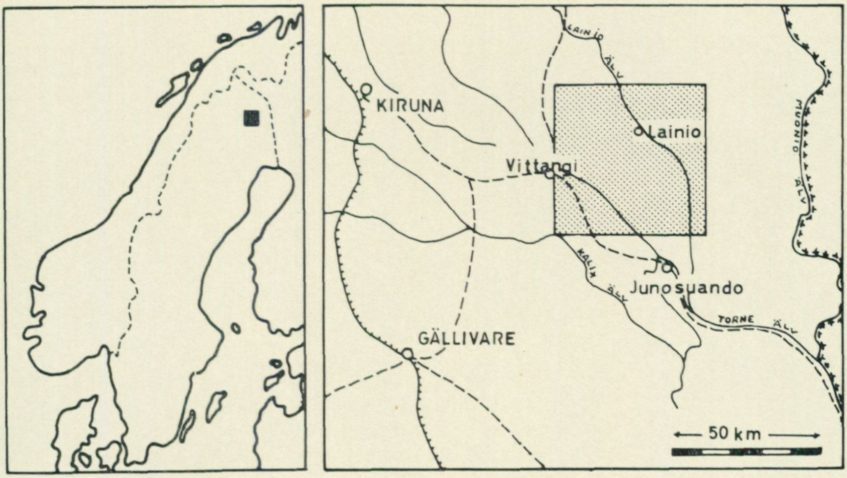

Fig. 1. Situation of the area investigated.
Kartbladets läge.

access is difficult and field investigation as well as a helicopter survey have shown that they are always poor in exposures. A large part of the thick dead-ice moraine deposits known as *Lainiobågen* (G. Lundqvist 1943) lies parallel to Lainioälven between Junosuando (Tärendö map-sheet) and Lainio. It covers approximatively 300 km^2 of the area investigated and is characterized by an abundance of small lakes and steep hills. It is almost devoid of exposures.

Mapping of the Lainio map-sheet started in June 1966 and ended in July 1968. The work has been carried out with the help of four students of geology: V. Andersson, S. Jonasson, C. Ebblin and H. Berner. An exposure-map from previous geological investigations was available. These exposures were re-visited in order to place them correctly on the photomaps at the scale of 1/20,000 which were the base for the present work. Apart from this, many new exposures have been discovered, especially in Lainio NO and SO.

The Lainio map-sheet has previously been mapped and described by different geologists and their results are summarized on the geological map of Norrbotten complied by Ödman (1957). Except for this and a few local investigations (Masugnsbyn iron-ore Geijer 1929, Meraslinkka

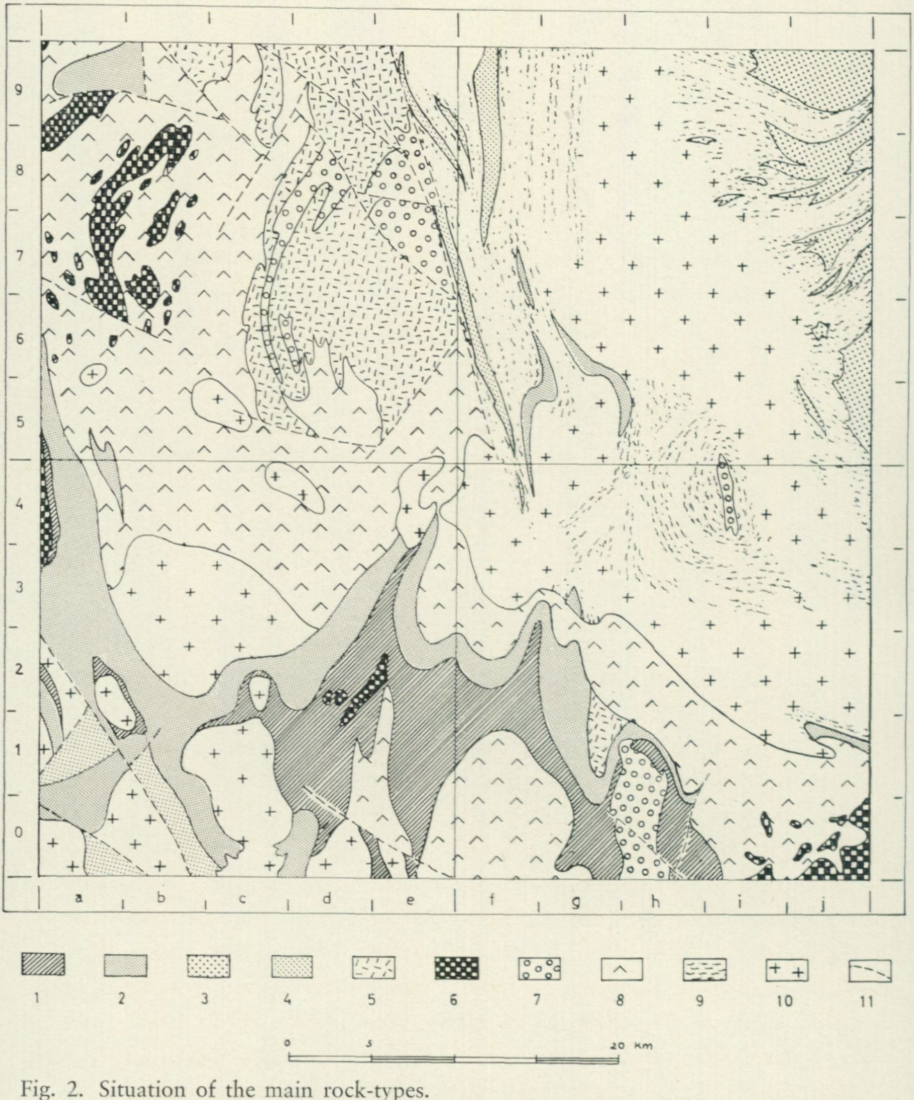

Fig. 2. Situation of the main rock-types.
1 – Veikkavaara Greenstone Group. 2 – Pahakurkio Group. 3 – Haaravaara Group. 4 – Ruutivaara Group. 5 – Porphyry Group. 6 – Gabbro. 7 – Perthite monzonite. 8 – Kangos Diorite and Porojoki Diorite. 9 – Jyryjoki Granite. 10 – Lina Granite. 11 – major faults.
Läget för huvudbergarterna inom kartbladet.
1 – Veikkavaara grönstensgrupp. 2 – Pahakurkiogruppen. 3 – Haaravaaragruppen. 4 – Ruutivaaragruppen. 5 – Porfyrgruppen. 6 – Gabbro. 7 – Pertitmonzonit. 8 – Kangosdiorit och Porojokidiorit. 9 – Jyryjokigranit. 10 – Linagranit. 11 – Huvudförkastningar.

graphite-bearing schists Lundqvist 1952 and the uranium-bearing bogs north-west of Masugnsbyn Armands 1967), there exists very little literature dealing with the map-sheet.

The rocks are all believed to be of Pre-Cambrian age and belong to the well known Fennoscandic Shield. The area investigated mainly consists of plutonic rocks, granites and diorites, often enclosing supracrustal fragments and relicts of very variable size. In a general manner, the supracrustal units of the area are similar to those found in the Kiruna (Offerberg 1967) and Tärendö (Padget 1970) map-sheets, which has permitted stratigraphical correlations to be made. There still remains however, many uncertainties in establishing regional or local stratigraphy, mainly due to metamorphism obscuring original rock structures and to the widespread occurence of faults belonging to a late deformation phase. The distribution of the main rock-units defined in the Lainio map-sheet is schematically shown on Fig. 2. Granites and diorites are however much more developed than this simplified picture shows.

The author wishes to thank all who by their efforts have contributed, directly or indirectly, to the results presented in this publication.

TERMINOLOGY AND METHODS OF INVESTIGATION

As rocks of this region have mainly been studied by microscope techniques, simple conventions based on mineralogy and texture have been adopted for naming them. This method of classification is especially well adapted to the strongly metamorphic and granitized rocks found in the map-sheet. A certain number of terms, often used in the text, are briefly described below.

Feldspathic schists and quartzites: They are strongly to totally recrystallized rocks with a texture ranging from granular to granolepidoblastic. In the map-sheet, they seldom display relicts of primary sedimentary origin such as graded-bedding, cross-bedding etc. *Feldspathic schists* are best preserved in the south-west part of the map. Their schistosity is the result of the parallel orientation of biotite flakes. Compositional banding occurs locally and there exist all transitional stages between them and banded gneisses. They are principally made up of feldspar, biotite and quartz in variable proportions. *Feldspathic quartzites* are not as widely distributed as feldspathic schists. They are massive, light coloured and usually contain more than 25 % feldspar. Through metamorphism they have generally acquired a granular (or granitoidal) texture with more or less sutured crystal boundaries. At a certain stage of recrystallization, it becomes difficult to differentiate them from granites. Differentiation between the two is however often made possible by the presence in the feldspathic quartzites of an equigranular texture (rare in granites of this region), a differential alteration of the constituent minerals, a high quartz content or the presence of muscovite, sillimanite, tourmaline and other minerals rarely encountered in granites of the area.

Meta- (-gabbro, -dolerite, etc.): This prefix is used here only in the case of metamorphic rocks conserving relicts of their original texture or structure.

Granitization: Although some authors prefer to use this term only for metasomatic granites, the author follows here the advice of Raguin (1957) and keeps for "granitization" its more general meaning which can be defined in the following manner: "all transformations leading to granite, regardless of the processes". In the area investigated, granitization has often not gone to completion, resulting in widespread hybrid facies.

Gneisses: This term is used here only for banded recrystallized rocks or for rocks presenting an augen texture (less common). Most gneisses of this area are of acid- to intermediate-composition. The gradual transition from feldspathic schists to gneisses often observed indicates that the great majority, if not all, are paragneisses. They are therefore described in the same chapter as the supracrustal rocks. In fact, gneissic horizons occur in most of the supracrustal rock-groups described hereafter.

Plutonic rocks of acid or intermediate composition have been classified with the help of the well-known quartz-plagioclase-microcline diagram presented on Fig. 3. It is based on the relation 1:2 between the proportions of plagioclase and potassic feldspar. The lines corresponding respectively to 10 % quartz, 10 % plagioclase and 10 % microcline, can be considered as correct for rocks containing no more than 10 % dark minerals. They must however be slightly corrected for higher values. K-feldspar, which generally figures on the original diagram, has here been replaced by microcline (M) for it is the only potassic feldspar present in the rocks investigated. The anorthite content of the plagioclase, provided that it is lower than 50 % (higher values corresponding to basic rocks), is not taken into accout in this classification. In order to render the classi-

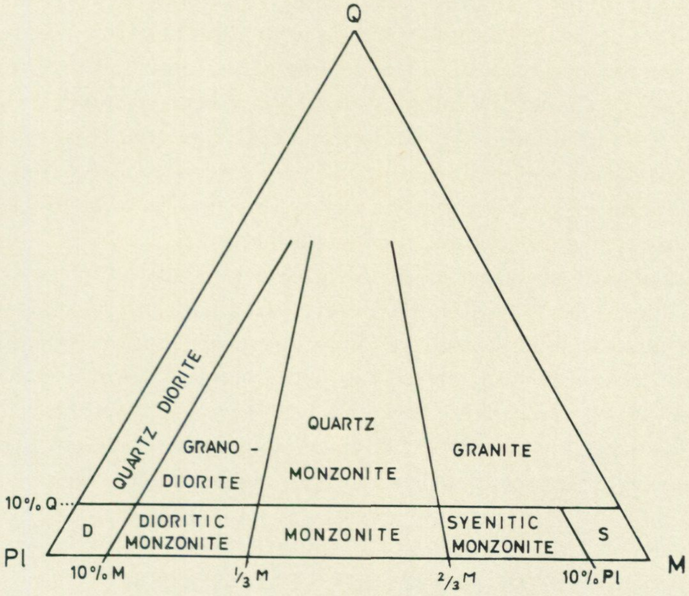

Fig. 3. Quartz-plagioclase-microcline diagram for naming rocks of acid and intermediate composition. D = diorite, S = syenite.
Kvarts-plagioklas-mikroklindiagram för klassifiering av bergarter med sur och intermediär sammansättning. D = diorit, S = syenit.

fication more precise, the two terms ”dioritic monzonite” and ”syenitic monzonite” have here been adopted. They correspond respectively to the granodioritic and to the granitic domains with less than 10 % quartz.

Many rocks, formerly designated under the name of ”syenite” on previous maps of this region, correspond in reality to *monzonites* or to *dioritic monzonites* according to the terminology here adopted. Furthermore, microscope investigation of rocks of intermediate composition has shown clearly that they present a strong ”dioritic” tendency with a predominance of plagioclase (mainly oligoclase) over microcline.

Whenever possible, modal calculation of the mineral content of the rocks has been made with the help of a point-counter (See Figs 63 to 65.). Our purpose was not to calculate the chemical composition of rocks through modal analysis but to obtain rapid mineral estimations of as large a number of samples as possible in order to study and compare different groups of rocks by their "dispersion pattern" on Q-Pl-M diagrams. The number of points counted varies as a function of grain-size and rock-texture but in many cases, when dealing with rather uniform-textured rocks, no more than a few hundred points have been counted per section. The precision of the method has been checked by counts of over 1 000 points and the error on major minerals never exceeded a few percent and was generally below 2 %. This is well within the limits of precision required for the type of investigation made here.

Chemical analyses of rocks of this area are presented in the last part of this paper (Figs 55 to 62). They have been made by spectrographical methods and can be described as "analyses for orientation" because their precision does not allow the classic petrochemical "norm" calculation (See p. 88.) to be made. They have however been most useful for comparing the distribution of major and trace elements in different groups of rocks, as well as for comparing them with petrographical data.

THE SUPRACRUSTAL ROCKS

Structural and petrographical considerations as well as correlations with the map-sheets 29J Kiruna and 28L Tärendö, (See Fig. 4.) have permitted a subdivision of the supracrustal rocks into five main groups. These are presented below in stratigraphical order.

(youngest) – The Porphyry Group
– The Ruutivaara Group
– The Pahakurkio and Haaravaara groups
(oldest) – The Veikkavaara Greenstone Group

On account of their weak resistance to glacial erosion, supracrustal rocks are but poorly exposed in the map-sheet. It is often only due to the presence of granite in their immediate vicinity that they have been preserved. Aeromagnetic maps show that most high-anomaly zones (corresponding generally to magnetite-bearing meta-sediments or to basic volcanics) are situated over large marshes devoid of exposures.

A – THE VEIKKAVAARA GREENSTONE GROUP

In a general way, the Veikkavaara Greenstone Group (Defined by Padget, 1970.) consists of a complex succession of rocks of volcanic, volcano-se-

KIRUNA 29J (J. Offerberg, 1967)	TÄRENDÖ 28L (P. Padget, 1970)	LAINIO 29L (present paper)	
		SE, SW, NW	NE
Upper Hauki Complex	Rissavaara Quartzite	–	–
Paittasjärvi Greenstones	–	–	-
Kiruna Porphyries	Kalixälv Group	Porphyry Group	–
		Ruutivaara Group	–
Kurravaara Conglomerate	Pahakurkio Group	Pahakurkio Group	Haaravaara Group
Greenstones cf Kiruna type	Veikkavaara Greenstone Group	Veikkavaara Greenstone Group	?
Granite basement	?	?	?

Fig. 4. Schematical stratigraphical correlations established for different groups of supracrustal rocks.
Stratigrafisk korrelation mellan olika ytbergartsgrupper.

dimentary or sedimentary origin. Due to their mixed origin, the rocks display variable mineralogical and textural characters. Basic and intermediate composition types predominate.

A detailed stratigraphy within this group of rocks is not possible in the Lanio map-sheet, metamorphism and intense granitization having generally obscured all traces of primary structures. The rock-units are better preserved in the Tärendö map-sheet, permitting the establishment of a rough stratigraphy there, and the reader should refer to this map description (Padget 1970) for a more complete view of this group.

The rather high magnetic anomalies corresponding to most of the rocks of this group finds an explanation in the widespread magnetite dis-

Fig. 5. Clastic rock with diorite pebbles and fragments at Meraslinkka.
Klastisk bergart med dioritfragment, Meraslinkka.

semination, this mineral often amounting to a few percent (volume percent) of the rock.

1 – GREENSTONES

Greenstones are widespread in Lainio south-west and to a lesser extent in Lainio south-east. They are generally medium-to-fine-grained, strongly recrystallized and display in places a relict doleritic texture thereby indicating that they are, at least partly, of (basic) volcanic or hypabyssal origin. Aeromagnetic maps indicate that greenstones occur as rather continuous horizons at various levels of the Veikkavaara Greenstone Group. They are mainly made up of plagioclase (oligoclase and more seldom andesine), irregular amphibole aggregates (green hornblende or actinolite-tremolite), biotite and epidote-saussurite. The latter often forms a very fine-grained and somewhat diffuse groundmass. The main accessories are, in order of importance: magnetite, titanite, quartz, chlorite and pyroxene (diopside, rare). Scapolitization is common.

As result of a partial assimilation of greenstones by diorites, transitional stages between these two rock-types occur at Meraslinkka. This is again discussed in the chapter dealing with the Kangos Diorite (p. 46).

At *Meraslinkka* (2e), along Torneälven, a peculiar clastic formation has been found. It is a few metres thick, strikes NNE–SSW and dips steeply WNW. It consists of more or less rounded, light coloured fragments enclosed in a dark green matrix made up mainly of green hornblende (See Fig. 5.). The fragments have a medium-grained granular texture and a dioritic composition. They are strongly metamorphic as can be deduced from the large development of crystal-aggregates of green hornblende, chlorite, sericite and saussurite. In places, the plagioclase (andesine) is partially recrystallized. Structural considerations indicate that this clastic formation underlies the graphite-bearing schists found not far to the west and to the north. It is possible that the ”conglomerate with granite pebbles, partly rich in carbonates” found in the lower part of the Kiruna Greenstones and described by Offerberg (1967) may represent a less metamorphic aspect of the same formation. The scarceness of exposures in this region does not permit further speculation as to the origin of this type of rock.

2 – SCHISTS AND GNEISSES

The Veikkavaara Greenstone Group contains various schist and gneiss horizons of probable sedimentary or volcano-sedimentary origin. They are often associated with the greenstones described above and generally contain a high percentage of green hornblende. In the area investigated, they are devoid of primary structures. The main constituent minerals are: plagioclase (oligoclase or andesine), amphibole (green hornblende), biotite and sometimes quartz. The texture is granolepidoblastic. Incipient augen texture has also been locally observed. Graphite-bearing schists have been found at four localities: Vähävaara (drill cores from the iron-ore at Masugnsbyn), Meraslinkka (Lundqvist 1952), Merasvaara and Pöyvionpalo. Electrical measurements made at Meraslinkka indicate that graphite-bearing horizons are somewhat discontinuous and can be traced for a few hundred metres only.

On account of their weak resistance to erosion, schistose rocks are poorly exposed in the map-sheet and have therefore not been studied in detail. For a more complete description, the reader is referred to Padget (1970) and Lundqvist (1952).

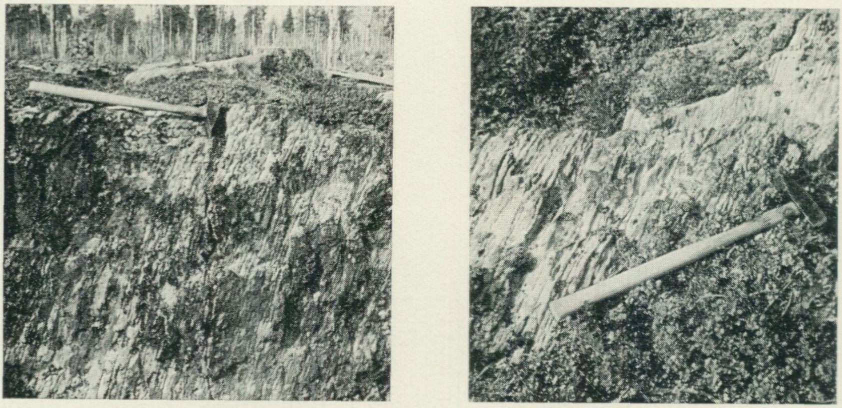

Fig. 6. Schistose and banded quartz-albite rock of the Sakarinpalo suite.
Förskiffrad och bandad kvarts-albitbergart, Sakarinpalosviten.

3 – THE SAKARINPALO SUITE

Highly siliceous and sodic fine-grained rocks are found intimately related to greenstones and schists at Sakarinpalo (0e), in the south-west part of the map.

The most acid rock-type (analysis FW 233a, Fig. 55) roughly forms two large bands (300 and 500 metres wide) with an average N–S strike, and, in places, a steep dip to the west. This type is light grey, slightly schistose (this is mainly apparent on weathered surfaces) and cut by a rather dense network of discordant actinolite-epidote stringers. A well-developed schistosity and a fine banding have sometimes been observed (Fig. 6). The mineralogic composition is rather constant, quartz and plagioclase (albite or albite-oligoclase) forming a fine-grained groundmass. Microcline is sometimes present in the groundmass. Magnetite, titanite, sericite, biotite and chlorite are the main accessories. Actinolite and epidote form crystal aggregates or irregular veinlets and have crystallized after the minerals mentioned above. The texture is generally finely equigranular with, however, numerous coarser zones or ”patches” resulting from partial recrystallization of the groundmass. Sutured mineral boundaries are common. The banding, when present, is due to alternating bands of different grain size. These acid types are, to a certain extent, comparable with certain fine-grained meta-sediments found in the northern part of the iron-ore zone at Masugnsbyn.

A gradual transition between the acid rock-type described above and amphibole schists is represented by a finely banded type, the lighter bands being composed of an equigranular, fine-grained quartz-albite groundmass of the type described above, while the darker bands contain a certain amount of green hornblende.

There also exists a close relationship between this last type and basic rocks which are in places banded. These basic rocks are mainly: a dolerite with medium-grained texture and a dolerite with fine-grained texture. They often display a large number of amphibole stringers with bleached margins. Irregular brecciated zones occur locally. Greenstones (probably meta-dolerites) also occur frequently.

Within the areas where basic rocks predominate, minor occurrences of garnet-bearing muscovite schist and a foliated, recrystallized heterogeneous rock containing sub-angular fragments (pyroclasts?), have also been found.

The strike of the schistosity and banding of all of the members of this suite of rocks is rather constant (average N–S), the dip being always very steep, usually to the west.

It is the author's impression that the Sakarinpalo suite belongs to a volcano-sedimentary complex of local extention. The most acid members of the suite, containing as much as 76 % silica and displaying in places a fine banding, are probably of sedimentary origin while the more basic members represent the volcanic or volcano-sedimentary components. The high soda content observed in some cases possibly reflects the "spilitic" character of this suite of rocks. On the other hand, rocks presenting certain similarities with some members of this suite of rocks are described as "leucodiabases" in literature dealing with this part of Sweden (See Padget 1959 and Frietsch 1966.). Leucodiabases are however generally poor in silica.

4 – SKARNS AND ASSOCIATED ROCKS

In the Lainio map-area, the main skarn occurrence is found in the northern part of the Masugnsbyn iron-ore, the southern part of this ore being situated in the Tärendö map-sheet. Small skarn exposures have been found to the north of Merasvaara (2c). Irregular skarn horizons also occur within the basic members of the Sakarinpalo suite. Although no skarn exposures have been discovered in the south-east part of the map,

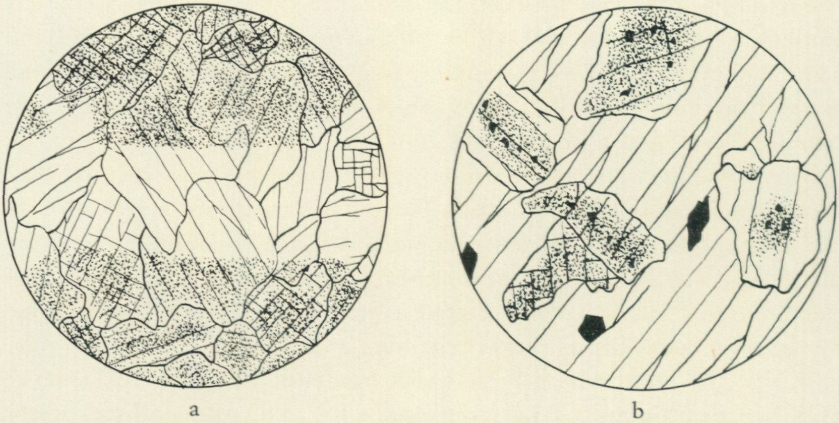

Fig. 7. Augite skarn at Merasvaara:
a – (Normal light x 45.) Augite crystals containing minute impurities in a somewhat zoned manner. The absence of the latter from a band which does not respect crystal boundaries is probably the result of the combined effects of stress and metamorphism.
b – (Normal light x 45.) Clear augite poikiloblasts containing smaller augite crystals described in *a* and a few magnetite crystals.
Augitskarn, Merasvaara.

the presence there of large skarn boulders (Junosuando-Purnuvaara road) and of extensive, thin magnetic anomalies of the type usually found in better-known skarn areas, indicate that skarn is certainly well developed in this area.

Since an extensive and detailed description of the skarns associated with the iron-ore of Masugnsbyn already exists (Geijer 1929) and a drilling programme is currently under way, these rocks will not be discussed here to any extent. The skarn horizon, which was well developed in the Tärendö map-sheet, is somewhat thinner and is locally absent from the northern part of this iron-ore. The main type is a porphyroblastic augite-tremolite-actinolite skarn containing irregular distributions of magnetite. The other minerals often encountered are: phlogopite, serpentine (in the ore zone), pyrite, pyrrhotite, calcite och chondrodite (the latter only known, as yet, from the southern part of the ore).

An augite skarn in contact with graphite-bearing schists is exposed to the north of *Merasvaara* (2c). A large fragment of skarn is enclosed in the granite forming the northern slopes of the hill. Local boulders of augite-actinolite-tremolite skarn containing well-formed molybdenite crystals have been found in the direct vicinity of skarn exposures. Small molybdenite crystals also occur in neigbouring pegmatites which enclose a few skarn relicts. The skarn at Merasvaara is interesting in that it shows two generations of augite (Fig. 7b). The first generation consist of small granular crystals containing "clouds" of finely disseminated opaque inclusions (magnetite?) while the second generation consists of larger clear poikiloblasts often enclosing crystals of the first generation.

The problem concerning the formation of skarn is discussed to some extent in the last part of this chapter.

B – THE PAHAKURKIO GROUP

This group of rocks (Defined by Padget, 1970.) consists of metamorphic sediments such as feldspathic schists, feldspathic quartzites and banded gneisses. Original structures are seldom preserved and granitization is generally at an advanced stage.

1 – FELDSPATHIC SCHISTS AND QUARTZITES

The study of drill cores from the iron-ore of *Masugnsbyn* indicates that, in normal succession to the greenstones and skarns of the Veikkavaara Greenstones Group, the base of the Pahakurkio Group is represented by magnetite-rich meta-sediments displaying rather variable petrographic characters from one place to another. The main type is a medium-to-fine-grained biotite (and less commonly phlogopite) schist with a granolepidoblastic texture. The groundmass consists of recrystallized quartz, plagioclase, microcline and biotite. Magnetite can be abundant, either as small disseminated crystals, or as somewhat large poikiloblasts. The principal accessories are: tourmaline, apatite and sometimes muscovite.

Drill cores from the extreme northern part of the Masugnsbyn iron-ore have shown the existence there of a very fine-grained rock displaying beautiful banding between lighter and darker bands a few millimetres to a few centimetres in thickness. This rock is quite magnetic in places and mainly consists of a fine-grained granular quartz groundmass containing variable proportions of biotite, magnetite and feldspar. The darker bands are rich in small disseminated magnetite crystals while the lighter bands are almost devoid of them. The grain-size is slightly coarser in the lighter bands and a few recrystallized quartz veinlets, devoid of magnetite, can be traced in the darker bands (Fig. 8). This last observation indicates that recrystallization has certainly played an important part in the mobilization of iron. Magnetite concentration could be due, at least partly, to phenomena of this type. The type of rock described above is probably a metamorphosed shale.

Magnetite-rich horizons of the southern part of the iron-ore of Masugnsbyn are mainly found in association with skarns and greenstones while in the northern part of the ore they often occur in meta-sediments rich in quartz. This rather peculiar occurrence of ore in two different rock-types (the aeromagnetic maps indicate the presence of only one somewhat continuous sheet-like ore-body) can be explained in the following manner: at the time of deposition of the ore there existed a basin of local extention but deeper of the north. This is in agreement with observations made in the southern part of the ore showing a certain thickening of rock-units towards the north (interpretation of electrical measurements made by Padget). In the southern part of the basin mentioned above, carbonate- and magnetite-rich sediments and basic volcanics were being deposited, followed by the deposition of quartzo-feldspathic material (probably of arkosic type). In its northern and deeper part, however, the sedimentation mainly consisted of fine-grained, highly siliceous material (probably an iron-rich clay). This would explain the weaker and more dispersed iron mineralization found in the northern (and thicker) part of this ore zone.

Quartzites and feldspathic quartzites are in contact with folded schistose meta-sediments in the north-western part of *Paloleuska* (2a). The former have a rather variable mineralogical composition from one place to another although they always contain a high quartz percentage. The other constituant minerals are, in order of importance: microcline, plagioclase and biotite. The main accessories are: muscovite, magnetite, hematite, apatite, zircon, tourmaline and sometimes sillimanite. They are always strongly to totally recrystallized and are often difficult to differentiate from the neighbouring granites. A conglomerate consisting of more or less angular quartzite fragments and pebbles enclosed in a quartzitic or somewhat gneissose cement (Fig. 9) is well exposed along the crest of Paloleuska. It strikes NW–SE and dips rather steeply to the NE. Folded schistose meta-sediments (Fig. 10) displaying in a few places preserved cross-bedding are found in contact with the conglomerate (to the south-

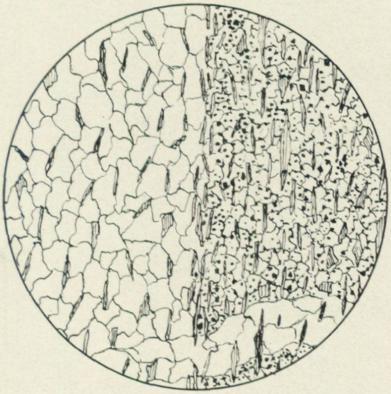

Fig. 8. (Normal light x 35.) Metamorphic shale 5 km north of Masugnsbyn. The dark band (right) displays abundantly disseminated magnetite, while the lighter band (left) is devoid of it. Biotite flakes show a rather good preferred orientation. Note the difference in grain-size between the two parts of the thin section, and the recrystallized veinlet (lower right) devoid of magnetite. *Metamorf skiffer, 5 km norr om Masugnsbyn.*

west of the conglomerate). The direction of younging is to the south-west thereby indicating an inversion of rock-units (overturned limb of an anticline as shown in the profiles IV and V, Pl 2). Massive hematite-bearing quartzites and feldspathic quartzites, in place strongly granitized, are found to the north-east of the conglomerate and therefore lie stratigraphically under it. A few minor conglomeratic horizons with quartzite pebbles and fragments in a biotite-rich schistose matrix have also been found to the south-west of the main conglomerate described above. In the north-west extremity of Paloleuska, these supracrustal rocks stop abruptly along a fault striking NE–SW, bringing them in sharp contact with a homogeneous Lina Granite. The monomict part of the conglomerate above, composed of somewhat elongated quartzite pebbles in a quartzite matrix, closely resembles the conglomerate described and figured by Eriksson (1954, Fig. 7) in the Käymäjärvi area (28M Pajala).

Small occurrences of quartzites or feldspathic quartzites have also been found at Tolpukkavaara (9b), Palovaara (5a), 4 km to the north-west of Masugnsbyn on the Masugnsbyn-Merasjärvi road and at Matala Kuusivaara (0a) where it is possible to observe a neat discordance bet-

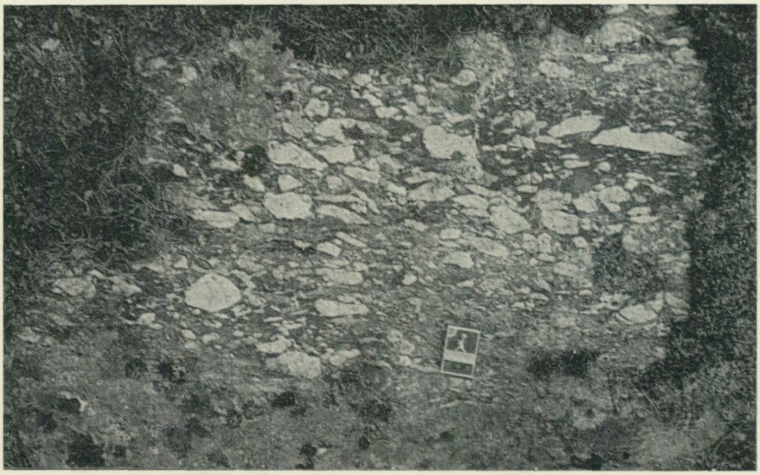

Fig. 9. Quartzitic conglomerate at Paloleuska.
Konglomerat med kvartsitbollar. Paloleuska.

ween steeply dipping feldspathic quartzites underlying sub-horizontal granites of the Lina type.

In a general manner, quartzites apparently occur as rather thin and continuous horizons within biotite-rich feldspathic schists as for example in the area situated to the west of the Masugnsbyn iron-ore zone.

2 – GNEISSES

In many places, feldspathic schists pass gradually to medium-grained banded gneisses. Plagioclase and biotite are the main minerals together with minor proportions of quartz, microcline and sometimes amphibole or sillimanite. The main accessories are: magnetite, titanite, apatite, zircon and epidote.

Sillimanite-bearing gneisses and schists are rather common to the north of Nedre Parakka (0a) and at Paloleuska. Microscopic investigation shows that sillimanite occurs in two different manners: as more or less parallel sillimanite needles entirely confined to quartz or to plagioclase grains (See Fig. 11.) or, more frequently, as randomly orientated needles generally discordant to the main schistosity plane.

In the south-east part of the map there exist many occurrences of schists

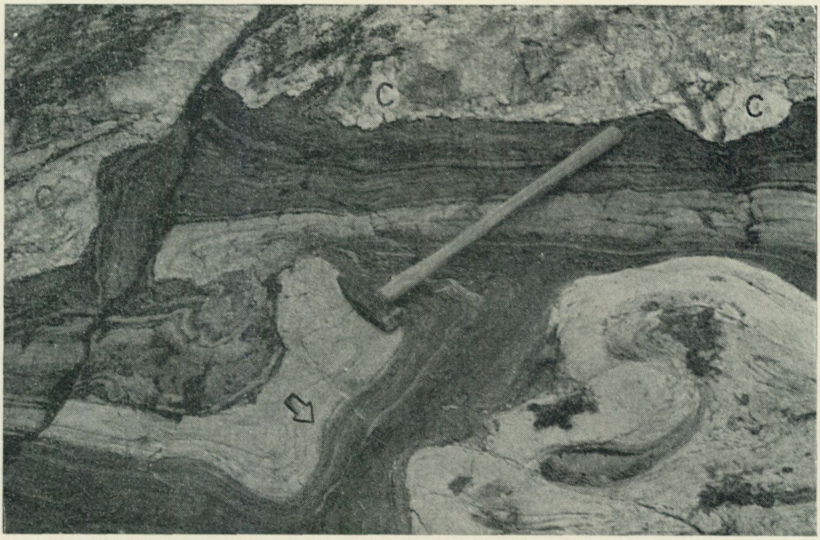

Fig. 10. Tigthly folded meta-sediments in contact with a quartzitic conglomerate (C) at Paloleuska. Preserved cross-bedding in meta-sediments indicate a younging in the direction of the arrow.
Veckade metasediment i kontakt med ett kvartsitbollförande konglomerat (C), Paloleuska. Bevarad strömskiktning i metasedimentet visar stratigrafiskt "uppåt" i pilens riktning.

and gneisses which rarely show any traces of a sedimentary origin. For structural and petrographic reasons these rocks have been interpreted as belonging to the Pahakurkio Group. Petrographically, they are similar to the gneisses and schists of the Haaravaara Group described below.

C – THE HAARAVAARA GROUP

The Haaravaara Group consists of a monotonous succession of banded gneisses which are well exposed in the north-east part of the map. The northern part of the hill Haaravaara (7j) is crossed by a small river with steep banks where these gneisses can best be observed. From aeromagnetic interpretation, these gneisses belong to a major "structure" covering more than 500 km^2 and mainly situated on the adjacent map-sheets Lannavaara, Muonionalusta and Huuki.

The Haaravaara Group is here described together with other supra-

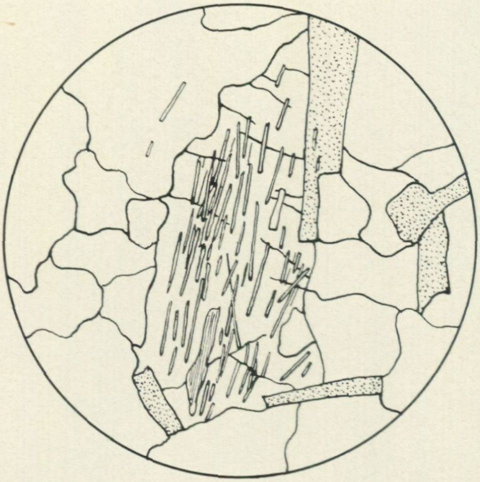

Fig. 11. (Normal light x 45.) Strongly recrystallized feldspathic quartzite at Paloleuska. A fractured plagioclase contains a large quantity of more or less parallel minute silliminate needles, and a small muscovite flake. The shaded mineral is biotite.
Omkristalliserad fältspatförande kvartsit, Paloleuska.

crustal units in spite of the fact that it is made up, in the area investigated, of rocks displaying no relicts of sedimentary origin. The geological map of Norrbotten county (Ödman op. cit.) shows, however, that quartzites do occur in the northern and north-eastern prolongation of these gneisses (north of Paittasjärvi in the Karesuando map-sheet and north of Muodoslompolo in the Muonionalusta map-sheet). Furthermore, the gneisses of this group present many similarities with the gneisses found in the Pahakurkio Group and it is the author's opinion that the Haaravaara Group is equivalent to the Pahakurkio Group. The main difference between the two lies in the fact that the former is strongly granitized and lies rather flat while the latter is generally less metamorphic and dips rather steeply. The high state of granitization in which the Haaravaara gneisses are found explains the absence of preserved sedimentary structures in the area investigated.

These gneisses show a succession of light coloured horizons of granitic composition and somewhat darker biotite-rich bands, a few centimetres to a few decimetres thick. A close association exists between gneiss, foli-

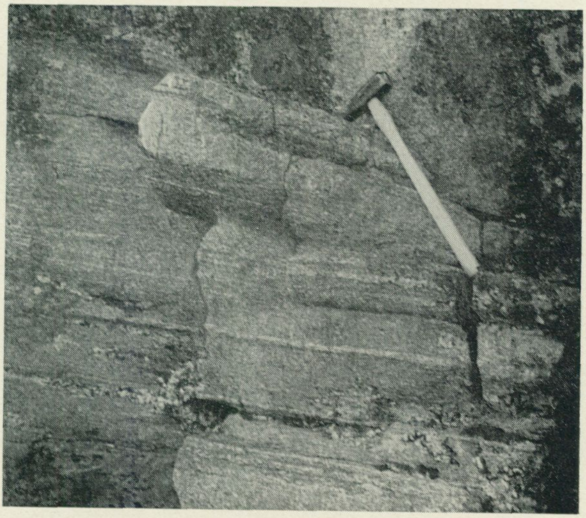

Fig. 12. Banded gneisses along Parkajoki.
Bandad gnejs längs Parkajoki.

ated granite and granite. In places, a gradual transition from banded gneiss to foliated granite has been observed. In this case, there is no notable change in the direction of foliation from one type to the other. In other places, a concordant to sub-concordant granitization occurs. The result is a succession of parallel bands of granite (of the Lina type) and of biotite-rich bands. Still in other places, the granitization displays neat discordant characters with granite and pegmatite dykes and veins sharply cutting the gneisses. Some veins have been observed to be discordant in places while they are concordant in others.

The rock-texture is mainly granular for the light-coloured bands and granular to granolepidoblastic for the darker, biotite-rich bands. Besides the preferred orientation of biotite, the schistosity is marked by elongated quartz cores and schlieren. Sometimes, an imperfect banding between plagioclase-rich bands and microcline-rich bands occurs. Stress, in relation to the recrystallization of these rocks, seems to have been important, as can be deduced from the widespread sutured crystal boundaries and the very irregular grain-size observed. In order of importance, the major minerals are: microcline, oligoclase, quartz and biotite. The first three are often porphyroblastic. The most common accessories are: muscovite, sericite, titanite, zircon and tourmaline.

D – THE RUUTIVAARA GROUP

Ruutivaara is a small hill situated in Lainio SV (0c) where large exposures of somewhat granitized amphibole schists and gneisses occur. From aeromagnetic interpretation and field investigation, the amphibole schists and gneisses of the Ruutivaara Group apparently form a large band (more than 2 km broad) striking NNW–SSE between Ruutivaara to the south and the Naankijärvi region to the north. The dip of the banding and of the schistosity is always very steep, often to the west.

Structural considerations indicate that the Ruutivaara Group lies in normal succession to the Pahakurkio Group. In agreement with this, a petrographical investigation made on rocks found in the contact-area between these two groups has shown that there exists a gradual transition from one group to the other, the feldspathic schists of the Pahakurkio Group containing an increasing content of green hornblende as one approaches the dark amphibole schists of the Ruutivaara Group.

Rocks belonging to the Ruutivaara Group generally correspond to rather high and simple anomalies on aeromagnetic maps, strongly contrasting with the somewhat higher and more complex anomalies of the Veikkavaara Greenstones Group. It has therefore been possible, to a certain extent, to trace them in regions devoid of exposures. Amphibole gneisses, petrographically similar to those encountered in the Ruutivaara region and giving rise to the same style of magnetic anomalies, have been discovered in the north-east and in the north-west parts of the map (8e, 9e, 9f, 8f, 7f etc.). They have been provisionally placed in the Ruutivaara Group although, in the absence of definite structural and stratigraphical verifications, this still remains hypothetical.

Rocks of this group have often been affected by the emplacement of granites. Gneisses resulting from a concordant granitization and feldsparization are common.

The amphibole schists and gneisses are principally composed of green hornblende and oligoclase. Actinolite and epidote often fill microfractures, their crystallization always being later than crystallization of hornblende. The former also form large pegmatoidal aggregates in which the size of single epidote crystals can reach a few decimetres. The schistosity of the rock is due to the preferred orientation of hornblende. Magnetite often forms thin concordant stringers displaying bleached borders. Finely banded gneisses, consisting of light-coloured bands of granitic composition (with sometimes large microcline poikiloblasts) alternating with amphibole-rich dark bands, are quite common. In the northern part of the map, the amphibole gneisses contain small amounts of quartz and biotite while these two minerals are seldom found in the Ruutivaara region. In order of importance, the accessories are: magnetite (which in some cases makes up a few percent of the rock), sericite, titanite and apatite. Diopside is present in one thin section.

In contrast to the Veikkavaara Greenstone Group, no basic intrusives or effusives have been found in association with the Ruutivaara Group and it is highly probable that the latter is formed of metamorphic sediments which were initially carbonate-rich. Metamorphism of the amphibolite facies has given them their present aspect.

E – THE PORPHYRY GROUP

Porphyries are scarcely exposed in the Lainio map-sheet and in only one large exposure, situated in the vicinity of the Viksvaara-Laulajavaara perthite monzonite massif, can an idea of their mode of emplacement be obtained. Structural considerations, drill cores from Lainio and Vivungi as well as the presence of local porphyry boulders in the Vivungi region, indicate that porphyries are probably abundantly distributed in the northwest map. Very few exposures have however been encountered in this water-clogged area and the interpretation of th Vivungi region still remains very uncertain.

1 – PORPHYRIES NORTH-WEST OF LAULAJAVAARA

A large and complex exposure, partly made of porphyry, occurs a few hundred metres to the north-west of Laulajavaara (1g). The porphyries are of two types: a dark purplish type displaying a good porphyritic texture and a pink, medium-to-fine-grained type, poor in dark minerals. The former contains more than 10 % green hornblende, a small amount of augite and many disseminated accessories (epidote, magnetite, titanite, biotite and apatite). Scapolitization is common. Very irregular magnetite (Fig. 13) and epidote concentrations occur locally. Both types mentioned above have a monzonitic composition (See Fig. 26.).

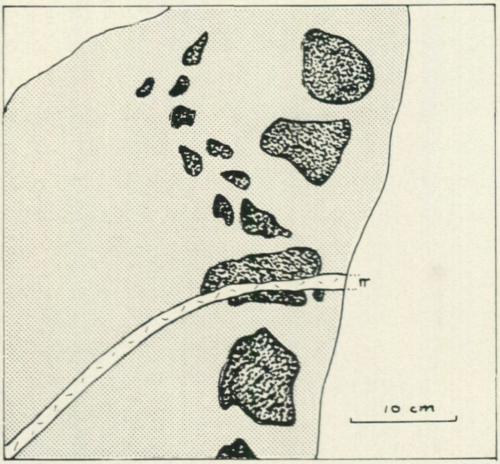

Fig. 13. Grey porphyry (slightly banded in the field) with magnetite inclusions. The rock is sharply cut by a thin, pink pegmatite of the Lina type (π). Exposure north-west of Laulajavaara.
Magnetitinneslutning i grå porfyr. π = skär pegmatit av Linatyp.

In places, the pink porphyry is somewhat younger than the dark one and cuts it sharply. In other places, there occurs a complex and irregular banding between the two (Fig. 14) possibly reflecting their effusive origin. A poor and unexplained banding has sometimes been observed between granodiorites, well exposed in the area, and porphyries. Pegmatites of the Lina type and irregular quartz veins sharply cut the porphyries.

Porphyry veinlets locally cut a diorite and sometimes enclose small xenoliths of diorite. This type of relation between porphyries and diorites has, as yet, never been observed in other parts of Norrbotten. For structural and petrographical reasons it is improbable that the diorite above represents a relict of basement formations older than the Veikkavaara Greenstone Group (See also the clastic formation at Meraslinkka p. 19.). It is probable that this diorite was emplaced after the deposition of the Pahakurkio Group and before the emplacement of the Prophyry Group. It apparently belongs to the Kangos Diorite This problem is again discussed on p. 47.

The aeromagnetic map indicates that the porphyries apparently occur in the core of a tight synform with axial plunge to the north and that they

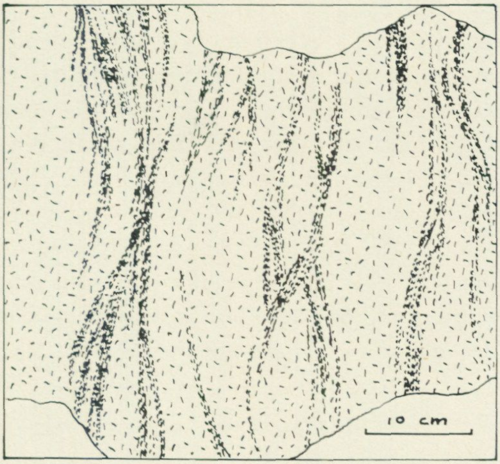

Fig. 14. Complex and irregular banding between a fine-grained pink porphyry (thin bands), and a pyroxene-bearing grey porphyry. Exposure north-west of Laulajavaara.
Oregelbunden banding i porfyr, nordväst om Laulajavaara.

are bordered by rocks of the Pahakurkio Group. Biotite-schist relicts are commonly enclosed in the porphyries. Their schistosity is parallel to the sub-banding of the porphyries thereby indicating a possible concordant (synkinematic) emplacement of the latter.

2 – PORPHYRIES OF THE VIVUNGI BASIN

The interpretation of this area (Lainio north-west), almost devoid of exposures, is highly hypothetical. The geological boundaries have mainly been drawn with the help of aeromagnetic maps.

The principal feature of the aeromagnetic map Lainio north-west is a north-south-elongated, large, rounded and regular structure. It has been interpreted as a basin according to magnetic dip-directions (See p. 73.). Except for the occurrence of a few perthite monzonite exposures (6c, 7c, 8e), this area is devoid of exposures. The aeromagnetic map indicates, however, hat it is highly improbable that this major structure is occupied by only one rock-type. Three drill-holes have therefore been emplaced in regions presenting interesting magnetic anomalies (Vivungi

5e, 6d and Lainio 6f). Samples from these drill-holes have shown the presence there of a complex succession of rocks of volcanic or hypabyssal origin, mainly magnetite-rich meta-dolerites, andesites and porphyrites, of intermediate- to basic-composition. These types of rocks are known to be commonly associated with more acid facies of the Porphyry Group in the Kiruna map-sheet (Offerberg op. cit.) and in the Fjällåsen map-sheet (28J, observations made by the author.). Although no acid porphyry has actually been encountered in the drillings mentioned above, their presence can be inferred by the occurrence of local boulders of pink acid volcanics and porphyries, and of granodiorite boulders enclosing sometimes xenoliths of andesite and syenite porphyry (Vivungi-Lainio road).

According to M. Ambros, a few scattered porphyry exposures occur on the map-sheet 30L Lannavaara in the area situated directly to the north of the Vivungi basin and further to the west. Furthermore, a small andesite exposure together with many local porphyritic boulders have been discovered at Saarivaara (9c) on the northern border of Lainio north-west.

From a structural and stratigraphical point of view, the presence of porphyries in the Vivungi basin, overlying meta-sediments of the Ruutivaara and Pahakurkio Groups, fits very well with the general stratigraphical sequence established in Norrbotten. The main rock-types encountered in the Vivungi-Lainio region are briefly described below.

Porphyrites are made up of a dark green hornblende matrix containing elongated andesine-labradorite laths (0,5 to 2 cm in length). In contrast to the gabbros found in the area investigated augite, when present, does not display interstitial habits towards plagioclase but is found as subhedral crystals. Magnetite represents in some case as much as 20⁰/₀ (vol. ⁰/₀), easily explaining the rather high magnetic anomalies corresponding to these rocks.

Magnetite-rich *andesites and dolerites* are both found in drill core samples and as xenoliths in local boulders of granodiorite. The rock is generally fine-grained and the texture is doleritic or porphyritic though generally much obscured by metamorphism. As in the case of porphyrites, magnetite is abundant (as much as 20 vol. ⁰/₀) and occurs as minute disseminated crystals. The composition of the plagioclase ranges from oligoclase-andesine to labradorite. Besides magnetite, green hornblende, actinolite and biotite are the main dark minerals. Magnetite is sometimes

Fig. 15. (Normal light x 20.) Pyroclastic rock from a drill-hole in the Vivungi region. Mineral- (mainly augite) and rock-fragments are enclosed in a rather fine-grained chlorite-magnetite-feldspar groundmass. Muscovite and biotite are also present in the groundmass. D = diorite fragment.
Pyroklastisk bergart ur borrhål från Vivungiområdet.

concentrated in bands. Actinolite displays, in some cases, a rather good preferred orientation.

Xenoliths of *syenite porphyry* are enclosed in local boulders of granodiorite (of the Porojoki type) along the Vivungi-Lainio road and along the wood-road going to the south, between Vivungi and Lainio. It consists of rectangular perthitic microcline phenocrysts in a dark matrix mainly made of green hornblende.

A *pyroclastic basic rock* consisting of non-deformed augite, plagioclase and rock-fragments enclosed in a fine-grained chlorite-plagioclase groundmass (Fig. 15), makes up a few centrimetres of the core samples from the Vivungi region. The plagioclase is andesinic. Magnetite is abundant (10–15 vol. %) and occurs as somewhat large crystals often surrounded by a thin zoisite rim.

All of the rock-types described above contain a high apatite percentage. Apatite occurs either as elongated needles or as rather large crystals making up about 10 vol. % of the rock.

F – METAMORPHISM OF SUPRACRUSTAL ROCKS AND ITS RELATION TO THE EMPLACEMENT OF PLUTONIC ROCKS

In a general way, the grade of metamorphism and the main metamorphic mineral parageneses of the supracrustal rocks found are in many places the same as those described in the Tärendö map-sheet (Padget 1970). The regional metamorphism in the Tärendö map-sheet is characterized by mineral parageneses belonging to the *almandine-amphibolite facies* and to the *staurolite-almandine sub-facies* according to the classification of Turner and Verhoogen (1960). Although this is also true for most of the southern part of the area investigated, lower-grade mineral assemblages of the *greenschist facies* are commonly observed in intermediate- to basic-composition rocks of the Veikkavaara and Ruutivaara groups. The highest grade of metamorphism found in the Lainio map-sheet is apparently represented by the sillimanite-bearing schists and gneisses belonging to the Pahakurkio Group (See p. 26.), exposed in the southwest part of the map.

Plutonic rocks, mainly granites and diorites, are widespread in the Lainio map-sheet. The extensive development of hybrid types containing supracrustal relicts indicates, however, that the supracrustal rocks were certainly widespread before the emplacement of plutonic rocks. It seems as though the actual surface of erosion coincides more or less precisely with the *roof of granitization* (sensu lato) and supracrustal rocks probably disappear rapidly with depth due to their assimilation by plutonic rocks. Supracrustal relicts of small dimensions are generally strongly assimilated while larger fragments are almost always cut by a complex and dense network of granite veins. The study of supracrustal rocks is thus rendered difficult here by the important compositional and textural modifications to which they have been subjected during the emplacement of the plutonic rocks. It must be emphasized here that, when dealing with the chemical or petrographical characters of these rocks, the possibility of a late "pollution" due to *endo- exomorphic-reactions* or to *metasomatism,* must always be seriously taken into consideration. This is also true for radiometric age-determinations which may be later performed on some rocks of this area and especially for those which are in any way related to the potassium content of the rock for, as we will see later, microcline often presents metasomatic characters.

1 – METAMORPHISM OF BASIC ROCKS

It is a well-known fact that there exists, in basic volcano-sedimentary complexes, a metamorphic convergence between rocks of different origin. For example, medium-grade metamorphism of carbonate-bearing sediments often gives the same mineral parageneses as metamorphism affecting basic intrusives and effusives. In the area investigated, metamorphism of gabbros and dolerites is widespread and is mainly characterized by the development of uralite, epidote-saussurite, fibrous amphibole, chlorite and sericite (greenshist facies assemblages), mainly at the expense of plagioclase and pyroxene. If this type of metamorphism reaches completion, the result will generally be amphibolites or greenschists with very irregular textures. Amphibole and biotite have a strong tendency to gather in rather large crystal aggregates thus further destroying the original texture.

Besides the types of metamorphism described above, basic intrusives and perthite monzonites often display the effects of what will be called here a *pegmatoidal metamorphism.* This is characterized by a late crystallization of large, clear amphibole and biotite poikiloblasts and sometimes magnetite.

2 – THE PROBLEM OF SKARN-FORMATION

The problem concerning the formation of skarn is of great interest both from a geological and from a metallogenic point of view for, as we know, skarns are commonly associated with ore concentrations (mainly magnetite in this part of Sweden). Because of the scarceness of exposed skarn in the area investigated, only a few aspects of this problem will be discussed here. An investigation of drill-cores from the skarn iron-ore of Masugnsbyn has proved to be most useful for understanding the relations existing between skarn and granite. Sharp contacts have often been observed between granite and skarn and only minor mineralogical modifications of the skarn are visible in the direct vicinity of the granite. Furthermore, many granite veins sharply cut the skarn without noticeable contact phenomena. This is in agreement with the fact that the granites of this area are in a general way devoid of metamorphic aureoles of thermal origin (absence of hornfels). It must also be mentioned here that ”skarnic horizons” often occur in such a manner that no direct relation between

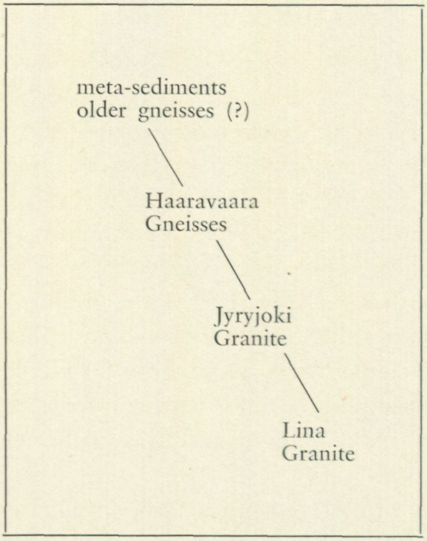

Fig. 16. Migmatitic series observed between different rock-types in the north-east of the map.
Migmatitiska övergångsformer.

them and granites can be established (Sakarinpalo suite, Ruutivaara Group etc.).

These facts indicate that there does not necessarily exist a direct relation between skarn-formation and granite emplacement. It is known from other metamorphic terrains that monoclinic pyroxene can appear under the amphibolite facies of metamorphism and that it is rather common in the almandine-amphibolite facies (Turner and Verhoogen op. cit.). The tremolite-actinolite-diopside skarn found at Masugnsbyn and Merasvaara is thus in equilibrium with the metamorphism prevailing here and described in the beginning of this chapter. It seems reasonable therefore to suppose that the occurrence of skarn is not necessarily related to granite intrusion but may have originated during regional metamorphism. It is the author's opinion that most carbonate-bearing rocks have been transformed to skarn during regional metamorphism and that granite intrusions belong to a much later phase.

3 – MAJOR TRANSFORMATIONS OCCURRING IN ACIDIC SEDIMENTS

Petrography and field investigation made on rocks of the Pahakurkio Group, the Haaravaara Group and the Lina Granite Series have shown that there exists a continuous *migmatitic series* from meta-sediments to granite. This is schematically shown on Fig. 16. All stages of transition between these different rock-types have been observed and no precise delimitation can be established between them. This has been interpreted as the result of a progressive *homogeneization* with depth (For further explanation see Raguin 1957, pp. 250–252.) in which such factors as the original composition of the rock, the geochemical environment and the level of emplacement have certainly played an important part. This problem is more thoroughly discussed in the chapters dealing with the Lina Granite Series.

THE PLUTONIC ROCKS

It is possible to say in a general way that there exists in the map-area a complete petrographic series of plutonic rocks of basic, intermediate and acid composition. Contact relationships indicate that gabbros are older than rocks of intermediate composition which are in turn older than granites. The following rock-types are described in this chapter:

(youngest) – The Lina Granite Series
– The Porojoki Diorite
– Perhite monzonites
– The Kangos Diorite
(oldest) – Gabbros and dolerites

A – GABBROS AND DOLERITES

According to their mode of emplacement the basic plutonic and hypabyssal rocks occurring in the Lainio map-sheet have been subdivided into three categories as follows:

1) Concordant to sub-concordant sheet-like dolerite sills and dykes found closely associated with various greenstones of the Veikkavaara Greenstone Group. As mentioned before (p. 18), some greenstones found in Lainio south-west and south-east display somewhat obscured relicts of a doleritic texture. Dolerites are often referred to as ”diabases” in publications dealing with this part of Sweden.

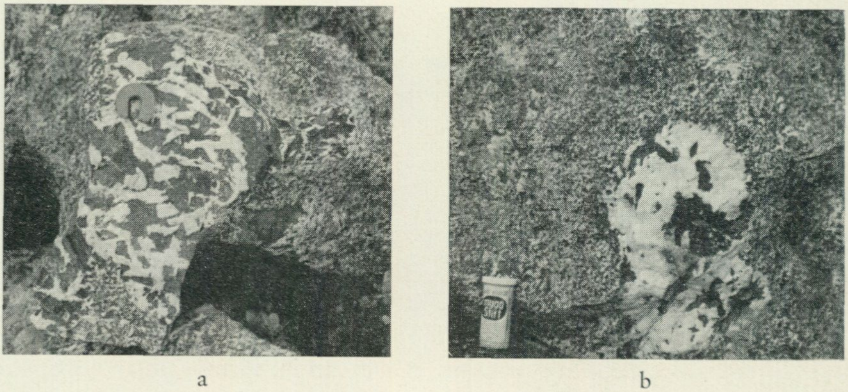

Fig. 17. Gabbro containing irregular coarse-grained parts, exposed at about 5 km to the north-north-west of Kuoksu. A coarse-grained ophitic texture is well developed in *a*. *b* shows a large plagioclase core containing subhedral amphiboles.
Gabbro, delvis grovkornig, NNV om Kuoksu.

2) Gabbro massifs of variable size and shape, but generally rather large, found mainly in regions where diorites of the Kangos type predominate. These gabbro bodies often occur in large marsh-areas and their delimitation has mainly been based on interpretation of the aeromagnetic maps. This chapter mainly deals with this category.

3) Magnetite-rich basic- to intermediate-rocks presenting a relict doleritic texture (dolerites and porphyrites) found in association with the Porphyry Group (See pp. 34, 35.). From aeromagnetic interpretation, they are concordant with the other members of the Porphyry Group and have therefore probably been emplaced as sills during the same volcanic phase as the porphyries. Frequent transitions from basic types to types of intermediate composition are in agreement with this assumption. They often contain more than 10 % magnetite and give rise to characteristic elongated, thin, high anomalies on aeromagnetic maps. The same phenomenon apparently occurs in the Kiruna map-sheet (Offerberg op. cit.).

1 – PETROGRAPHY

Due to their very variable stage of metamorphism the basic intrusives display a wide range of mineralogical and petrographical types. The dolerites are generally more metamorphosed than the gabbros and very sel-

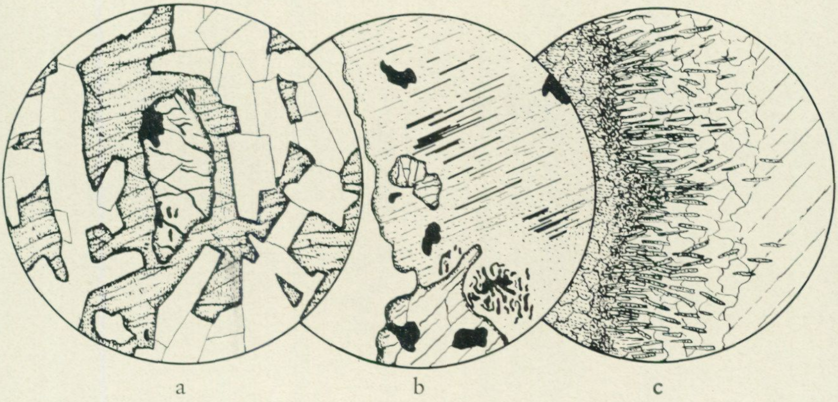

Fig. 18. Gabbro.

a – (Normal light x 15.). Diopside (shaded) containing a clear olivine crystal (center). The texture is ophitic. All of the diopside in the picture presents common optical proprieties. The opaque mineral is magnetite. Square 2a.

b – (Normal light x 65.). Uralite (shaded) containing magnetite inclusions occurring either in cleavage planes, or as "ink-spots" (lower right) in less coloured parts. The clear, fractured mineral is diopside. Square 4b.

c – (Normal light x 65.). Boundary between a granular hornblende aggregate (to the left) and a large plagioclase (to the right). Actinolite needles penetrate a zone consisting of finely recrystallized plagioclase. Square 4b.

Gabbro.

a) Olivinförande gabbro (2a).

b) och c) Metagabbro (4b).

dom contain rests of pyroxene. The average gabbro is medium-to-coarse-grained, dark violet and often contains large biotite flakes.

About 5 km to the north-north-west of Kuoksu, peculiar coarse-grained zones and "cores" occur in a gabbro. They often display an ophitic texture (Fig. 17a) and contain large crystals of light blue apatite, titanite, pyrite and minor chalcopyrite.

Microscope investigation of various types of gabbro permits the following general remarks to be made about their mineral content. The *plagioclase* forms large subhedral elongated crystals displaying zoned extinctions under polarized light. Scapolitization, saussuritization and sericitization are the principal types of alteration. Labradorite or bytownite are the most common types. The *amphibole* is mainly green hornblende. During metamorphism, uralite, actinolite and tremolite were formed. They often contain a large quantity of small disseminated magnetite crystals

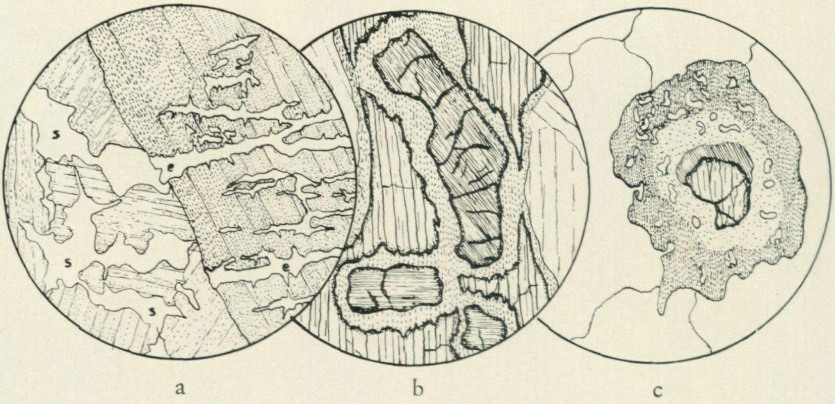

Fig. 19. Gabbro.

a – (Normal light x 15.) Epidote veinlets (e) and scapolites (s), product of the alteration of plagioclase (shaded). Square 4b.

b – (Normal light x 65.) Hypersthene (fractured and tightly cleaved) surrounded by an uralite rim (shaded), enclosed in a large augite crystal. The clear mineral is plagioclase. Square 1d.

c – (Normal light x 65.) Complex alteration-rim around an augite crystal (center) composed of the following mineral succession from the center towards the border: biotite (shaded), light coloured uralite, dark coloured uralite. Square 9a.

Gabbro. Olika omvandlingsformer.

a) (4b) Skapolit- och epidotomvandling hos plagioklas.

b) (1d) och c) (9a) Uralitisering.

and have a tendency to gather in crystal aggregates together with biotite and other dark minerals. Large clear hornblende and biotite poikiloblasts are the products of a later pegmatoidal metamorphic phase (See p. 37.). The *pyroxene* is mainly represented by augite, less commonly by diopside or hypersthene. Monoclinic pyroxene always shows interstitial habits towards the plagioclase. This is not the case for hypersthene which generally forms somewhat elongated, reddish-brown, subhedral crystals (Fig. 19b). Pyroxenes of both types are generally strongly uralitized (Fig. 19b, c) and sometimes contain magnetite inclusions arranged in complex patterns. A first generation of *biotite* is represented by small dark brown flakes. A second generation is represented by greenish-brown flakes found together with uralite and magnetite, often forming complex rims around pyroxene (Fig. 19c). The poikiloblastic flakes belonging to the pegmatoidal metamorphic phase can reach a few centimetres in length.

1st generation rock-building phase	2nd generation metamorphic phase	3rd generation pegmatoidal phase
apatite		
magnetite	magnetite	
olivine (rare)	serpentine (rare)	
hypersthene	uralite biotite magnetite	
plagioclase	sericite saussurite	
augite diopside	uralite biotite magnetite	
hornblende	actinolite saussurite	large green-hornblende and biotite poikiloblasts and crystal aggregates
biotite	biotite	

Fig. 20. Schematical mineral succession in gabbros and dolerites from microscope observation.
Kristallisationsföljden i gabbro och diabas.

Olivine has only been found in gabbro relicts enclosed in a granodiorite about 4 km to the north of Naankitunturi. Well-preserved olivine crystals are often enclosed in diopside (Fig. 18 a) and contain, in place, disseminated opaque minerals. *Magnetite* and *apatite* are the two most common accessory minerals, the former occurring either as small, well-formed crystals probably belonging to a first generation, or as minute inclusions in augite, hypersthene or uralite, of a second generation. Magnetite crystals, when large, are often surrounded by a thin titanite rim. *Scapolitization* and sericitization affect gabbros in a very irregular manner and often proceed along microfractures thereby indicating their relation to a rigid deformation phase.

2 – MODE OF EMPLACEMENT

Contacts between gabbros and other rock-types are rare in the map-sheet, mainly because gabbros generally occur in marshes (Ainettivuoma, Ripakaisenvuoma etc.) where geological observations are extremely scarce. The problem concerning the delimination of gabbro massifs is therefore difficult and mainly depends on aeromagnetic data.

Field investigation has shown that there exists a close relationship between rocks of the Veikkavaara Greenstone Group and metamorphic basic intrusives of the first category described earlier in this sub-chapter (p. 39). This impression is strongly confirmed by microscope observation showing similar mineral assemblages and many transitional stages between greenstones and basic intrusives. It seems therefore reasonable to suppose that the basic intrusives (dolerites) occurring within the Veikkavaara Greenstone Group are the hypabyssal components of a basic intrusive-effusive volcanic complex. No known facts are in disagreement with this hypothesis which permits the simplest explanation of the geological, petrographical and structural affinities between these different rock-types. The predominance of sill-type intrusions would account for the concordant position of many dolerites.

Gabbros of the second category defined earlier (p. 40), generally forming large massives, are mostly found in regions where diorites of the Kangos type predominate. No known contacts with supracrustal rocks have been found in the area investigated. In all cases where contact relationships between gabbros and diorites have been observed, gabbros have been found to be older than rocks of intermediate composition. Except for this fact and for the fact that they are commonly cut by granite and pegmatite veins of the Lina type, it is rather difficult to deduce their relative time of emplacement. Field investigation has shown the gabbros to be structureless. The aeromagnetic maps indicate, however, that when large bodies are considered, somewhat regular magnetic ”zones” and patterns can often be observed. In a general manner, these zones are quite regular and lie parallel to the border of the gabbro massifs and to magnetic features observed in the host-rocks. Furthermore, aeromagnetic maps covering larger parts of Northern Sweden show that many gabbro massifs are elongated in the same direction as the foliation or compositional banding of the host rocks. These observations are in favor of an emplacement contemporaneous to tectonic deformation. The intense metamorphism of many basic intrusives could thus be the result of a certain pressure-temperature disequilibrium existing during their emplacement.

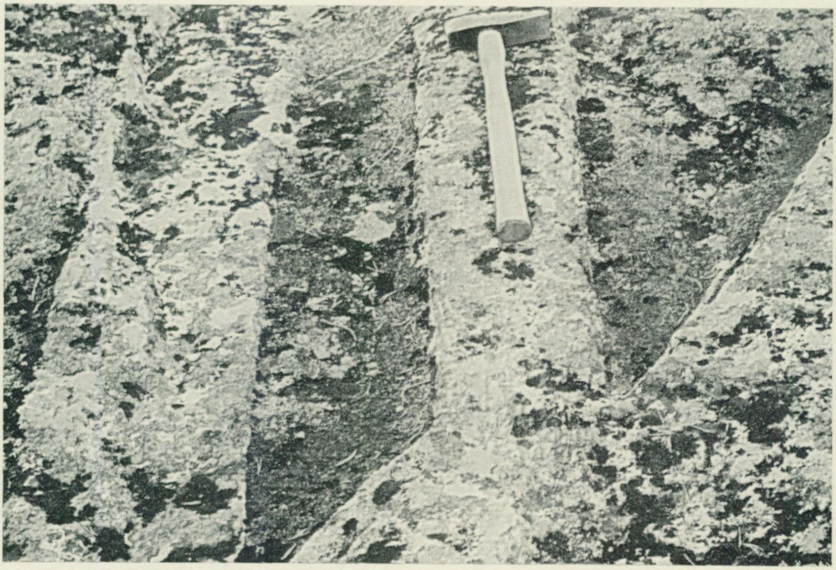

Fig. 21. A diorite of the Kangos type is sharply cut by a system of lighter pegmatoidal granite veins (Lina Granite type) at Meraslinkka.
Kangosdiorit genomsatt av granitådror. Meraslinkka.

This could also explain the relative scareness of noritic or olivine-bearing types in the area investigated.

In the Ripakainen gabbro (8a, 9a) there occurs a small number of perthite crystals closely resembling those found in the perthite-monzonite described in the next sub-chapter. This indicates a possible genetic relation existing between these two types of rocks. No contacts between the two have, however, been observed.

Basic rocks belonging to the third category defined earlier (p. 40) are described together with other rock-types of the Porphyry Group (See pp. 34, 35.). They are believed to be somewhat younger than the gabbros described above.

B – THE KANGOS DIORITE

Kangos is a village situated on Lainioälven, in Lainio SO. The type locality is to be found on the western slopes of the hill Akavaara, along the road parallel to the eastern bank of the river, opposite Kangos.

Being poorly exposed in the area investigated, this rock-type has mainly been delimited with the help of aeromagnetic maps. This is particularly true for the two large massifs found at Ainettivuoma (SO) and at Ripakaisenvuoma (NV). The magnetic anomalies corresponding to these diorites are situated (in intensity) between the rather high anomalies corresponding to gabbros and the low anomalies corresponding to granites. The magnetic patterns are generally complex and no distinction can be made on aeromagnetic maps between different types of intermediate-composition rocks.

1 – PETROGRAPHY

The texture of the Kangos Diorite is characteristic and has permitted to differentiate this rock-type from other rocks of intermediate composition. It consists of randomly orientated plagioclase laths enclosed in a darker amphibolic groundmass. In order of importance, the principal petrographic types represented are: dioritic monzonites, monzonites, diorites and quartz-diorites. The average rock-type is medium-grained, grey to greyish-violet and composed of subhedral plagioclase (57 %), microcline (17 %), green hornblende (15 %) and biotite (6 %). Quartz can be present. The presence of strongly uralitized pigeonite has been observed in one case. The composition of the *plagioclase* varies from albite to andesine, the average being an oligoclase containing between 15 and 25 % anorthite. Moderate sericitization is common. *Microcline* occurs mainly as large poikiloblasts with or without crystal boundaries, often displaying assimilative habits towards the plagioclase (See Figs 52, 53.). The main accessories are: *titanite, magnetite, apatite* and *sericite*. *Quartz,* when it occurs, is interstitial.

2 – MODE OF EMPLACEMENT

Contact relationships of the type shown in Fig. 21 are common and indicate that these diorites are invariably older than the Lina Granite. At Meraslinkka (2e), it is possible to observe every stage of transition between amphibolites of the Veikkavaara Greenstone Group and diorites of the Kangos type. This phenomenon, which has also been observed in some other places, as well as the strong assimilation of basic xenoliths, points to the important *endomorphism and exomorphism* which have certainly accompanied the emplacement of these diorites.

From aeromagnetic interpretation and field evidence it has been established that the Kangos Diorite is essentially found in the direct vicinity of gabbros which it apparently surrounds totally. Apart from the rare occurrence of a sub-ophitic texture in the diorite, the present investigation has not found transitional stages between rocks of the Kangos type and gabbros. In every case where these two rock-types are found together, the diorites invariably enclose xenoliths of the basic rock thereby indicating their younger age. It is not impossible, however, that at deeper levels of the crust there exists transitions from one type to the other. In this case, the Kangos diorite could find its origin in a late differentiation stage having occurred in gabbroic magmas. This could explain the relationships observed between these two rock-types (See above.).

Rocks of the Kangos type present characters suggesting a magmatic origin. These are mainly: subhedral plagioclases displaying zoned extinctions under polarized light, a slight sub-ophitic tendency in places (See above.) and a rather constant grain-size and mineralogical composition. According to observations made in the Pre-Cambrian of West-Africa by Bodin (1951), post-tectonic intrusive rocks of magmatic origin are generally characterized by a hypidiomorphic, non-orientated texture (the ”plagidiomorphic” texture of some French authors) and by a granodioritic or dioritic composition. This description corresponds rather well to the Kangos Diorite. Furthermore, the absence of concordant sheet-like intrusions and the absence of border migmatites are also facts pointing to a late- to post-tectonic emplacement of the Kangos Diorite.

The description above indicates that the Kangos Diorite is part of the *Haparanda Granite Series* defined in earlier publications (Ödman 1957). The term ”Haparanda Granite Series” has however often been used as field-term covering many plutonic rocks of basic, intermediate and acid composition of undetermined origin which are possibly of different ages. It has therefore been avoided in the present description.

In the region situated to the north-west of Laulajavaara (1g), diorites presenting characters of the Kangos type are locally cut by porphyries of intermediate composition (See pp. 31–33.). The porphyries also enclose in places a few small diorite xenoliths. This has led to the conclusion that *a certain plutonic activity of intermediate composition has occurred between the time of deposition of the sedimentary groups (Veikkavaara, Pahakurkio and Ruutivaara groups) and the emplacement of the porphyries.* This assumption is also based on preliminary results from radiometric (Rb/Sr) age-measurements which give for the Haparanda Granite

Series a definitively older age (1880 m.y. ±50) than for the porphyries at Kiruna (1610 m.y. ±65). These measurements have been made by Welin on rocks of the Haparanda and Kiruna map-sheets. The occurrence in 30L Lannavaara of an uncomformity between the sedimentary groups (See above.) and the porphyries (oral communication by Ambros) strengthens the interpretation above.

The Q-Pl-M diagram and other diagrams are presented on Figs 27–29, where the Kangos Diorite and the Porojoki Diorite have been grouped for comparison.

C – PERTHITE MONZONITES

Perthite monzonites are best exposed in the long Viksvaara-Vinsavaara-Hulmeenvaara-Laulajavaara massif situated in the south-east part of the map. They are also well-exposed along the banks of Lainioälven (4i) where they form a smaller, north-south-elongated massif corresponding exactly to a rather high magnetic anomaly on the aeromagnetic map. Poorly exposed massifs of perthite monzonite have been discovered in the north-west part of the map (Pasmavaara, Huhtalompolo etc.). Their boundaries have mainly been determined with the help of aeromagnetic maps.

Perthite monzonites are relatively homogenous rocks which present particular petrographic characters easily distinguishing them from the other rock-types of this map-sheet. The term *"monzonite"* is here preferred to the term *"syenite"* used formerly to designate them because they are made up of approximately the same amount of microcline and plagioclase (albite to andesine) and are devoid of quartz. Perthite monzonites have already been thoroughly investigated by Geijer (1931). From a petrographical point of view, they represent the most interesting plutonic component of the region.

1 – PETROGRAPHY

Macroscopically, perthite monzonites are mainly of two types: a pink variety containing mainly perthite and amphibole and a darker, purplish-grey variety containing a certain amount of pyroxene. Measurements for point-counting purposes are rather difficult to make, even on stained sections, because of the high complexity of the perthites. Perthite monzonites are found in a well-delimited and characteristic area on the Q-Pl-M diagram (Fig. 26).

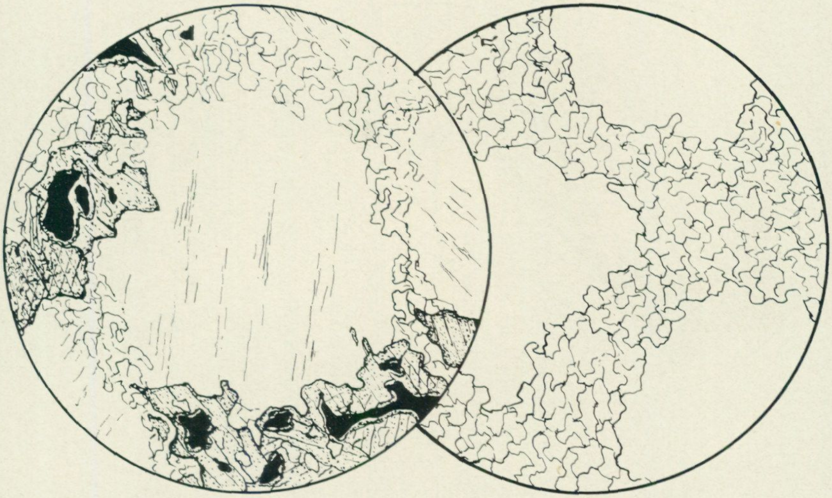

Fig. 22. (Normal light x 18.) Two examples of compartimented textures observed in pethite monzonites. Perthite cores displaying sutured boundaries are surrounded by a sutured fine-grained groundmass. Square 4i.
"Cloisonnée"-textur i pertitmonzonit.

The average rock-type is medium-to-somewhat-coarse-grained and consists mainly of perthite (70 %), amphibole (10 %), pyroxene (7 %, not always present), biotite (5 %) and many disseminated accessories. The texture is generally granular, very irregular and sutured perthite boundaries are common. A partial granulation or "*compartimented texture*" (Fig. 22) has been observed in places.

The study of more than 30 thin sections, 8 of which have been stained with sodium cobaltinitrite for mineral estimation purpose, permits the following remarks to be made. The *perthites* are made up of complex intergrowth of microcline and plagioclase and represent from 60 to 80 % of the mineral content of the monzonites. Typical perthitic and antiperthitic intergrowths are thoroughly described by Geijer (1931). Many samples from the Viksvaara-Laulajavaara and Lainioälven massifs display irregular plagioclase "cores" surrounded and more or less corroded by microcline in such a manner that it seems evident that microcline has crystallized later than the plagioclase (Fig. 23a). This is confirmed by patterns observed on stained sections in which the corrosion of the pla-

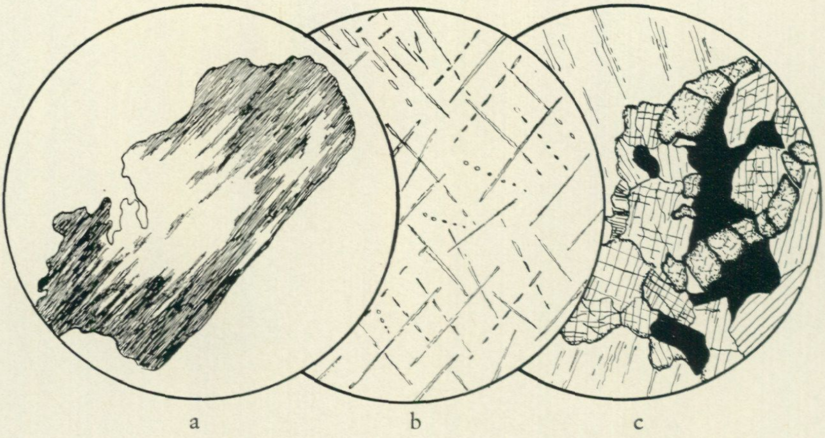

Fig. 23. Perthite monzonites:

a – (Crossed nicols x 15.) Perthite crystal displaying a strongly corroded plagioclase core (clear). Square 4i.

b – (Normal light x 350.) Typical perthite crystals showing under high magnification a dense lattice of rutile needles disposed preferentially along three planes. Square 4i.

c – (Normal light x 15.) Interstitial late-crystallization habit of magnetite. The clear mineral is perthite. The well cleaved minerals are augite and hornblende and the fractured, elongated crystals are apatite. Square 4i.

Petitmonzonit (4i).

gioclase by microcline is evident (Fig. 24 a). The plagioclase varies in composition from an albite to an andesine. The *amphibole* (2 to 19 %) occurs in various ways. A first generation is represented by green to green-blue hornblende. The main alteration product of pyroxene is a light green to brownish-green uralite often enclosing minute magnetite inclusions. Large hornblende poikiloblasts with inclusions of perthite, biotite, magnetite and apatite have crystallized during a pegmatoidal phase (See p. 37.). They often form crystal aggregates together with biotite and magnetite. The *pyroxene* (0 to 16 %) is mainly represented by augite. It is generally strongly uralitized and some crystals display well-developed 100 cleavages. Hypersthene is less common and has, as yet, only been observed in the Veikkavaara-Laulajavaara massif. It is weakly coloured reddish-brown and is often more or less uralitized. Biotite is another alteration product (Fig. 24b). *Biotite* (0 to 12 %) occurs either

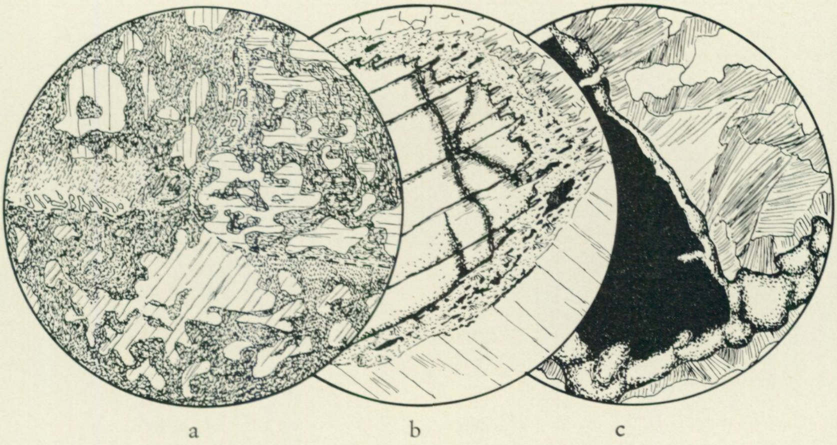

Fig. 24. Perthite monzonites.

a – (Normal light x 15.) Stained section showing partly three plagioclases (clear) strongly replaced by microcline (stained). Square 4i.

b – (Normal light x 35.) Hypersthene (clear and fissured) surrounded by an alteration-rim of biotite and sericite (shaded) containing minute magnetite inclusions. Biotite flakes are developing perpendicularly to fractures in the pyroxene. Square 0h.

c – (Normal light x 50.) Magnetite (black) is surrounded by a titanite rim, surrounded itself by a biotite-chlorite rim. Square 4i.

Pertitmonzonit (4i, 0h, 4i).

as small flakes in association with magnetite, titanite and chlorite (Fig. 24c) or as large poikiloblasts of the pegmatoidal phase. The latter often reach a few centimetres in length. Some accessory minerals occur in a manner which is characteristic for perthite monzonites and will therefore be briefly described. *Magnetite* (up to 7 %) is the principal accessory and its abundance accounts for the high magnetic anomalies corresponding generally to this type of rock. It is very frequently surrounded by a thin titanite rim (Fig. 24c) and less frequently by a biotite-chlorite rim. It occurs in three different ways: a first generation of small, well-formed crystals, a second generation of minute inclusions in uralite and biotite, and a third generation of rather large interstitial crystals (Fig. 23c) with hornblende-biotite crystal aggregates of the pegmatoidal metamorphic phase. *Apatite* (up to 5 %) is generally found as large, broken and elongated crystals. It is apparently the first rock-forming mineral to have

1st generation rock-building phase	2nd generation metamorphic phase	3rd generation pegmatoidal phase
apatite		
magnetite		
rutile		
hypersthene augite	uralite biotite magnetite	
hornblende		
biotite	chlorite	large green-hornblende and biotite poikiloblasts, crystal aggregates and interstitial magnetite
perthite	sericite saussurite	
(quartz)		

Fig. 25. Schematical mineral succession in perthite monzonites from microscope observation.
Kristallisationsföljden i pertitmonzonit.

crystallized. *Rutile* is almost always present and forms a dense lattice of very small needles in perthite crystals (Fig. 23b). On account of the high amount of titanite and rutile in perthite monzonites, they show the highest titanium content of all rock-types investigated in the Lainio map-sheet (See Fig. 66.). *Quartz* is rare in the perthite monzonites occuring in the southern part of the map. Exposures of quartz-bearing perthitic rocks have been discovered in the north-west part of the map though they are limited in extent. Quartz always occurs interstitially to the perthitic minerals. *Scapolitization* is well developed in the small massif situated a few km to the west of Kurkkio (1e).

2 – MODE OF EMPLACEMENT

Along Lainioälven, perthite monzonites are frequently cut by red pegmatites belonging to the Lina granite. The absence of exposed contacts with other rock-types makes it difficult to determine with precision the place

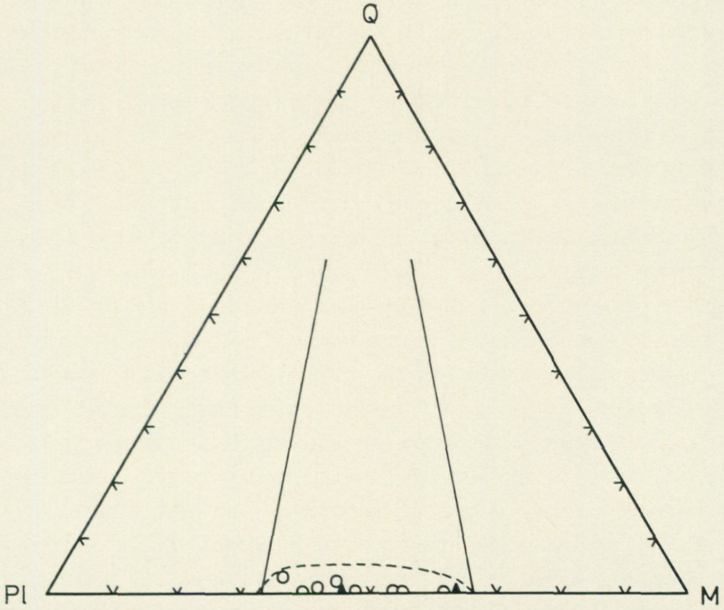

Fig. 26. Quartz-plagioclase-microcline diagram for perthite monzonites (o). Porphyries found in the direct vicinity of perthite monzonites are shown for comparison (▲).
Kvarts-plagioklas-mikroklindiagram för pertitmonzonit.

of the perthite monzonites in a chronological order of events. Other types of observation permit, however, their relative time of emplacement to be deduced.

Rapid and large variations in the composition of the plagioclase are common. Variations of more than 30 % in the anorthite content of distinct plagioclases of the same thin section have been observed. Large variations also occur in single crystals. The rock-forming minerals often show important border-reactions, colour variations and many other optical irregularities. These facts, together with the presence of an infinite variety of complex perthitic and antiperthitic intergrowths, point to an important chemical and physical disequilibrium probably contemporaneous with the main rock-forming phase. Moreover, the occurrence of a well-developed metamorphism could be the result of a constant readjustment of these rocks to varying conditions during their crystallization.

Most of the observations above are better understood if it is supposed that the emplacement of perthite monzonites occurred during a phase of tectonic deformation. A certain number of facts are in agreement with this assumption. The boundaries of the north-south elongated Viksvaara-Laulajavaara massif are apparently concordant with the layering of the Veikkavaara greenstones (from aeromagnetic interpretation and by analogy with the better-exposed area situated to the south, in the Tärendö map-sheet). The rather well-exposed Lainioälven massif (4i) also appears, from aeromagnetic interpretation, to be concordant with the host foliated granite. The aeromagnetic map (north-west) indicates that the perthite monzonite exposures found at Pasmavaara (6c) and further to the north (7c), belong to the same horizon which lies concordantly within the large Vivungi basin (See p. 73.). Furthermore, the compartimented textures figured above (Fig. 22) as well as the highly sutured crystal boundaries of perthites are known to be generally related to migmatitic rocks (Jung and Roques 1952) and are also known to occur in highly stressed rocks of the synkinematic type (Witschard 1965). Mineral deformations are also visible and a particular type of antiperthite strongly suggests that it is due to micro-fracture filling of microcline by albite.

When all the above facts are taken into consideration, it is possible to infer that the most probable mode of emplacement of perthite monzonites occurred in the following manner: They were first intruded, in relatively deep-seated conditions, in various formations of the Veikkavaara and Pahakurkio groups and violent folding brought this somewhat fluid mass to higher levels of the crust where normal crystallization conditions no longer existed for minerals having been formed at deeper levels. A constant readjustment to varying pressure-temperature conditions caused continuous changes in the characters and associations of minerals, thus accounting for the facts observed.

Minor occurrences of monzonite porphyry or of andesite have been found in the direct vicinity of perthite monzonite massifs (Vinsavaara-Laulajavaara, Lainioälven, Huhtalompolo). The author has also observed, in the Fjällåsen map-sheet (28J), that coarse- and medium-grained perthites are often closely associated with porphyritic rocks. Furthermore, the presence of concordant perthite monzonites massifs has been established by aeromagnetic interpretation in the Vivungi basin where porphyries apparently predominate. These facts indicate that a genetic relation probably exist between perthite monzonites and porphyries. Due to the scarceness of exposed porphyries in the Lainio map-sheet, this problem cannot be studied further here.

As a rule, potassic feldspar is rather uncommon in hypersthene- and augite-bearing rocks. Two hypothesis would account for its presence in perthite monzonites: 1) *A primary origin of the potassic feldspar*. Perthite monzonites would have originated, in this case, from a hyperpotassic basic magma, possibly as a result of differentiation within a gabbroic type of magma. This assumption is strengthened by the occurrence, in the Ripakainen gabbro, of perthite crystals very similar to those found in perthite monzonites. This has, however, only rarely been observed. 2) *A secondary origin of the potassic feldspar*. In this case it would have been "borrowed" from host rocks (e.g. rheomorphic feldspathic schists or gneisses) in a deep-seated phase during which the original basic magma was in contact with potassium-rich rocks. Widespread endo-exomorphic exchanges would account for the rather homogeneous composition of the perthite monzonites.

It is not possible, in our present state of knownledge, to choose between these two different hypotheses which both have the advantage of making potassium appear at an early stage of the formation of the perthite monzonites.

A third hypothesis whereby the potassic feldspar was brought in by potassium metasomatism related to the emplacement of the Lina Granite has here been abandoned because, in the area investigated, phenomena of this type always give rise to highly heterogeneous rocks. The rather homogeneous composition of the perthite monzonites, together with the very unstable characters of their constituant minerals, plus many other typical petrographical features of these rocks, do not find a satisfactory explanation in this hypothesis.

In a general manner, it seems reasonable to infer that although microcline has crystallized somewhat later than the plagioclase in most cases, the presence of perthitic and antiperthitic intergrowths of the type called "eutectoperthites" by Geijer (1931) indicates that potassium was present during the main rock-building phase, and cannot therefore be considered as a late-comer.

D – THE POROJOKI DIORITE

Porojoki is a small tributary of Lainioälven situated in Lainio SO in an area where diorites of the Porojoki type are well exposed.

The Porojoki Diorite is almost always found together with younger dykes, veins and small massifs of Lina Granite and pegmatites. In order to simplify, the later are not figured on the map in dioritic areas.

These rocks have often been referred to as ”syenites” in previous publications but this term is incorrect and should be abandoned. According to the terminology adopted here (Fig. 3), all plutonic rocks of intermediate composition found in the Lainio map-sheet present a strong ”dioritic” tendency with a predominance of plagioclase (oligoclase 15 to 25 % anorthite) over microcline. This is evident on Fig. 27 where the Porojoki Diorite and the Kangos Diorite have been placed on the same Q-Pl-M diagram for comparison.

1 – PETROGRAPHY

The average rock-type is pink, medium-grained and composed of plagioclase (52 %), microcline (14 %), green hornblende (17 %), quartz (7 %) and biotite (7 %). The texture is granular and very irregular. In places, the plagioclase presents a slight hypidiomorphic tendency, but never as well developed as was the case for the Kangos Diorite. The principal petrographic types represented are, in order of importance: diorite, granodiorite, dioritic monzonite, monzonite and quartz-monzonite. A preferred orientation of the dark minerals is rather common. When present, this foliation is generally parallel to dark schlieren possibly representing strongly assimilated relicts. The composition of the *plagioclase* varies from albite to andesine but is generally an oligoclase 15 to 25 % anorthite. *Microcline* is poeciloblastic and often replaces more or less the plagioclase (Fig. 50). The *amphibole* is green hornblende and it presents a

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Fig. 27. Quartz-plagioclase-microcline diagram for diorites and granodiorites.
+ = Kangos type, o = Porojoki type.
Kvarts-plagioklas-mikroklindiagram för diorit och granodiorit.
+ = Kangosdiorit, o = Porojokidiorit.

Fig. 28. Feldspar composition diagram.
Diagram över fältspatinnehållet.

Fig. 29. Quartz-plagioclase diagram.
Kvarts-plagioklasdiagram.

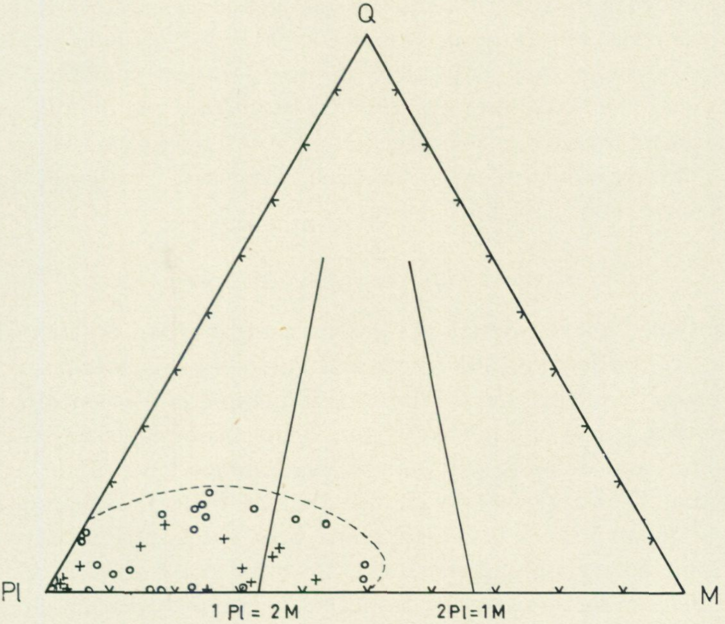


Fig. 27

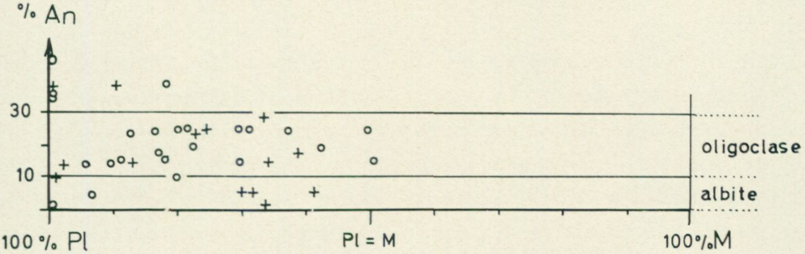


Fig. 28

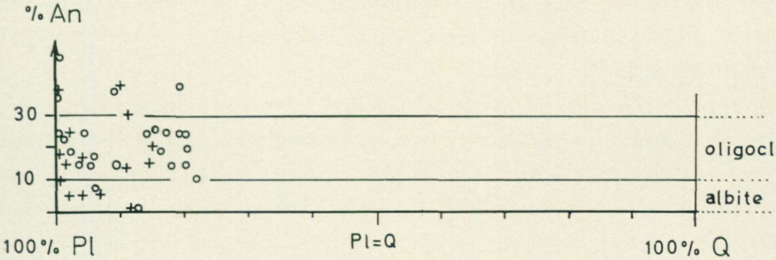


Fig. 29

strong tendency to gather in large crystal aggregates together with other mafic minerals. *Biotite* occurs mainly in crystal aggregates mentioned above. The main type is a greenish-brown variety sometimes rather chloritized. The accessories are: *titanite, magnetite, apatite* and *sericite.*

Cataclastic textures of the type presented in Figs 47 and 48 are common. They are related to what has been called here ”post-Lina Granite rigid deformation” (See pp. 77–81.).

2 – MODE OF EMPLACEMENT

As mentioned above, some types present a rather good foliation due to the preferred orientation of biotite and amphibole. This foliation is, in most cases, parallel to the compositional banding and schistosity of the surrounding schists and gneisses. More or less assimilated relicts of biotite schists and of basic volcanics or greenstones have often been encountered. They are generally elongated along the main foliation plane.

These foliated types have apparently been emplaced during a phase of tectonic deformation. There exist, however, many non-foliated types whose place in the stratigraphy cannot be determined with any precision. Schematically, it can be inferred that the Porojoki Diorite has been emplaced during a phase of decreasing tectonic activity (late- to post-orogenic phase).

Along the Kuoksu-Lainio road, in the region where this road crosses the Vivungi basin (See p. 73.), local boulders of diorite enclosing well-preserved xenoliths of syenite porphyry have been found (p. 35). This indicates that the diorites are younger than the porphyries.

Microcline occurs in the Porojoki Diorite in such a manner that *potassic metasomatism* is most probable. Therefore, *the area corresponding these rocks on the Q-Pl-M diagram (Fig. 27) was certainly more restricted to the lower left corner (diorite domain) at the time of their emplacement*. Potassic metasomatism is probably related to the emplacement of the Lina Granite Series.

Although the Porojoki Diorite is strongly granitized by the Lina Granite, and that transitional facies between these two rock-types have sometimes been observed (assimilation of the former by the latter), the petrography, petrology, and field evidence indicate that *there does not seem to exist a continuous (genetic) series of rocks from the Porojoki Diorite to the Lina Granite.*

Fig. 30. Sub-horizontally foliated and jointed Jyryjoki Granite along the banks of Parkajoki.
Jyryjokigranit. Längs Parkajoki.

E – THE LINA GRANITE SERIES

The Lina Granite Series is composed of the youngest plutonic rock-units known to exist in the map-sheet. Rocks of this series have been defined and extensively investigated by Geijer (1929, 1931, 1966). It is subdivided here into three main units, presenting each particular petrographic characters and which are:

1 – The Jyryjoki Granite
2 – The Lina Granite
3 – The Perthite Granite

Preliminary results from radiometric (Rb/Sr) age-measurements made on the Lina Granite and on the perthite granite (samples not on the Lainio map-sheet) indicate that these two units are of approximatively the same age (1540 m.y. ±90).

1 – THE JYRYJOKI GRANITE

The Jyryjoki Granite is mainly exposed along the many steep river banks of Lainio NO, especially along Jyryjoki. It is characterized by granites which display an imperfect foliation (relict-foliation) due to the preferred orientation of biotite. On previous maps, it has generally not been differentiated from the Lina Granite but, as we will see later, its petrographic characters indicate that it forms a rock-type distinct from the latter.

In the south-west part of the map, there exist many transitions from the Jyryjoki Granite to various hybrid granites mentioned earlier in this publication (See p. 36.) and a delimitation between these two rock-types is rather subjective. Gradual transitions have also been observed from the Jyryjoki Granite to the Lina Granite on the one hand, and to banded gneisses of the Haaravaara Group on the other hand (See Fig. 16.).

a – Petrography

The Jyryjoki Granite is medium-grained, pink, generally contains less than 10 % biotite and displays a more or less perfect foliation. The main petrographic types represented are, in order of importance: granodiorite, quartz-monzonite, quartz-diorite and dioritic monzonite. A microscope investigation of more than 20 thin sections, all of which have been point-counted, indicates that the average rock-type is composed of plagioclase (47 %), microcline (22 %), quartz (16 %), biotite (9 %) and a few accessory minerals. A comparison with the average Lina Granite (See Fig. 31.) shows that the Jyryjoki Granite is richer in plagioclase and biotite, and poorer in quartz and to a lesser extent in microcline, than the former.

The *plagioclase* is mainly an oligoclase which is sometimes strongly sericitized. *Microcline* is generally poikiloblastic and replaces the plagioclase irregularly. *Quartz* is mostly granular but, in some cases, has recrystallized as somewhat elongated crystal aggregates or "cores" outlining the main foliation. Sutured crystal boundaries and irregular extinctions in polarized light are common. *Amphibole* (green hornblende) is sometimes present and forms large poikiloblasts. *Magnetite* is the principal accessory mineral, the others being: *titanite* and *apatite*. Myrmekites occurring at the boundary between plagioclase and microcline are common.

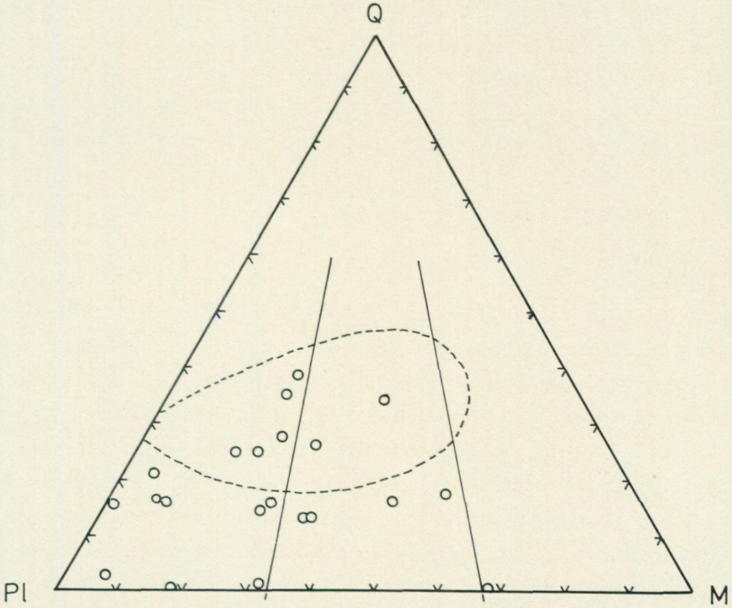


Fig. 31. Quartz-plagioclase-microcline diagram for the Jyryjoki Granite. For comparison, the area limited by a dotted line corresponds to the Lina Granite. *Kvarts-plagioklas-mikroklindiagram för Jyryjokigranit. Området inom den streckade linjen motsvarar Linagranit.*

b – Discussion of the genesis

Large-scale observations are of the greatest help in order to understand the mode of genesis of the Jyryjoki Granite. In Lainio NO, a zoneography around the NNW-SSE elongated Lina Granite massif shows that the granite is bordered by large bands of Jyryjoki Granite. As we go further away from the Lina Granite, the Jyryjoki Granite passes gradually to more or less banded gneisses of the Haaravaara type. The picture is in fact somewhat obscured by a profusion of granite dykes and pegmatite veins sharply cutting the Jyryjoki Granite as well as the gneisses. If however they are not taken into consideration, the relationships given above are valid, and no sharp boundaries can be traced between these types of rocks. We are apparently in the presence of a migmatitic series of the type schematically drawn on Fig. 16.

The Q-Pl-M diagram corresponding to the Jyryjoki Granite (Fig. 31) shows a wide distribution of petrographic types, strongly contrasting with the well-delimited area corresponding to the Lina Granite. The latter, described in the next sub-chapter, has a rather homogeneous mineralogical composition which corresponds roughly to the "normal granite field" (See p. 66.). In the migmatitic series mentioned above, the Lina Granite would correspond to the deepest component, its rather homogeneous composition having been reached in conditions where large-scale chemical exchanges were possible (conditions of anatexis). On the contrary, the wide range of petrographic types corresponding to the Jyryjoki Granite can be explained by the fact that, although these rocks have acquired a granitoidal aspect through recrystallization in relation to metamorphism, they have been less affected by "homogenization" (See p. 39.) than the Lina Granite. Their variable petrographic characters, together with their intimate association and transition to banded gneisses, probably reflects their sedimentary origin. Another fact in agreement with this interpretation is that, in almost every case observed, the foliation of the Jyryjoki Granite is parallel to the schistosity and compositional banding of the surrounding schists and gneisses. As the latter have been found to be generally parallel to lithological boundaries, they apparently reflect in most cases structures of primary origin. The preferred orientation of biotite in the Jyryjoki Granite thus probably represent a *relict-schistosity* of the original rock, rather than being the result of later tectonic deformation. This problem is again discussed in the next sub-chapter.

As mentioned above, there exists a gradual transition from the Jyryjoki Granite to the Lina Granite, the foliation of the former becoming less and less apparent as one approaches large Lina Granite massifs. The Q-Pl-M diagram (Fig. 31) and the chemical analyses corresponding to the Jyryjoki Granite (Fig. 61) indicate that the transformation from the Jyryjoki Granite to the Lina Granite cannot be accounted for only by a simple recrystallization or mineral rearrangement in a closed system, but that it must also have involved extensive *metasomatism*. Petrographic and chemical data agree in indicating that the Lina Granite is richer in silica (or quartz) and to a lesser extent in potassium (or microcline), and poorer in iron (mainly present in biotite and magnetite) than the Jyryjoki Granite (See Fig. 66.). Insufficient data do not permit further speculation on this subject.

2 – THE LINA GRANITE

On account of its resistance to glacial erosion, the Lina Granite is well exposed in the Lainio map-sheet. It either forms somewhat homogeneous massifs of variable dimensions, or occurs as dykes and veins charply cutting all other rocks present. An important pegmatitic phase has accompanied the emplacement of the Lina Granite. Except for a few cases (e.g. Naankitunturi), pegmatites always accompany the Lina Granite. In order to simplify, they have not therefore been figured on the map.

a – Petrography

The great majority are quartz-monzonites, although granites, granodiorites and quartz-diorites also occur ot a lesser extent. The main rock-type is pink, medium-grained and is essentially made up of plagioclase (average 39 %), quartz (31 %), microcline (27 %) and seldom more than 5 % biotite. A gradual transition to the Jyryjoki Granite has often been observed in Lainio NO and consists of a slightly foliated type, the foliation being due to the preferred orientation of biotite. As a rule, the texture is granular and rather irregular.

Pegmatites are mineralogically very poor and are mainly made up of strongly perthitic microcline, plagioclase and quartz. Graphic and micrographic textures are common. At Merasvaara, a local pegmatite displays a few large crystals of black tourmaline. Biotite is sometimes present. Large crystals of magnetite, often well-formed, are not uncommon. Pegmatites are either intrabatholitic or external with respect to the large granite massifs. Irregular and badly delimited pegmatoidal pockets and zones have been observed in most Lina Granite massifs.

A microscope investigation on more than 25 thin sections cut in the Lina Granite allows us to make the following observations. *Quartz* (18 to 43 %) occurs generally interstitially with respect to the plagioclase. It presents the tendency to form elongated cores displaying very irregular extinctions under polarized light. The *plagioclase* (20 to 70 %) is mainly represented by an oligoclase with an anorthite content generally situated between 15 and 25 %. A few samples contain a small proportion of albite. *Microcline* (1 to 45 %) is almost always characterized by late-crystallization habits. It has a tendency to form large and somewhat irregular poikiloblasts (See Fig. 49.) giving rise in some cases to the development

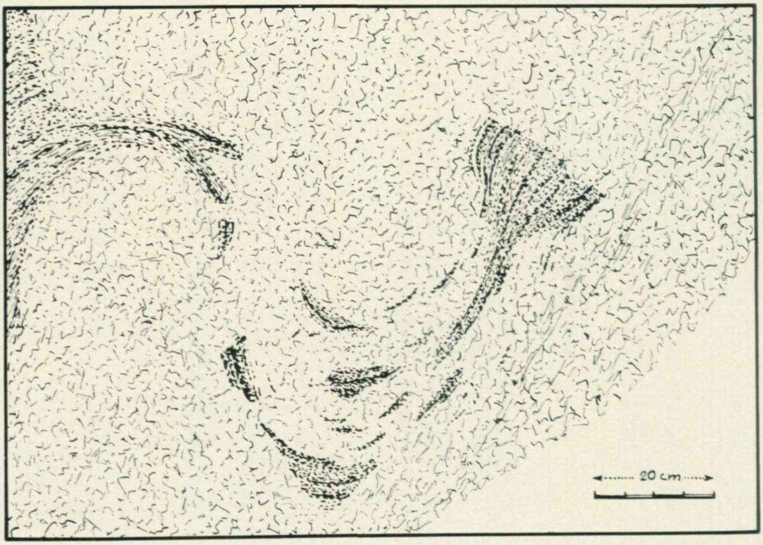


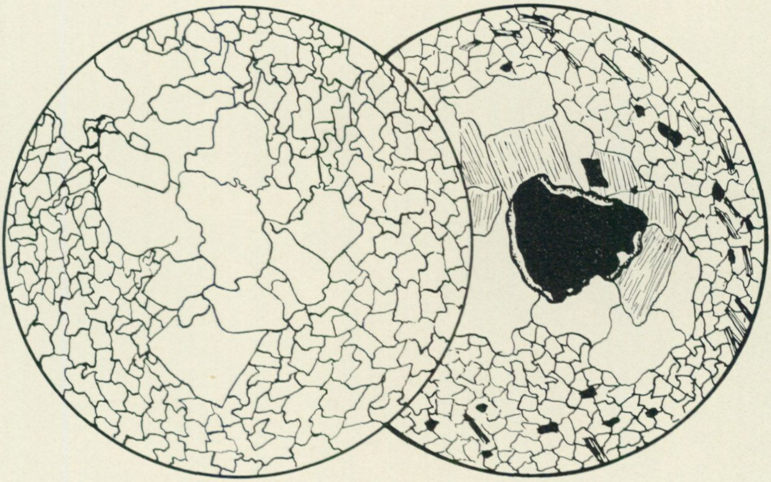
Fig. 32. Undisturbed relicts of folded biotite schists in a pegmatoidal granite vein to the north-west of Paloleuska.
Rester av biotitskiffer i granitgång.

of incipient augen. Perthites are rather scarce. *Biotite* (0 to 7 %) is mainly represented by a greenish-brown variety. It is generally transformed to chlorite in rocks displaying various cataclastic textures. The accessory minerals occur as disseminated crystals. They never amount to more than a few perent of the total mineral content of the rock. In order of importance they are: *sericite* (alteration-product of plagioclase), *chlorite* (alteration of biotite), *epidote, muscovite, titanite, magnetite* and *apatite.*

b – Discussion of the genesis

The Lina Granite shows many different relationships with its host-rocks ranging from typical intrusive habits to a very gentle assimilation.

As can best be observed in Lainio SO and SV, Lina Granite veins and pegmatites sharply cut various types of rocks belonging to the Veikkavaara, Pahakurkio and Ruutivaara groups. Although the intrusive habits of these granites and pegmatites cannot be questioned when dealing with host-rocks of predominantly basic composition, the occurrence of



a b

Fig. 33. Recrystallized supracrustal rocks.

a – (Normal light x 18.) Recrystallized, medium-grained cores of granitic composition in a fine-grained rock of the Sakarinpalo suite. Square 0d.

b – (Normal light x 18.) Same phenomenon in a feldspathic schist of the Pahakurkio Group. Square 2a.

Omkristalliserade ytbergarter.

a) Sakarinpalosviten, 0d.

b) Pahakurkiogruppen, 2d.

undisturbed relicts of tightly folded biotite schists found in a pegmatoidal granite vein at Paloleuska (Fig. 32) indicates that granite emplacement can, in some cases, be very gentle.

It has been mentioned in the previous sub-chapter that there exists a continuous and gradual transition between the Lina Granite and the Jyryjoki Granite. The very slight foliation which can then be observed in the Lina granite is parallel to the more accentuated foliation of the Jyryjoki Granite. The latter is in turn parallel to the schistosity and compositional banding of the surrounding schists and gneisses, to the elongation of schist-relicts in granitic rocks and to lithological boundaries. This has led to the conclusion that we are dealing with a ”relict-schistosity”. If this is correct, the transformation of meta-sediments (schists and gneisses) to granites of the Jyryjoki type and further, to granites of the Lina

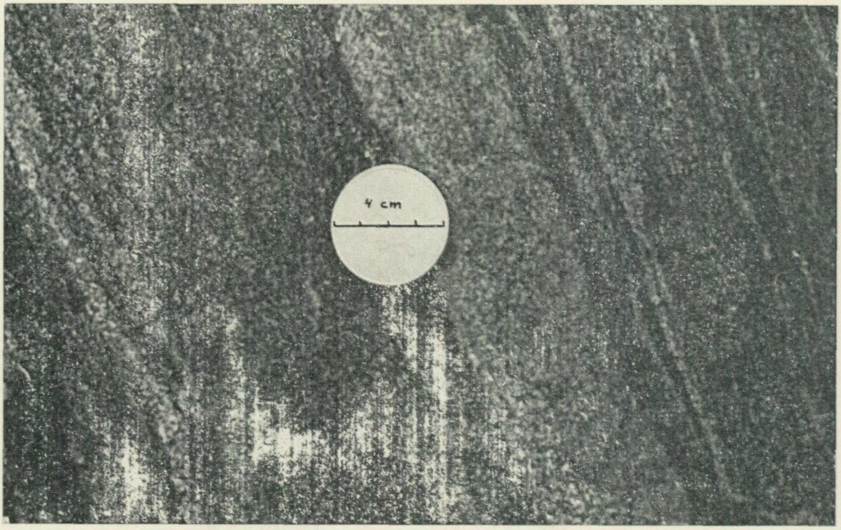


Fig. 34. Concordant to sub-concordant granitization of a biotite schist of the Haaravaara Group. Haaravaara.
Konkordant till subkonkordant granitisation av biotitskiffer ur Haaravaaragruppen. Haararvaara.

type, was very gradual. In agreement with this, fine-grained acidic metasediments (feldspathic quartzites) often display coarse-grained irregular zones or spots (Fig. 33), as if they were on the point of being transformed to granite at the moment when their evolution stopped. Concordant granitization of the type shown in Fig. 34 is also in favor of a gentle granitization.

The composition of the Lina Granite, taken as a whole, is rather constant and corresponds to a well-delimited area on the Q-Pl-M diagram (Fig. 35). Literature and diagrams dealing with granites in other parts of the world indicate that the Lina Granite corresponds rather well to what can be called *the normal granite field.*

The feldspar composition diagram (Fig. 36) and the quartz-plagioclase diagram (Fig. 37) show that no notable change occurs in the composition of the plagioclase, when the proportion of quartz or microcline increases in the rock. This is apparently due to the fact that quartz and microcline have crystallized in a late phase of granite-formation. The reason for this phenomenon probably lies in a remobilization of silica and potassium.

This has also permitted these two elements to act as metasomatic agents at the margin of granite massifs thus accounting for the widespread introduction of microcline and to a lesser extent of quartz in host-rocks.

From the facts above it is possible to say that the Lina Granite presents on the one hand neat intrusive characters which have probably originated from a rather "fluid" original condition prevailing during its emplacement. The widespread occurrence of veins and dykes of granite cutting and brecciating the host rocks, the rather homogeneous and "normal" composition of granites and the presence of sub-horizontal granites lying over steeply dipping schists (Matala Kuusivaara, Malmivaara) and apparently representing the base of strongly eroded laccolithic intrusions, are all facts in favor of an intrusive emplacement of granite. On the other hand, granites often seem to have been emplaced under rather calm conditions. Concordant granitization (Fig. 34), the presence of undisturbed folded relicts in granite, the gradual transition from sediments to gneiss, to foliated-granite and further to granite as well as the *magnetic continuity* generally observed on aeromagnetic maps between granitic areas and supracrustal areas, are all facts indicating a relatively "gentle" emplacement of granite.

These two contradictory modes of emplacement of the Lina Granite presented above find a satisfactory interpretation if it is inferred that different types of granites have originated at different levels of the crust.

In places where transitions to the Jyryjoki Granite are common and where relict fragments exist, the granite has probably originated from a deepseated and slow recrystallization of sediments of acidic composition. A total melt was apparently never reached in this case.

On the contrary, a magmatic stage has probably been reached in the case of homogeneous granite massifs and in the case of granite and pegmatite veins cutting and brecciating the host-rocks. These types have probably originated at a level of the crust where anatexis was active, deeper than the type above. They were then injected, as a fluid mass, in overlying formations. A system of batholiths and laccoliths has certainly existed as indicated by the discordant granites lying flatly over steeply dipping supracrustals.

The original material for the formation of granite seems to have been, at least partly, meta-sediments belonging to the Pahakurkio and Haaravaara groups, with certain reservations, however, concerning their low

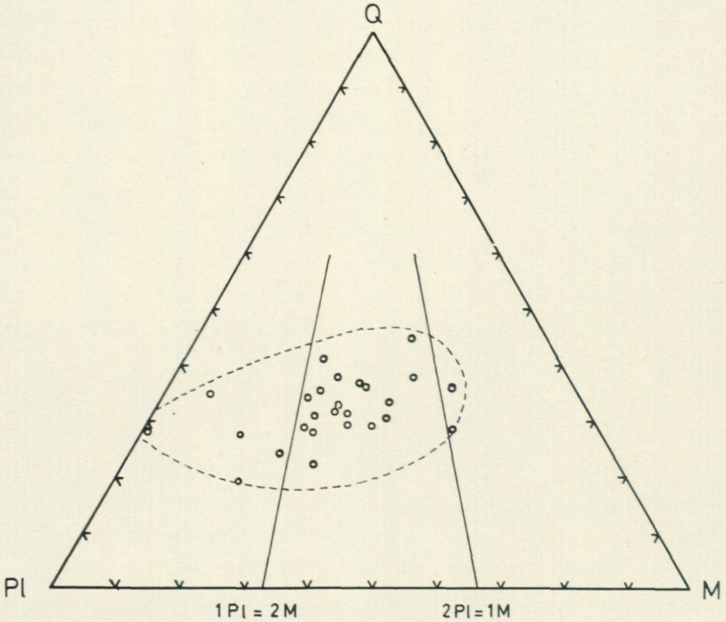


Fig. 35. Quartz-plagioclase-microcline diagram for the Lina Granite.
Kvarts-plagioklas-mikroklindiagram för Linagranit.

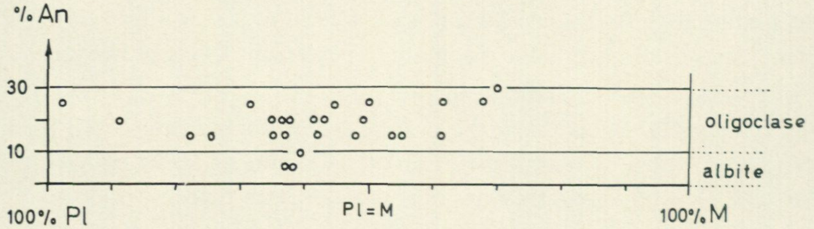


Fig. 36. Feldspar composition diagram.
Diagram över fältspatinnehållet.

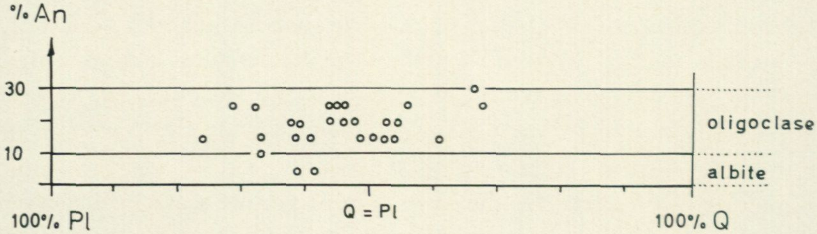


Fig. 37. Quartz-plagioclase diagram.
Kvarts-plagioklasdiagram.

silica and potassium content when compared to granites. The emplacement of granite and its relation to tectonic deformation is discussed below (pp. 76, 77).

3 – THE PERTHITE GRANITE

Perthite granite has only been encountered in ore-drillings of the northern part of the iron-ore of Masugnsbyn. It belongs to a rather homogeneous massif well exposed in the Tärendö map-sheet (Padget 1970). It has been thoroughly described by Geijer (1929, 1931) and therefore need not be discussed here at any length. Provisional results from radiometric age-measurements give approximatively the same age (1540 m. y.) for the perthite granite as for the Lina Granite (oral communication by Welin). The perthite granite of Masugnsbyn is bordered by a few metres of albite granite often displaying porphyritic characters (The phenocrysts are perthite.) as shown in Fig. 54.

TECTONIC INTERPRETATION

The author has made a large use of the aeromagnetic maps for the tectonic interpretation of the Lainio map-sheet. It must be emphasized here that the structural interpretation of such an area where plutonic rocks greatly predominate over supracrustal ones is, in our state of knowledge, highly hypothetical. Whenever possible, the structures discovered have been graphically verified by the construction of fold interference-patterns. Although this has often given good results, the tectonic interpretation given below is schematic and must be considered as *a logical image of the tectonic style.*

A – FOLDS AND STRUCTURES IN SUPRACRUSTAL ROCKS

In places where it can be verified, there generally exists a good correspondence between aeromagnetic maps and tectonic observations made in the field. For example, the strike of magnetic anomalies is, in most cases, parallel to the strike of the schistosity, foliation or compositional banding of the rocks. When it is known that most of these orientated features are parallel to lithological boundaries, the interest of aeromagnetic interpretation becomes evident. Furthermore, the different types of patterns made by magnetic anomalies over areas of variable size is highly significant for determining the type of rock present.

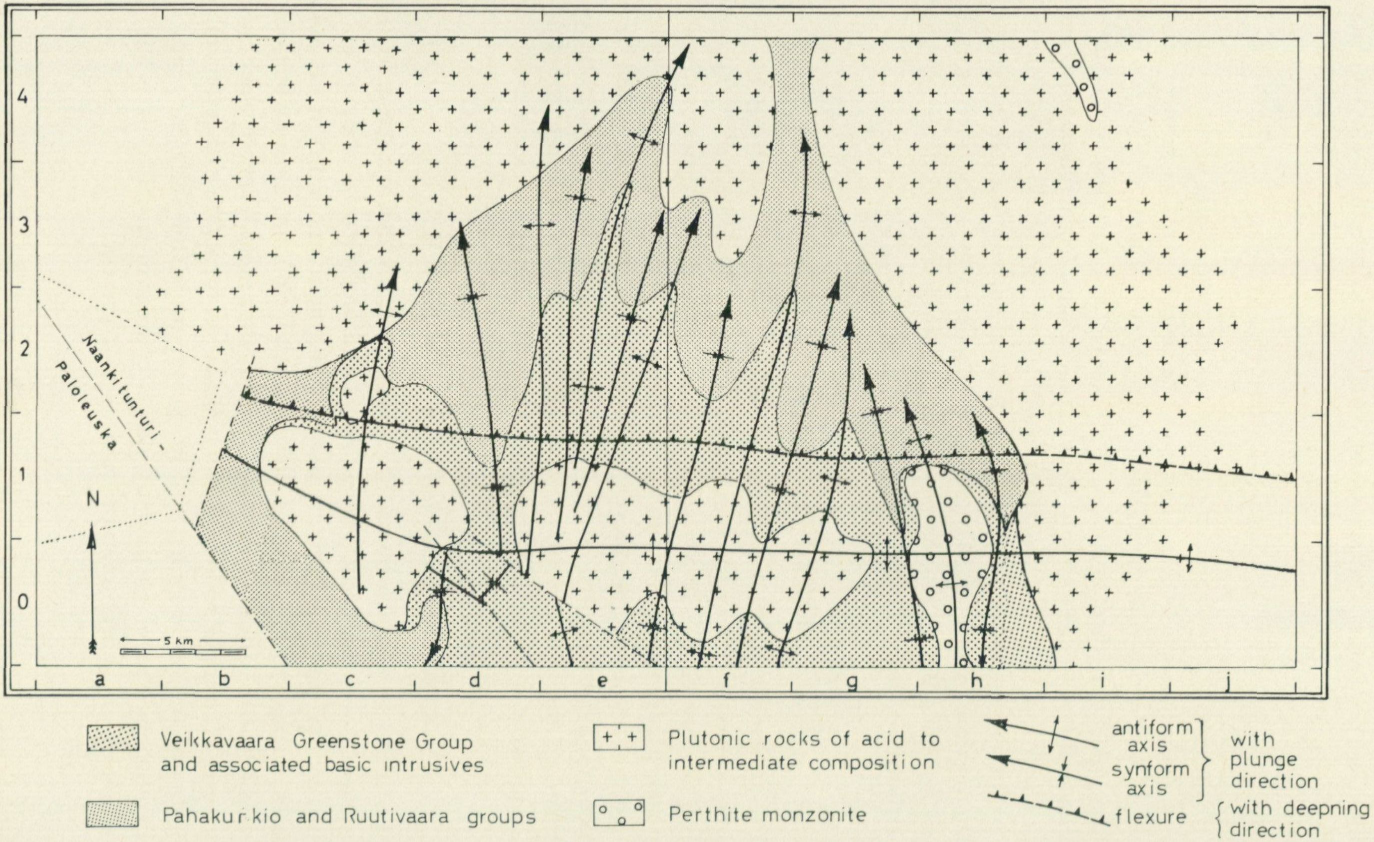

4
3
2
1
0
N
5 km
Naankitunturi - Paloleuska
a
b
c
d
e
f
g
h
i
j
Veikkavaara Greenstone Group and associated basic intrusives
Pahakurkio and Ruutivaara groups
Plutonic rocks of acid to intermediate composition
Perthite monzonite
antiform axis
synform axis
with plunge direction
flexure
with deepning direction

Fig. 38.

The scarceness in the supracrustal rocks of preserved sedimentary structures such as cross-bedding, graded bedding etc. as well as the very rare occurrence of polymict conglomerates has rendered problematic many aspects of the structural interpretation of the Lainio map-sheet. For this reason, when referring to folds, the terms *synform* and *antiform* will generally be used. They present the advantage of describing the geometrical position of rocks without involving stratigraphy. For descriptive purposes the Lainio map-sheet is subdivided into five areas, each with its own tectonic style. They are respectively:

1 – Lainio south-west and south-east
2 – The Naankitunturi-Paloleuska region
3 – Lainio north-west
4 – The "rounded anomaly" in Lainio south-east
5 – Lainio north-east

1 – LAINIO SOUTH-WEST AND SOUTH-EAST

This region, not comprising the Naankitunturi-Paloleuska region described below, is mainly characterized by steeply dipping supracrustal rocks which are in places strongly folded. The magnetic anomalies corresponding to the Veikavaara Greenstone Group are generally rather high and complex. Those corresponding to the Ruutivaara Group are also somewhat high, but much simpler than the former. The anomalies over the Pahakurkio Group are complex but rather low. These differences are the base for the following interpretation.

A reasonable explanation for the disposition of magnetic anomalies, when compared to field measurements, is obtained by the combination of three main sets of folds (See Fig. 38 where the geology has been somewhat schematized in order to render the tectonic interpretation more clear.):

1) *A set of large-amplitude folds with* E-W *axial direction.* An extended structural feature which has here been interpreted as a *flexure,* resulting in a steep northerly dip of rock-units, belongs to this set of folds. This interpretation is based on the fact that the aeromagnetic maps indicate

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Fig. 38. Schematic structural map of Lainio SV and SO.
Översiktlig strukturkarta. 29L Lainio SV och SO.

that the supracrustal rocks apparently disappear rather abruptly to the north of a rather straignt line, orientated E-W, and which can be traced quite far on adjacent map-sheets. This flexure affects a large *antiform* with an average E-W axial strike, and which is visible a few km to the south of the flexure above.

2) *A large antiform with a N-S orientated axis* which accounts, when combined with the antiform mentioned above, for the occurrence of a major *dome-structure* situated partly in the Tärendö, and partly in the Lainio map-sheets. In the area investigated, this structure reveals in its central part various formations belonging to the Veikkavaara Greenstone Group as well as granites, diorites, perthite monzonites and gabbros. It is probably totally surrounded to the north by schists and gneisses of the Pahakurkio Group. This has been schematically represented on Fig. 38. The axis of this antiform cannot be placed with any precision on the map and therefore does not figure on Fig. 38.

3) *A rather tight set of folds with roughly N-S axes and northerly plunge.* They are affected by the flexure described above. This is not the case for the Masugnsbyn Syncline (Padget 1970) which plunges to the south.

2 – THE NAANKITUNTURI-PALOLEUSKA REGION

This region is situated in Lainio SV as indicated in Fig. 38. The tectonic style is here quite different from what has been described in the preceding paragraph. The main axial strike of folds is here SE-NW, a direction frequently encountered in the Tärendö map-sheet (Padget 1970).

Cross-bedding found in meta-sediments of the Pahakurkio Group at Paloleuska (See pp. 24, 25.) indicates that we are here in presence of overturned beds with an average dip of 50° to the north-east.

Dip estimations from the aeromagnetic map as well as fold-patterns observed on the same map, north-west of Naankitunturi, indicate that we are apparently dealing here with the same tectonic style as in Paloleuska.

Paloleuska and Naankitunturi thus appear to belong to the same system of folds with SE-NW orientated axes, the former and the latter representing two anticlines with overturned south-west limbs. In agreement with the "anticline" position of Naankitunturi, field investigation has shown that greenstones and other basic- to intermediate-gneisses apparently belonging to the Veikkavaara Greenstone Group reappear in the border of the Naankitunturi Lina Granite massif. They are steeply dipping. The aeromagnetic map indicates that the anticline is probably plunging to the north-west and to the south-east respectively at the corresponding extremities of the hill resulting in a somewhat irregular dome sructure. The tectonic interpretation of the Naankitunturi-Paloleuska region is shown on the profiles IV and V (Plate 2).

It must be added here that the fold axial direction of this region (SE-NW) is parallel to the strike of what is probably a major fault (from aeromagnetic interpretation). This could mean that the fault represents an old thrust-plane related to folds of the Naankitunturi-Paloleuska type which may have facilitated later displacements during the post-Lina Granite rigid phase.

3 – LAINIO NORTH-WEST

The tectonic interpretation of this area is almost totally based on the aeromagnetic map because of the scarceness of exposed bedrock. Only large features will therefore be discussed.

The main structural element visible on the aeromagnetic map is a large N-S elongated structure, more than 20 km in length, with a maximum width of about 13 km. This somewhat rounded structure consists of more or less regular magnetic sheets disposed around a rather strongly magnetic center. Estimations of the dip of the magnetic sheets indicate that it must be interpreted as a *basin* for the dips are invariably directed towards its center. A reasonable explanation for the pattern observed can be obtained by a combination of two large synforms, respectively: 1) *An asymetrical synform with a N-S axis* having a western limb dipping gently to the east and an eastern limb dipping rather steeply to the west (See Profile III, Plate 1.). 2) *A large and somewhat regular synform with an E-W axis* probably belonging to the first set of folds described in Lainio south-west and south-east (p. 71).

The major structural element described above has been called here the *Vivungi basin.* It is affected by a minor fold with an E-W axial strike, about 2 km to the east-south-east of Vivungi.

Although field investigation has only revealed a few perthite monzonite exposures in the vast area occupied by this basin, the pattern observed on the aeromagnetic map indicates that this rock-type is not the only one present. Verification of this has been obtained from three drillholes in the Vivungi and Lainio regions. For reasons discussed earlier in this publication, it is the author's opinion that the Vivungi basin consists of a succession of acid, intermediate, and basic rocks of volcanic origin. They are probably strongly granitized as indicated by rather large zones where the magnetic pattern is somewhat obscured, these zones corresponding to lower magnetic anomalies.

From calculated dips of the magnetic sheets, the irregular and somewhat rounded structure visible at Ahmavuoma (9c), to the north-west of the Vivungi basin, is apparently an antiform.

The aeromagnetic map also shows that the area occupied by the large Ripakainen and Ripakaisenvuoma gabbro massifs displays elongated magnetic anomalies which are in general parallel to the boundaries of the Vivungi basin. This has suggested that gabbros were emplaced during a phase of deformation. This remains, however, hypothetical.

4 – THE ”ROUNDED ANOMALY” IN LAINIO SOUTH-EAST

A rather regular, rounded magnetic anomaly is visible in the south-east and to a lesser extent in the north-east aeromagnetic maps (3h, 3i, 4h, 4i). Exposures found along Lainioälven show that the high-anomaly zone (dark blue on the aeromagnetic maps), corresponds precisely to a perthite monzonite massif. It is possible that the rounded area of lower magnetic intensity (light blue), making up the largest part of the area considered here, corresponds to the presence at shallow depth of a large perthite monzonite massif.

A second interpretation of the rounded anomaly infers that the perthite monzonite massif corresponds only to the highest magnetic anomaly but that during its emplacement it has uplifted meta-sediments which were slightly more magnetic than the overlying rock-units. A dome structure would thus have been formed, accounting for the rounded shape of the anomaly. This is in agreement with observations made along Lainioälven (3i), where gneisses are dipping towards the south or the south-south-east.

A detailed geophysical study of the rounded anomaly (See the appendix by Niskanen, pp. 113–115.) indicates that a third interpretation is possible and involves a basin-shaped body, faulted in its eastern margin. Fig. 73 suggests that we are dealing with a ”ring dyke” structure comprising a thin, circular and rather magnetic dyke partly surrounding a body which is somewhat less magnetic. A logical geological explanation of Fig. 74 is that a ”volcanic cauldron subsidence” phenomenon is associated to the central part of the ring dyke above. The latter represents, in this case, a subsided bloc, the subside part being filled with volcanic material (e. g. basic lavas). The presence of andesite along Lainioälven (4i) and the close relationship existing between porphyries and perthite monzonites (See p. 54.), are also facts in favor of a "volcanic interpretation of this anomaly.

The absence of exposed bedrock in the central part of the rounded anomaly does not permit, however, to choose between the three interpretations above. Similar types of anomalies are rather frequent in this part of Sweden and a careful geological and geophysical investigation in better exposed areas, is bound to bring more light on their geological significance.

5 – LAINIO NORTH-EAST

On the western side of the large NNW-SSE orientated Lina Granite massif, gneisses and foliated granites, apparently representing metamorphic equivalents of the Pahakurkio and Ruutivaara groups, mainly strike N-S and dip rather steeply to the east or to the west. This is probably the result of a set of folds of the third type described for Lainio south-west and south-east (p. 72). Amphibole gneisses and foliated granites are limited to the west by an important fault striking NNW-SSE bringing them in contact with the porphyries of the Vivungi basin. This fault is well marked on the aeromagnetic maps (north-east and north-west) but no exposure permits verification in the field.

On the eastern side of the large Lina Granite massif mentioned above the tectonic style is quite different and gneisses as well as foliated granites dip gently in various directions, but mainly to the south. In many places, they lie horizontally and the aeromagnetic map gives here a good picture of slightly magnetic gneisses lying flat over less magnetic granites, as observed in the field.

B – RELATIONS EXISTING BETWEEN THE EMPLACEMENT OF PLUTONIC ROCKS AND TECTONIC DEFORMATION

The present investigation, mainly based on the study of contact-relationships, on the petrographic characters of rocks and on aeromagnetic interpretation, has shown that the emplacement of plutonic rocks is often related to tectonic deformation. A summary of the conclusions concerning this problem in the Lainio map-sheet is given below.

Gabbros and dolerites: An early stage of hypabyssal basic intrusion (dolerite sills) is probably contemporaneous with the deposition of the Veikkavaara Greenstone Group and has probably occurred in geosynclinal conditions. They can, to a certain extent, be compared with the "*roches vertes*" of the French authors. It is possible that the large gabbro massifs, belonging to a later intrusive stage, were emplaced during a phase of tectonic deformation. This is still hypothetical and some large gabbro massifs of Norrbotten have possibly been emplaced in rather calm conditions. A third and later stage of emplacement of basic- to intermediate-composition hypabyssal rocks(dolerite, porphyrite) is apparently contemporaneous with the emplacement and deposition of the Porphyry Group. A certain tectonic activity seems to have prevailed during this period.

The Kangos Diorite: Diorites of the Kangos type display many post-orogenic characters and are possibly genetically related to the gabbros although their emplacement occurred somewhat later.

Perthite monzonites: Petrographical considerations as well as aeromagnetic interpretation indicate that perthite monzonites were probably emplaced during a phase of rather intense tectonic deformation.

The Porojoki Diorite: Field investigation has shown that the foliation of the Porojoki Diorite, when present, is often concordant with the main orientated structures of surrounding supracrustals. Aeromagnetic maps show that the magnetic patterns occurring in large diorite massifs are more or less elongated in the direction of the schistosity and compositional banding of the supracrustal host-rocks. It is reasonable to suppose that these foliated types were emplaced during a phase of tectonic deformation. The non-foliated types are probably post-tectonic.

The Lina Granite and the Jyryjoki Granite: The aeromagnetic maps covering a large part of Norrbotten show that the large granite massifs are not randomly distributed but, on the contrary, display certain arrangements and elongated forms which suggest the influence of tectonic deformation probably contemporaneous with their emplacement. In a general way, these massifs are more or less elongated, often in a "sub-concordant" manner with the supracrustal host-rocks. They give rise on aeromagnetic maps to low magnetic patterns or "domains" which suggest the existence of two main sets of folds: a first set has an average fold axial-direction striking N-S while a second set (less accentuated) has an average fold axial-direction striking E-W. It is apparently the combination of these two sets of folds which results in the extensive ”dome and basin” structures visible on small-scale aeromagnetic maps. It is thus possible to infer that the transformation from gneiss to foliated granite and further to granite, discussed above (pp. 39, 61–62 and 64–69), has been caused by large amplitude folds, bringing meta-sediments at different levels of the crust, causing them to be progressively ”granitized” with increasing depth. In many cases, however, the transformation has not been total, as in the case of the Jyryjoki Granite displaying a relict-schistosity.

C – POST – LINA GRANITE RIGID DEFORMATION

The interpretation of aeromagnetic maps as well as field investigation in the Lainio map-sheet have shown that there exist important structures which are posterior to the emplacement of the Lina Granite. These include faults, breccia zones and joints and characterize what has been called here the *rigid deformation phase.*

Many important linear discontinuities of the type shown on Fig. 40 can be traced on the aeromagnetic maps. Their length can exceed 100 km, their width varying between a few tens of metres and a few kilometres. The two most common average strikes are NW-SE and NE-SW. They can best be observed in areas of high magnetic anomalies corresponding mainly to basic volcanics and to magnetite-rich meta-sediments. They can nevertheless often be traced in areas presenting low magnetic anomalies and corresponding generally to granites, foliated granites or diorites. The magnetic patterns situated on either sides of these linear discontinuities are often quite different from each other strongly suggesting important displacement along these features. Due to the absence of well-determined reference horizons, the amount of displacement cannot be estimated with any precision.

The strike of more than 400 measurements of fractures measured in the field have been plotted on a direction or ”rose” diagram (Fig. 41). Two major maxima have been obtained: a rather broad distribution of values situated between W 20° N and N 30° W (average NW-SE) and a narrow distribution of values situated between N 10° E and NE (average N 30° E). A less marked maximum is also visible in an E-W direction.

Detailed mapping of a few chosen areas containing many exposures

Fig. 39. Strongly crushed Lina Granite containing a dark biotite schist relict in the lower part of the picture. The exposure is situated along the banks of Jyryjoki.

Krossad Linagranit. Längs Jyryjoki.

indicates that there exists in most cases a good correspondence between the average strike observed in fractures and the strike of the linear discontinuities of magnetic anomalies in the same area. For example, The Purnuvaara region (2g) shows important E-W rock-fractures and faults corresponding to well-marked E-W features on the aeromagnetic map (SO).

A detailed microscope investigation of cataclastic textures has con-

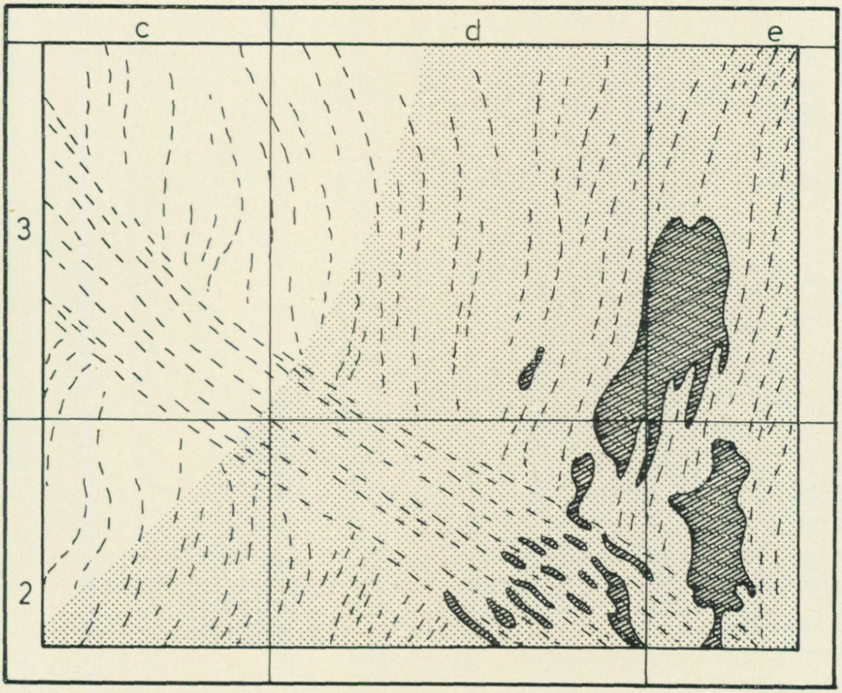

Fig. 40. Linear discontinuity of the strike of magnetic anomalies. The broken lines represent schematically the strike of the magnetic anomalies. The dark shadowed zones to the right are high magnetic anomalies (above 52 000 gammas) devoid of rock-exposures. The light grey represents an area where biotite schists and gneisses are rather well exposed. The non-shaded area is a Lina Granite massive. The normal magnetic trend, which is to north, is cut by a rather straight band in which the strike of the magnetic anomalies is to the north-west. Note the effect of this band on the high anomalies.
Lineär diskontinuitet i de magnetiska strukturerna.

firmed the widespread distribution of this rigid deformation and its considerable effect on rock-forming minerals. Some of the most common cataclastic textures observed are presented in the last part of this description (Figs 43–48). Except for the frequent transformation of biotite to chlorite and some small-scale recrystallization (mainly quartz), is can be said that *no notable thermal metamorphism has accompanied this rigid deformation phase.*

Large slip-grooves and slickenside surfaces, commonly observed in

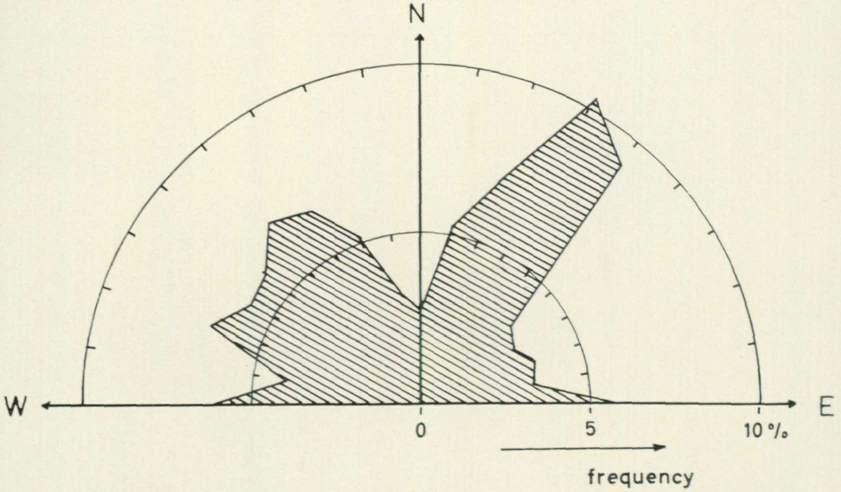

Fig. 41. Diagram showing the distribution of the strike of about 450 fractures and faults measured in the Lainio map-sheet. The data is here presented as a percentage of the total number of measurements and has been grouped in tens of degrees.

Fördelningen av riktningen på sprickor och förkastningar. 450 mätningar från kartbladet 29L Lainio.

sub-mylonitic areas, indicate that relative displacement along faults and shear-zones has often occurred.

An extensive sub-mylonitic area covering more than 250 km^2 has been found in the south-east and, to a lesser extent, in the north-east part of the map. It covers a broad zone (about 10 km) between the Purnuvaara region and the perthite monzonite massif situated along Lainioälven and further to the north. An explanation to this widespread cataclasis has not yet been found.

Measurements of fault directions, crush, shear etc. have been made over the entire area investigated and deal with almost every type of rock encountered, from plutonic to supracrustal rocks. This points to the fact that *the rigid phase has occurred after the deposition and emplacement of all rock-types present in the map-sheet*. The absence of any significant metamorphism associated with this rigid phase indicates that it has occurred later than the regional metamorphism. The presence of two major fault directions has led to the conclusions that rigid deformation is unrelated to any particular plutonic emplacement (Since there would then exist specific directions for every massif considered, the total effect would be a wide distribution of fault directions.), but that *it reflects a widespread phenomenon probably affecting a large part, if not all, of the Pre-Cambrian of Northern Sweden.*

A certain "compartimenting" of the map sheet into large, more or less rectangular blocks, results from the presence of two major fault-directions. Vertical mouvement of these blocks relative to each other would have strongly contributed to the preservition, by sinking, of supracrustal rocks and their disappearance by erosion following uplift. It is probable that, in this highly granitized region, supracrustal rocks, when present, must generally be rather thin (See p. 36.). If this is true, even small vertical mouvements can account for important surface effects and thus explain quite well the chaotic magnetic patterns observed in Lainio south-east and south-west. In regions where granite predominates, the effects of the rigid deformation phase are evidently less apparent.

Our purpose has been primarily to find an explanation to the linear features which can be traced on the aeromagnetic maps. Although the present field investigation indicates that the main surfaces of displacement of the rigid phase are steeply dipping (from the observation of slickenside surfaces), a three-dimentional study of these phenomena, in order to explain the behavior of rocks with depth, remains quite problematic in a region devoid of reference horizons and in any case would demand more data than has been gathered here.

GEOLOGICAL HISTORY

Although it has not been possible, in the area investigated, to establish a stratigraphy based on a definite sedimentary sequence because of the lack of "way-up" structures in supracrustal rocks, the most probable succession of events having occurred can often be deduced from a study of the nature, distribution and relationships existing between different types of rocks. The order of emplacement of plutonic rocks has mainly been established by the study of contact relationships and indirectly by an investigation of their texture and structure. Correlations between supracrustal and plutonic units have been attempted and are shown on Fig.

Supracrustal rocks	Hypabyssal rocks	Plutonic rocks	Radiometric age-measurements	Tectonic deformation
		Lina Granite, Jyryjoki Granite and perthite granite	1540 ± 90 m.y.	
		Porojoki Diorite		
		perthite monzonite		
Porphyry Group (acid, intermediate and basic effusives)	Porphyry Group (porphyrites, dolerites and intrusive porphyries)			
〰〰〰〰〰〰〰〰			1610 ± 65 m.y.	
		Kangos Diorite	1880 ± 50 m.y.	
		Gabbros		
Ruutivaara Group				
Pahakurkio and Haaravaara groups				
Veikkavaara Greenstone Group	dolerites			
〰〰〰 ? 〰〰〰				
Basement formations apparently not exposed in the Lainio map-sheet				

Fig. 42. Schematical stratigraphic succession established for the Lainio map-sheet showing the relations existing between the deposition of the supracrustal groups and the emplacement of the hypabyssal and plutonic rocks. The undulating lines indicate the place of supposed major unconformities. The radiometric age-measurements indicated here have been carried out on samples not situated on the Lainio map-sheet. The last column to the right is an attempt to indicate schematically the place and relative intensity (proportional to the thickness of the black line) of tectonic deformation.
Den geologiska utvecklingen och åldersföljden mellan bergartsgrupperna inom kartbladet 29L Lainio.

42. The geological evolution of the Lainio region presented below resumes the ideas and hypotheses which have been expressed earlier in this publication.

On an unknown basement (granite, diorite, gneiss?) and possibly in relation to a geosynclinal phase, a thick group of rocks, the Veikkavaara Group, was deposited. It is characterized by metamorphic basic rocks of probable effusive origin alternating with various meta-sediments. Basic intrusives (dolerites) are intimately associated to the supracrustal rocks of this group. The characters mentioned above are typical of a *basic volcano-sedimentary complex* of which there exist many examples in the Pre-Cambrian throughout the world. A radical change in the material deposited occurred at the top of this group where we find carbonate-rich horizons containing iron concentrations.

The *Pahakurkio Group,* consisting mainly of a succession of quartz-rich sediments, was apparently deposited in normal succession to the Veikkavaara Greenstone Group. The widespread distribution of detrital quartz-rich rocks, together with the presence of a local quartzitic conglomerate (Paloleuska) is possibly in relation to the beginning orogenic activity and uplift of acidic basement formations, thus accounting for the predominantly quartz-rich and somewhat heterogeneous sedimentation prevailing at the time. Rocks of the Pahakurkio Group have later been partly transformed to gneiss and it is probable that the *Haaravaara Group,* consisting only of gneisses, was originally made up of the same quartz-rich sediments as the Pahakurkio Group.

By an increase in dark minerals, mainly amphibole, the Pahakurkio Group passes progressively to what has here been called the *Ruutivaara Group*. It is probable that this group originally consisted of carbonate-bearing sediments. No basic intrusives or effusives have been found to be associated to this group.

It is possible that orogenic activity continued for some time after the deposition of the sedimentary groups described above. *Gabbros* were apparently emplaced partly during a folding phase and partly after. The *Kangos Diorite* which is possibly genetically related to the gabbros was emplaced during a post-orogenic phase.

Rocks of hypabyssal and volcanic origin belonging to the *Porphyry Group* were emplaced and deposited after the emplacement of the Kangos Diorite, as indicated by contact relationships observed between these two rock-types north-west of Laulajavaara. Many facts suggest that orogenic activity was again active at that time.

During an intense folding phase which apparently followed the deposition of the Porphyry Group, the *Perthite-monzonite* was emplaced. A genetic relation probably exists between the porphyries and the perthite monzonite although the Lainio map-area does not permit direct verification of this.

Later than the emplacement of the Perthite monzonite, but at a time which is difficult to decide with any certainty, the *Porojoki Diorite* was emplaced. Foliated types were probably emplaced during a phase of tectonic deformation while the non-fioliated types are possibly post-tectonic.

Probably during the lapse of a considerable period of time the *Jyryjoki Granite* and the *Lina Granite* were slowly formed and emplaced. This apparently occurred in relation to a phase of tectonic deformation during which large-amplitude folds brought sediments of the Pahakurkio type to deeper levels of the crust where they were successively transformed to gneiss, to foliated granite or to rather homogeneous granite, depending on depth. Granites often reached a fluid state through anatexis and frequently injected the overlying rock-units. Though radiometric age-measurements give for the Lina Granite Series the youngest age known in the map area, the beginning of the transformation from sediments to granite may have occurred at a considerably older epoch.

Well – developped rigid post – Lina Granite deformation presenting two rather constant fault directions later strongly affected this region, giving to the Pre-Cambrian rocks their actual geological aspect.

ILLUSTRATIONS OF ROCK-TEXTURES

The drawings presented in this publication have been made by the author. They are often the result of a juxtaposition of observations made both under nomal and polarized light.

Figs 43—48. Cataclastic textures related to post-Lina-Granite deformation.
Kataklastisk textur orsakad av deformation yngre än Linagraniten.

Fig. 43. (Normal and polarized light x 15, square 3i.) *Lina Granite.* Broken and deformed plagioclase and fractured quartz with very irregular extinctions under polarized light indicate a deformation of medium intensity. Microcline is clear.

Fig. 44. (Normal light x 15, square 3g.) *Lina Granite.* Sub-molynitic veinlets display angular fragments of quartz and feldspar in a fine-grained, slightly recrystallized groundmass.

Fig. 45. (Normal an polarized light x 15, square 2g.) *Lina Granite.* Partly recrystallized cataclastic veinlets are outlined by thin saussurite-chlorite stringers. The center of the picture is occupied by a recrystallized quartz core.

Fig. 46. (Normal and polarized light x 15, square 8i.) *Lina Granite.* Sub-mylonitic texture with quartz and feldspar fragments in a non-recrystallized fine-grained groundmass made up of the same minerals.

Fig. 47. (Normal and polarized light x 15, square 6f.) *Porojoki Diorite.* Clear augens of cataclastic origin (center) are composed of angular quartz and feldspar fragments in a fine-grained recrystallized groundmass made up of the same minerals. These lenticular cores are outlined in a somewhat ”plastic” manner by saussurite-chlorite stringers.

Fig. 48. (Normal and polarized light x 15, square 9f.) *Porojoki Diorite.* Sub-mylonitic texture showing quartz and plagioclase fragments in a very fine-grained groundmass consisting principally of saussurite.

Figs 49—54. Various habits of microcline in different types of rocks.
Mikroklin i olika bergartstyper.

Fig. 49. (Normal light x 15, square 3i.) *Lina Granite.* A plagioclase area situated in the upper-part of the picture is penetrated by a poikiloblastic microcline gulf (clear).

Fig. 50. (Normal light x 15, square 3c.) *Porojoki Diorite.* Plagioclase (shaded) is strongly replaced by microcline (clear). All of the plagioclase relicts in the picture originally belonged to a single crystal as can be deduced by their common extinction under polarized light, as well as by their parallel cleavages.

Fig. 51. (Normal and polarized light x 15, square 2a.) *Meta-dolerite.* Typical ”enveloping” habit of microcline (clear). The shaded minerals are plagioclase and diopside.

Fig. 52. (Normal light x 15, square 1g.) *Kangos Diorite.* Poikiloblastic microcline (clear) shows no definite crystal boundaries, and corrodes slightly the plagioclase (shaded). The plagioclase is generally subhedral, strongly sericitized, and often contains clear myrmekitic parts in the vicinity of microcline.

Fig. 53. (Normal and polarized light x 15, square 9b.) *Kangos Diorite.* A poikiloblastic microcline porphyroblast (shaded) displays rather sharp and distinct crystal boundaries. The amphibole in the lower left corner presents interstitial habits towards the microcline porphyroblast. Plagioclase is slightly shaded, quartz is clear.

Fig. 54. (Normal and polarized light x 7, drill-core sample from the iron-ore at Masugnsbyn.) *Perthite poryhyry.* A subhedral plagioclase is surrounded by a subhedral perthite rim in a somewhat recrystallized quartz-feldspar matrix.

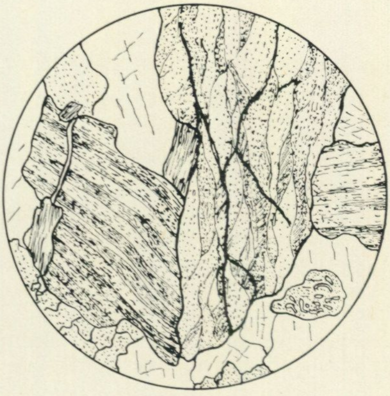

Fig. 43

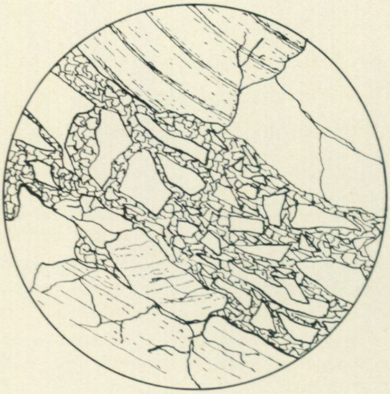

Fig. 44

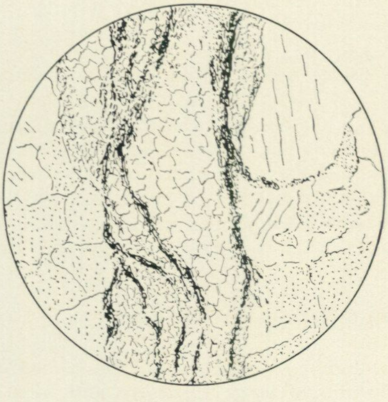

Fig. 45

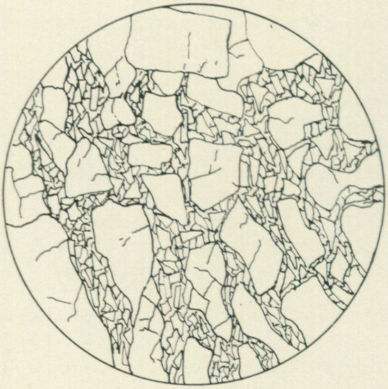

Fig. 46

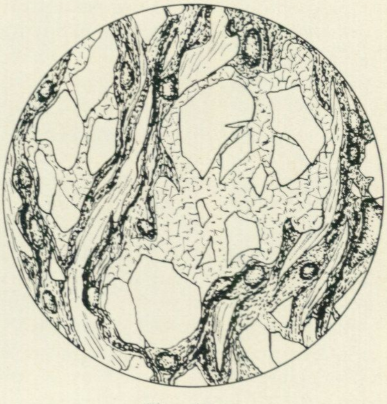

Fig. 47

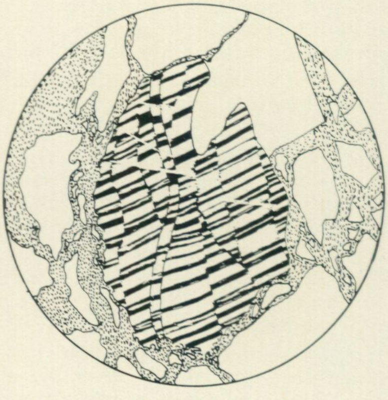

Fig. 48

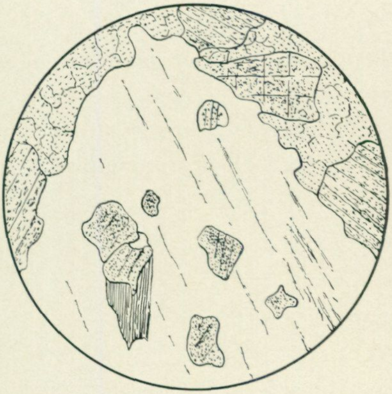

Fig. 49

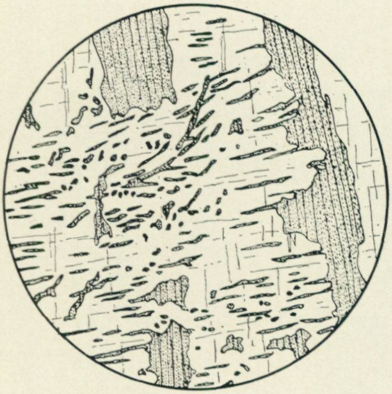

Fig. 50

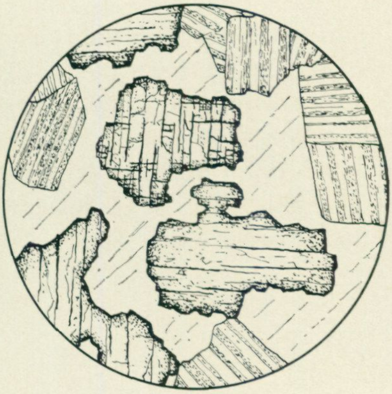

Fig. 51

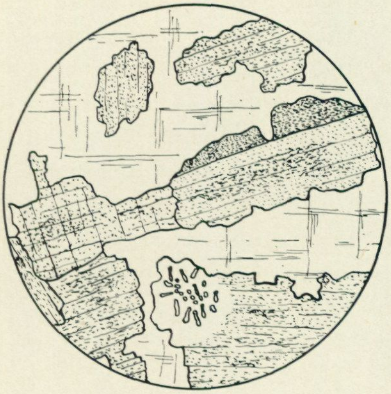

Fig. 52

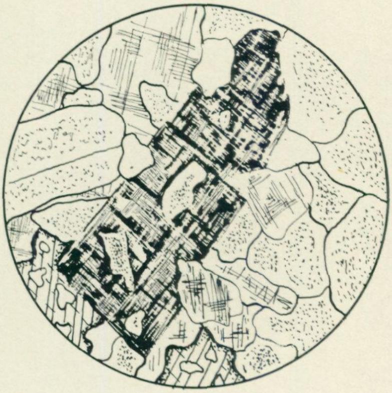

Fig. 53

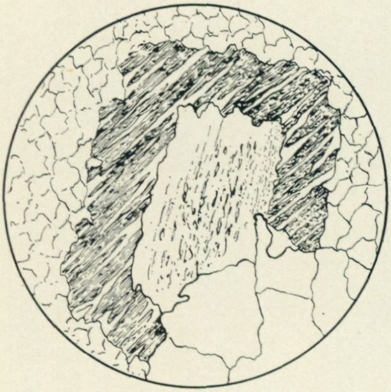

Fig. 54

ANALYSES, MEASUREMENTS, ETC.

Chemical analyses (Figs 55–62). The chemical analyses presented below have been made by the analyst B. Åkerlund of the Geological Survey of Sweden. The method is quantitative spectrography (Smältisoformering B). The following observations concern the precision of the method:

- The iron is totally estimated as Fe_2O_3.
- The relative error for SiO_2 is ±2 %.
- The relative error for Al_2O_3 is ±3 %.
- Not analyzed: H_2O, P_2O_5, CO_2, F and S.
- The results are given in weight-percent.

The analyses are presented separately for each rock-type, with decreasing silica content from the first to the last.

Mineralogical composition of rocks (Figs 63–65). The method of investigation by point-counter as well as the precision of the method is discussed on p. 16. Point-counting was mainly made on quartz (Q), plagioclase (Pl), microcline (M), biotite (B) and amphibole (A).

Average chemical and mineralogical composition of rocks (Fig. 66). For comparison, the average chemical and mineralogical composition of the plutonic rocks, calculated from the values given in Figs 55–65, is presented on Fig. 66.

	green-stone	Sakarinpalo suite			skarn							
sample N°	FW 32e	FW 233a	FW 236d	FW 235g	FW 290	FW 111	FW 293	FW 297	FW 298	FW 112a	FW 112b	FW 296
square	29L 2e	29L 0e	29L 0d	29L 0e	28L 9d	29L 2c	28L 9d	28L 9d	28L 9d	29L 2c	29L 2c	28L 9d
SiO_2	46.1	76.4	50.5	49.0	56.0	55.3	55.3	54.3	52.1	49.2	44.5	35.7
TiO_2	0.80	0.40	0.66	2.79	0.07	0.18	0.02	0.28	0.09	0.56	1.11	1.09
Al_2O_3	14.6	13.6	13.8	13.8	0.5	5.7	0.3	2.0	0.7	6.3	11.1	12.3
Fe_2O_3	13.9	0.2	13.0	17.1	2.7	4.3	6.1	7.7	1.3	8.8	4.3	16.9
MnO	0.27	0.01	0.21	0.13	0.14	0.27	0.08	0.07	0.35	0.22	0.12	0.13
CaO	10.5	0.3	9.7	4.9	14.9	19.4	12.4	9.8	22.3	17.7	17.1	0.9
MgO	8.3	0.3	6.3	4.4	22.1	12.0	22.5	19.5	18.9	13.7	10.7	17.6
Na_2O	2.6	7.5	3.3	5.3	0.1	1.5	0.1	2.6	–	0.3	–	0.1
K_2O	1.0	1.0	0.9	1.2	–	0.2	–	0.5	0.4	1.2	1.5	7.7
BaO	0.04	–	0.01	0.01	0.01	0.04	–	0.01	0.02	0.07	0.06	1.5
tot.	98.11	99.71	98.38	98.63	96.52	98.89	96.80	96.76	96.16	98.05	90.49	93.92

Fig. 55. The Veikkavaara Greenstone Group.
Veikkavaara grönstensgrupp.

	feldspathic quartzites					feldspathic schists					
sample N°	FW 93c	SJ 749b	FW 93d	FW 501	FW 291	FW 110a	FW 273	FW 79	FW 533	FW 105	FW 375b
square	29L 2a	29L 9b	29L 2a	29L 2a	28L 9d	29L 0a	29L 0d	29L 0c	29L 2a	29L 0a	29L 1j
SiO_2	79.2	76.2	75.4	72.0	69.6	65.7	64.7	60.6	60.0	58.1	57.3
TiO_2	0.90	0.45	0.85	0.45	0.67	0.45	1.2	0.86	0.85	0.88	1.43
Al_2O_3	8.6	9.7	10.6	12.4	11.6	15.6	11.6	15.0	17.2	19.7	16.4
Fe_2O_3	4.2	3.3	6.3	3.7	6.3	4.5	8.7	9.0	7.3	9.0	8.3
MnO	0.08	0.02	0.02	0.08	–	0.09	0.11	0.6	0.08	0.07	0.12
CaO	2.0	0.4	0.2	0.9	0.5	1.1	2.1	2.5	1.1	0.8	5.8
MgO	1.6	1.8	2.3	1.8	0.9	1.9	3.2	4.0	3.2	3.4	3.0
Na_2O	1.4	0.7	0.6	1.7	5.0	3.1	2.2	4.6	2.3	1.9	3.9
K_2O	1.6	3.7	2.7	5.0	0.7	6.4	2.6	2.5	3.7	3.7	2.8
BaO	0.04	0.07	0.05	0.17	0.02	0.33	0.05	0.14	0.09	0.11	0.18
tot.	99.62	96.34	99.02	98.20	95.29	99.17	96.46	99.26	95.82	97.66	99.23

Fig. 56. The Pahakurkio Group.
Pahakurkiogruppen.

Fig. 57. The Ruutivaara Group / *Ruutivaaragruppen* — The Porphyry Group / *Porfyrgruppen*

	The Ruutivaara Group *Ruutivaaragruppen*	The Porphyry Group *Porfyrgruppen*			
sample N°	FW 453	FW 146a	FW 450a	FW 476	FW 126
square	29L 9f	29L 1g	29L 8e	29L 9c	29L 4i
SiO_2	58.2	60.6	57.1	53.2	47.0
TiO_2	1.12	0.59	1.52	0.90	1.90
Al_2O_3	13.1	15.5	18.1	14.5	16.5
Fe_2O_3	9.9	6.2	6.9	10.5	14.4
MnO	0.16	0.21	0.12	0.23	0.17
CaO	5.3	5.2	4.4	6.6	6.6
MgO	4.2	2.5	2.3	4.5	5.0
Na_2O	3.1	3.2	5.6	3.7	4.1
K_2O	3.9	6.3	4.2	3.6	1.5
BaO	0.16	0.18	0.33	0.14	0.14
tot.	99.14	100.48	100.57	97.87	97.31

sample N°	FW 341a	FW 74	FW 320a	FW 214	FW 248c	FW 215a	FW 320b
square	29L 1d	29L 2c	29L 4b	29L 2d	29L 6a	29L 1d	29L 4b
SiO_2	53.3	51.7	51.4	51.1	50.7	50.7	50.6
TiO_2	0.60	1.59	0.43	0.73	1.70	0.83	0.38
Al_2O_3	13.7	15.7	25.3	18.7	15.5	19.3	19.8
Fe_2O_3	9.7	11.8	1.9	8.3	11.7	8.3	5.2
MnO	0.17	0.16	0.03	0.10	0.17	0.15	0.09
CaO	5.7	7.8	12.7	7.7	7.0	7.1	13.2
MgO	11.7	5.0	1.3	6.8	5.0	6.6	6.9
Na_2O	2.8	3.8	4.4	4.0	3.7	4.1	2.4
K_2O	0.8	1.6	0.3	1.4	2.0	1.7	0.4
BaO	0.10	0.09	0.03	0.13	0.07	0.19	0.04
tot.	98.57	99.24	97.79	98.96	97.54	98.97	99.01

sample N°	FW 213c	FW 320d	SJ 611c	FW 197c	SJ 742	FW 320c	FW 320e
square	29L 1d	29L 4b	29L 0d	29L 2a	29L 7c	29L 4b	29L 4b
SiO_2	49.5	49.2	48.9	48.8	47.6	47.6	47.4
TiO_2	0.37	0.75	0.70	0.54	0.60	1.42	0.51
Al_2O_3	16.8	14.1	15.3	18.6	15.5	14.6	13.8
Fe_2O_3	8.5	8.7	9.2	9.4	8.2	13.6	9.2
MnO	0.17	0.14	0.13	0.14	0.13	0.20	0.14
CaO	10.4	12.2	11.1	10.2	10.8	10.8	13.6
MgO	9.2	8.9	7.3	8.4	9.6	1.5	9.6
Na_2O	2.5	2.3	3.0	2.8	2.4	2.5	1.8
K_2O	0.7	0.4	0.8	0.4	0.5	0.7	0.5
BaO	0.07	0.06	0.03	0.04	0.03	0.05	0.03
tot.	98.21	96.75	96.46	99.32	95.36	92.97	96.58

Fig. 58. Gabbro.
Gabbro.

sample N°	FW 450b	SJ 619b	FW 152	FW 120	FW 149	FW 151	FW 203a	FW 203b	FW 154	SJ 619a
square	29L 8e	29L 0g	29L 0h	29L 4i	29L 1g	29L 0h	29L 0h	29L 0h	29L 0h	29L 0g
SiO_2	61.0	58.0	57.7	57.0	57.0	56.3	56.3	55.7	54.6	52.1
TiO_2	1.31	1.50	1.44	1.51	1.69	1.56	1.38	1.74	1.54	2.12
Al_2O_3	17.3	17.6	15.5	16.0	16.1	16.4	16.4	17.3	15.8	15.5
Fe_2O_3	4.8	5.8	7.1	7.5	7.5	7.8	7.4	7.3	7.7	9.6
MnO	0.08	0.05	0.13	0.15	0.13	0.12	0.11	0.13	0.13	0.13
CaO	2.3	3.3	4.9	3.9	4.2	4.9	5.3	5.3	6.5	6.1
MgO	1.2	1.9	3.0	2.4	2.1	2.7	3.4	2.4	4.1	2.5
Na_2O	5.3	5.0	4.3	5.4	5.1	4.9	4.7	4.7	4.1	3.9
K_2O	6.1	5.0	4.6	4.0	5.0	4.4	4.9	3.8	3.8	3.9
BaO	0.12	0.5	0.3	0.38	0.46	0.43	0.48	0.8	0.45	0.7
tot.	99.51	98.65	98.97	98.24	99.28	99.51	100.37	99.17	98.72	96.65

Fig. 59. Perthite monzonites.
Pertitmonzonit.

sample N°	FW* 56	SJ* 744	FW* 5	FW° 82	SJ* 748a	FW° 194g	FW° 194b
square	29L 3a	29L 7c	29L 3c	29L 0b	29L 9a	29L 0i	29L 0i
SiO_2	69.4	64.9	62.1	61.5	61.4	60.8	59.4
TiO_2	0.62	0.58	0.69	0.61	0.71	0.64	0.71
Al_2O_3	15.0	15.6	16.9	15.3	15.1	16.2	16.2
Fe_2O_3	1.6	3.6	4.8	6.1	6.4	4.8	6.6
MnO	0.05	0.03	0.07	0.12	0.10	0.05	0.10
CaO	1.8	2.4	3.5	4.5	3.9	3.2	5.1
MgO	1.1	1.6	2.2	2.5	2.3	3.0	3.2
Na_2O	5.9	5.3	5.2	3.6	3.8	6.5	5.0
K_2O	3.7	3.5	4.5	3.2	3.9	2.1	3.3
BaO	0.15	0.12	0.14	0.09	0.11	0.09	0.12
tot.	99.32	97.63	100.10	97.52	97.72	97.38	99.73

sample N°	FW* 245	FW° 194i	FW* 344	FW° 194e	SJ* 621	FW° 213g	SJ* 620
square	29L 6a	29L 0i	29L 2h	29L 0i	29L 2h	29L 1d	29L 2h
SiO_2	59.3	58.1	57.8	57.5	56.6	52.2	51.5
TiO_2	0.68	0.79	0.81	0.73	0.66	1.97	0.81
Al_2O_3	15.5	17.8	16.8	15.9	15.3	15.2	16.5
Fe_2O_3	6.5	4.6	6.8	6.5	7.3	4.8	9.5
MnO	0.13	0.02	0.12	0.11	0.11	0.14	0.15
CaO	5.0	1.0	5.6	4.6	4.8	6.2	8.0
MgO	3.2	4.4	3.3	3.1	3.7	4.1	5.5
Na_2O	4.5	7.9	4.4	4.6	4.5	4.4	4.0
K_2O	3.4	2.8	3.2	4.0	2.8	2.7	1.3
BaO	0.09	0.02	0.18	0.17	0.10	0.29	0.09
tot.	98.30	97.43	99.01	97.21	95.87	98.80	97.35

Fig. 60. o = Kangos Diorite. * = Porojoki Diorite.
*o = Kangodiorit. * = Porojokidiorit.*

sample N°	SJ 656	FW 370b	FW 119	SJ 646	FW 195b	FW 161
square	29L 7i	29L 4g	29L 3i	29L 9j	29L 2a	29L 2g
SiO_2	71.6	69.6	66.1	63.3	57.5	57.3
TiO_2	0.22	0.40	0.46	0.65	0.86	1.02
Al_2O_3	14.2	15.4	16.5	15.7	21.0	16.9
Fe_2O_3	2.0	2.4	3.3	5.7	6.1	9.8
MnO	0.03	0.04	0.05	0.06	0.08	0.08
CaO	1.7	2.5	2.9	1.9	4.3	3.3
MgO	0.6	1.0	1.2	1.9	1.4	1.8
Na_2O	3.8	4.4	4.7	4.0	4.9	3.9
K_2O	3.7	2.9	3.5	4.0	4.9	4.3
BaO	0.18	0.17	0.20	0.17	0.39	0.24
tot.	98.03	98.81	98.91	97.38	101.43	98.64

Fig. 61. Jyryjoki Granite.
Jyryjokigranit.

sample N°	FW 505	FW 6	FW 134	SJ 651	FW 349	FW 516a	FW 115b
square	29L 2a	29L 3c	29L 2i	29L 7j	29L 2h	29L 2a	29L 3i
SiO_2	76.0	75.8	75.5	73.5	73.5	73.4	71.7
TiO_2	0.10	0.11	0.08	0.07	0.28	0.08	0.28
Al_2O_3	12.2	13.6	13.2	13.3	14.0	13.9	13.9
Fe_2O_3	0.6	1.3	0.7	0.9	1.6	0.8	1.9
MnO	0.02	0.02	0.01	0.02	0.05	0.01	0.04
CaO	0.2	1.2	1.0	0.3	1.3	1.1	1.6
MgO	0.3	0.2	0.2	0.3	0.5	0.2	0.8
Na_2O	2.9	4.0	3.7	3.1	4.1	3.3	4.0
K_2O	5.3	4.5	4.0	5.4	4.2	4.9	4.0
BaO	0.05	0.05	0.08	0.15	0.14	0.12	0.15
tot.	97.67	100.78	99.47	97.04	99.67	97.81	98.37

Fig. 62. Lina Granite.
Linagranit.

* = samples of which there exists a chemical analysis – *kemiska analyser finns*
\+ = the mineral is present in small quantities – *mineralet uppträder blott i små mängder*

sample N°	rock-type	square	mineral percentage				
			Q	Pl	M	B	A
FW 5	P monzonite	* 3c	2.0	40.1	38.9	10.1	5.7
FW 51b	P granodiorite	3a	12.4	57.8	12.6	10.0	5.4
FW 51c	P dioritic-monz.	3a	1.0	49.5	14.0	10.5	17.5
FW 53	P dioritic-monz.	3a	8.8	54.0	13.7	8.0	13.0
FW 56	P granodiorite	* 3a	16.0	57.5	14.0	–	10.0
FW 59	P diorite	3b	2.0	48.0	5.0	15.0	28.0
FW 82	K dioritic-monz.	* 0b	8.5	52.5	17.5	10.0	11.0
FW 117b	P dioritic-monz.	4i	–	38.8	17.5	20.0	21.0
FW 145	K monzonite	1g	5.5	49.0	26.0	3.0	16.0
FW 157a	P granodiorite	2g	12.0	50.5	11.5	–	13.0
FW 194b	K dioritic-monz.	0i	1.5	62.5	20.0	5.0	11.0
FW 194c	K quartz-diorite	0i	10.5	59.5	9.5	13.0	6.0
FW 194e	K monzonite	* 0i	2.0	46.0	33.0	+	17.5
FW 194g	K dioritic-monz.	* 0i	2.0	58.0	27.0	+	12.5
FW 207b	P dioritic-monz.	1f	0.5	56.5	11.0	2.5	28.5
FW 219b	P diorite	6g	3.0	52.5	3.5	7.5	33.0
FW 245	K dioritic-monz.	6a	6.5	56.0	7.0	9.5	20.0
FW 341b	K diorite	1d	–	80.0	–	11.0	9.0
FW 344	P diorite	* 2h	3.1	56.7	7.2	13.3	17.4
FW 367b	P granodiorite	3g	11.6	46.3	19.6	8.1	12.4
FW 375a	P granodiorite	1j	10.2	50.4	12.6	5.6	20.0
FW 375c	P quartz-monz.	1j	10.5	42.8	25.3	5.3	14.8
FW 474	P quartz-monz.	5b	10.5	42.0	30.5	4.5	10.0
SJ 620	P diorite	* 2h	–	60.0	–	2.9	35.6
SJ 621	P monzonite	* 2h	3.5	33.1	33.4	–	29.0
SJ 631b	P diorite	4f	7.0	64.0	–	3.0	25.0
SJ 702	P diorite	9f	9.5	67.0	–	8.5	–
SJ 722	K diorite	5a	3.5	63.5	2.0	4.5	26.5
SJ 744	P granodiorite	* 7c	12.0	65.0	10.0	3.0	9.5
SJ 746a	K dioritic-monz.	9b	4.0	49.0	22.0	9.5	14.5
SJ 748a	K monzonite	* 9a	6.0	46.5	24.0	4.0	18.5

Fig. 63. Modal analyses: K = Kangos Diorite, P = Porojoki Diorite.
Q = quartz, Pl = plagioclase, M = microcline, B = biotite, A = amphibole.
Volumetriska bestämningar: K = Kangosdiorit, P = Porojokidiorit.
Q = kvarts, Pl = plagioklas, M = mikroklin, B = biotit, A = amfibol.

sample N°	rock-type	square	mineral percentage				
			Q	Pl	M	B	A
FW 8	quartz-diorite	3d	13.5	70.5	1.0	13.5	–
FW 20c	diorite	2d	2.5	67.5	4.5	21.0	0.5
FW 117a	granodiorite	4i	22.0	48.5	17.5	6.5	2.5
FW 119	quartz-monzonite	* 3i	22.5	39.5	24.0	12.5	0.5
FW 125a	quartz-monzonite	4i	32.0	29.5	32.0	6.5	+
FW 144a	monzonite	1g	–	44.5	29.5	26.0	–
FW 161	quartz-monzonite	* 2g	12.5	29.5	34.0	15.0	–
FW 162a	syenitic-monzonite	2g	–	22.5	48.0	–	24.0
FW 186	granodiorite	5i	26.0	47.0	20.0	6.0	–
FW 195b	dioritic-monzonite	* 2a	1.0	53.5	25.0	11.0	–
FW 231	dioritic-monzonite	5g	0.5	70.7	16.4	3.6	6.5
FW 367b	quartz-monzonite	3g	11.0	45.0	28.0	6.0	7.5
FW 370b	granodiorite	* 4g	33.0	43.0	17.0	6.0	+
FW 452a	granodiorite	8e	22.5	53.5	13.5	9.5	+
SJ 609	quartz-monzonite	0d	15.5	26.0	45.0	6.0	–
SJ 630	granodiorite	4f	14.5	56.0	24.0	5.5	–
SJ 656	granodiorite	* 7i	37.0	40.5	17.5	5.0	–
SJ 692	quartz-diorite	5g	17.5	60.0	4.0	10.0	8.5

Fig. 64. Modal analyses: Jyryjoki Granite.
Volumetriska bestämningar: Jyryjokigranit.

sample N°	rock-type	square	mineral percentage				
			Q	Pl	M	B	A
FW 6	quartz-monzonite	* 3c	31.0	37.0	29.5	2.0	–
FW 20a	granodiorite	2d	24.0	50.5	23.0	2.5	–
FW 43	quartz-monzonite	2a	41.6	37.1	21.2	–	–
FW 61	quartz-diorite	3b	34.0	56.0	7.0	3.0	–
FW 93f	quartz-monzonite	2a	32.6	29.4	34.4	2.2	–
FW 115a	quartz-monzonite	3i	36.0	32.0	30.5	1.0	–
FW 115b	quartz-monzonite	* 3i	29.0	41.0	24.5	5.5	–
FW 116a	quartz-monzonite	3i	30.0	38.5	31.5	+	–
FW 122	quartz-monzonite	4i	29.5	31.5	36.0	3.0	–
FW 123	quartz-monzonite	4i	27.5	43.5	23.5	5.5	–
FW 130	quartz-monzonite	2i	34.0	38.0	23.0	5.0	–
FW 134	quartz-monzonite	* 2i	34.0	43.0	22.5	0.5	–
FW 144d	quartz-diorite	1g	28.5	70.5	1.0	+	–
FW 165	quartz-monzonite	0d	29.7	35.3	35.0	+	–
FW 242	granite	7f	27.0	22.0	45.5	5.5	–
FW 349	quartz-monzonite	* 2h	36.5	35.5	25.0	3.0	–
FW 368	quartz-monzonite	3g	27.5	44.0	26.0	2.5	–
FW 369	quartz-monzonite	3g	37.5	24.5	38.0	+	–
FW 370b	granodiorite	4g	26.0	53.0	15.0	5.5	–
FW 388	granodiorite	8i	18.0	58.0	19.0	5.0	–
FW 449	quartz-monzonite	2g	21.0	43.5	27.5	5.5	–
FW 502	quartz-monzonite	2a	35.0	31.0	28.0	6.0	–
FW 505	quartz-monzonite	* 2a	43.0	20.0	32.0	5.0	–
FW 516a	quartz-monzonite	* 2a	33.0	38.5	27.5	1.0	–
SJ 651	granite	* 7j	35.0	18.5	42.5	2.5	–
SJ 673	quartz-monzonite	9h	29.0	37.3	26.7	7.0	–

Fig. 65. Modal analyses: Lina Granite.
Volumetriska bestämningar: Linagranit.

	Gabbros	Perthite monzonites	Diorites		Jyryjoki Granite	Lina Granite
			K	P		
SiO_2	49.8	56.6	60.2	58.7	64.2	74.2
TiO_2	0.8	1.6	0.7	0.9	0.6	0.1
Al_2O_3	16.8	16.4	15.9	15.9	16.6	13.4
Fe_2O_3	8.8	7.3	5.7	5.7	5.0	1.1
MnO	0.1	0.1	0.1	0.1	<0.1	<0.1
CaO	10.0	4.7	4.4	4.1	2.8	1.0
MgO	7.0	2.6	2.9	3.2	1.3	0.4
Na_2O	3.0	4.7	4.8	5.1	4.3	3.6
K_2O	0.9	4.6	3.2	3.1	3.9	4.6
BaO	<0.1	0.5	0.1	0.1	0.2	0.1
Cu	95	10	25		15	<10
Ni	135	20	30		20	10
Cr	375	280	85		60	<20
Sr	485	630	375		300	150
quartz		–	K 4 %	P 7 %	16 %	31 %
plagioclase		perthite 70 %	57 %	52 %	47 %	39 %
microcline			17 %	14 %	22 %	27 %
biotite		5 %	6 %	7 %	9 %	3 %
amphibole		10 %	15 %	17 %	3 %	–

K = Kangos type
P = Porojoki type

Fig. 66. Average composition of plutonic rocks.
Medelsammansättningen av djupbergarter.

SITUATION OF THE LOCALITIES MENTIONED IN THE TEXT

Lainio map-area	square
Ainettivuoma	0j
Ahmavuoma	9c
Akavaara	0i
Haaravaara	7j
Huhtalompolo	8e
Hulmeenvaara	1h
Jyryjoki	7i-7j-8j-9j
Kalixälven	0a
Kangos	0i
Kuoksu (Kuokso)	3c
Kurkkio	1e
Lainio	6f
Lainioälven	0i-1i-2i-3i-4i-5i-5h-6g-6f-7e-8d-9d-9c
Laulajavaara	1g-1h
Malmivaara	0b
Matala Kuusivaara	0a
Merasjärvi	1c
Meraslinkka (Meraslinka)	2e
Merasvaara	2c
Naankijärvi (Nankijärvi)	1b
Naankitunturi (Nankitunturi)	1a-1b-2a-2b
Nedre Parakka	0a
Olosjoki	5i-5h-6i-7g-7h-7i-8g-9f-9g
Pahturivuoma	1f-1g
Paharovanvuoma	1f-1g
Paloleuska	2a
Palo-Ripakainen	9b
Palovaara	5a
Parkajoki (Parajoki)	7i-7j-8i-8j
Pasmavaara	6c
Porojoki	2g-2h
Pororova	3g
Purnuvaara (Puornovaara)	2g
Poyviönpalo (Pövionpalo)	1d
Ripakainen	8a-9a
Ripakaisenvuoma	6a-6b-7a-7b
Ripakkajoki	7b-8b
Ruutivaara	0c
Saankijoki (Saangijoki)	7e-8e-9e
Saarivaara	9b-9c
Sakarinpalo	0e
Torneälven	0f-0g-1e-1f-2c-2d-2e-3b-3c-4a-4b
Tuolpukkavaara	9b
Viksvaara (Viksivaara)	0h
Vinsavaara	0h
Vivungi	6d
Vuosuvaara	9e
Vähävaara	0d

Other map-areas	map-sheet
Gällivare	28K
Huuki	29M
Junosuando	28L
Karesuando	31L
Kiruna	29J
Lannavaara	30L
Masugnsbyn	28L
Muonionalusta	30M
Pahakurkkio	28L
Tärendö	28L
Veikkavaara	28L
Vittangi	29K

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APPENDIX

THE AEROMAGNETIC MAPS LAINIO NV, NO, SV, SO

by

P. Niskanen

CONTENTS

INTRODUCTION

As part of a long-term aeromagnetic program, The Lainio map sheet was flown in two steps, in 1961 and 1963, and a first print of the total-intensity anomaly map became available in 1964. This major program is designed to provide complete aeromagnetic coverage of the iron-ore district of Norrbotten with the purpose of prospecting for magnetite-ores. At the same time the distribution of magnetic materials in the bedrock is revealed and provides valuable information for the structural and petrological interpretation.

Instrumentation as well as processing and presentation of results have been described by Werner (1963, 1967) and therefore only a few fundamental particulars for an over-all understanding of the geophysical content of the maps, are given below under "survey specifications".

A few, strong magnetic anomalies, indicating potential mineable magnetite deposits, have been followed-up with geophysical surveys on the ground.

In an attempt to overcome deficient information on the magnetic properties of the prevailing basement rocks, a statistical analysis of aeromagnetic anomaly features has been initiated. This investigation, intended to enhance the magnetic interpretation in badly exposed areas in general, started too late to benefit the Lainio geological map description. Some preliminary results are, however, presented in this appendix.

SURVEY SPECIFICATIONS

Parallel lines with a spacing of 200 m are flown W-E at an average height of only 30 m above the terrain. The bedrock is mostly covered by a 5 to 10 m thick layer of gacial drift. In-path as well as out-of-path positioning is kept within 50 m.

The total-intensity fluxgate magnetometer is read to 10 γ, which corresponds well with the "geological noise" and repeatability in control and tie-in flights over magnetically quiet areas. Instrument readings are corrected for daily variation. In order to allow connection with adjacent aeromagnetic maps, secular variation is accounted for by reduction to a common epoch (1960, 5) An analog record is run with a length scale of 1:50,000. However, the map processing is based on a digital print-out of readings for every 40 m of flight.

On the maps, magnetic contour lines have been drawn for intervals of 100, 500 and 2,500 γ, with increasing line-thickness. Figures indicate total-intensity values in hundreds of γ over an arbitrary base value of 48,000 γ. With an accepted normal field value of 51,600 γ, the isoanomaly contour marked 36 (3,600 γ above 48,000 γ) denotes the zero *anomaly-field*. Positive and negative anomalies, relative to this zero-value, are visualized respectively by graded blue and brown colouring when exceeding 500 γ.

GROUND SURVEYS

As standard procedure with the current iron-ore inventory program, of which the airborne survey forms the first step, the more conspicuous aeromagnetic anomalies are investigated further with detailed gravimetric and magnetic measurements on the ground. Some earlier surveys, however, were initiated with the purpose of prospecting for sulphide ores or graphite, in which case electromagnetic measurements with slingram equipment were used.

Ground surveys are always made in a rectangular grid, based on a system of lines staked and marked in the terrain. Usually magnetic and electromagnetic measurements are made every 10 or 20 m in profiles with 80 m spacing for reconnaissance, and 20 to 40 m spacing for detailed work. Corresponding figures for gravity surveys are 20 to 40 m stations in profiles spaced from 200 m down to 40 m. Results are presented as

Locality	Map division	Object	Survey specifications				Remarks
			method	instrument	area km^2	year	
Ahamavuoma	c/9	iron-ore	magn.	Askania Gfz	2,2	1968	Aeromagnetic indication. Small discrete lenses, gen. dip E, probably faulted at northern end.
			gravity	Worden	2,2	1968	
Merasvaara	c/2	sulphide mineralization	magn.	Askania Gfz	3,2	1968	Geological evidence for survey. Fault and fracture zone. Strong EM anomaly with N20W trend.
			el. magn.	Slingram 18 kc	3,2	1968	
Meraslinka	d–e/1–2	sulphides/ graphite	el. magn.	Slingram 3,6 kc	6,4	1949	Distinct, strong EM anomalies. Drilling proved mainly graphite schist, some chalcopyrite and pyrite.
			magn.	Tiberg balance	8,3	1950	
Masugnsbyn	c–d/0	iron-ore	magn.	Askania Gfz	13,8	1965	Folded and locally faulted northward cont. of main skarn ore situated on map sheet 28L Tärendö.
			gravity	Worden	13,8	1965	
Kivijänkkä	g/1	iron-ore	magn.	Askania Gfz	2,8	1968	Aeromagnetic indication. Small discrete lenses.
			gravity	Worden	2,8	1968	
Kangosfors	i–j/0	iron-ore	magn.	Tiberg balance	13,5	1949	Northward cont. of iron-ore survey at Junosuando on map 28L Tärendö.

Fig. 67. Geophysical ground surveys carried out by SGU on the map-sheet 29L Lainio.
Geofysiska markmätningar utförda av SGU inom 29L Lainio.

anomaly maps at a scale of 1:5,000 or for detail surveys at 1:2,000. These maps form the basis for an evaluation of geometry of the ore body and an estimation of ore quantity and quality. Any case-history found to be of general interest will be published elsewhere.

All ground surveys performed by SGU on the Lainio map sheet are plotted in Pl. 3 and summarized in Fig. 67.

REGIONAL MAGNETIC FEATURES

As appears in the geological description, aeromagnetic data have been utilized extensively in the compilation of the geological maps. Certain structural information gained from detailed magnetic interpretation of selected profiles is incorporated in these maps.

In the iron-ore district of Norrbotten, to which the Lainio area belongs, experience has shown that the magnetic anomaly pattern mainly reflects the distribution of magnetite in basement rocks. Unfortunately, it has not been possible to determine the magnetic properties of the prevailing rock-types directly on samples. However, in an effort to meet the need for supporting magnetic information in this badly exposed area, we have examined the possibility of classifying consistent anomaly features by means of suitable statistical measures, in the hope of finding a correlation with petrographical and/or structural elements.

Statistical analysis of aeromagnetic anomalies

Data for statistical treatment were taken from the rigital print-out of the magnetometer. Total field intensity values have been read at every point of a square grid 200×200 m, a total of 62,500 readings. These are grouped for computer processing in units of 2×2 km, or 100 readings. As only elementary statistical measures will be mentioned here, the calculations need no comment.

The frequency distribution histogram (Fig. 68) for all readings was first determined. The mean value proved to be 220 γ above the supposed normal value of 51,600 γ (Werner 1967). In our present state of knowledge it is impossible to decide, whether this deviation results from deep-seated sources or from a general surplus of magnetic material in the surface rocks. The standard deviation of 505 γ (See Fig. 69.) is quite high for Pre-Cambrian areas in general, but considerably lower than the average in the iron-ore district. The distribution appears

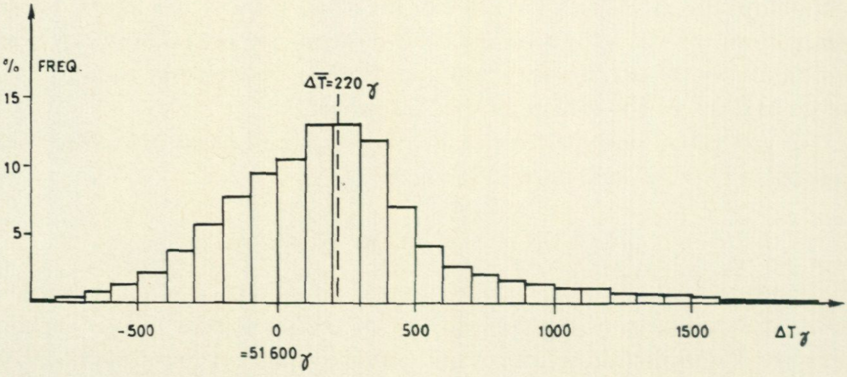

Fig. 68. Frequency histogram of magnetic total-intensity anomalies on the map-sheet 29L Lainio.
Frekvensdiagram över magnetisk totalintensitet inom 29L Lainio.

to be a sum of gaussian normal curves, though with a long positive tail. The frequency jump at $+100\ \gamma$ pobably falls between two modes, but the means of the component curves are too close to each other to allow a graphical separation. It is worth recalling, that aeromagnetic results show strong autocorrelation.

In a recent paper on aeromagnetic measurements over Pre-Cambrian in Finland, Puranen et al. (1967) found a convincing lognormal distribution of anomaly values. This investigation, however, covered a very large area, probably with a more representative distribution of rock-types. Some subdivisions of the area do show a frequency curve similar to that of the Lainio area, and hence the distribution function of magnetic anomalies may prove to have an important relationship to geology.

In a further attempt at classification by statistics, the whole map sheet was divided into a few "provinces", each with its own distinctive magnetic features. Pl. 3 shows boundary lines for 6 provinces, of which I, III and IV include areas with nearly consistent field values, but decreasing intensity of local deviations as reflected by the diminishing number of anomaly curves per unit of area. Province II accounts for the remaining, more "noisy" parts of the map, except for two distinctly different anomaly-types, separated in the rectangular provinces V and VI. This very rough division was made manually, as objectively as possible, and absolutely unbiased by any geological information. For each of the provinces

Province	$\Delta\overline{T}\ \gamma$	$S_T\ \gamma$	Observations in thousands
I	–80	240	9
II	330	651	25
III	150	148	9,7
IV	440	130	4
V	900	160–220	5,6
whole map	220	505	62,5

Fig. 69. Mean ($\Delta\overline{T}$) and standard deviation (S_T) of magnetic anomalies on 29L Lainio for provinces according to Pl. 3.
Medeltal och standardavvikelse för magnetiska anomalier inom 29L Lainio, provins I–V. (Jämför pl. 3.)

I–V, mean and standard deviation are listed in Fig. 69. The presumably significant differences in these simple statistical measures, seem to indicate the feasibility of dividing the characteristic anomaly-types into well defined classes.

An attempt to correlate such statistical-magnetic quantities with geological evidence is demonstrated in Fig. 70. Mean and standard deviation are here calculated for 2×2 km squares (100 readings) situated over some of the few places where abundant outcrops allow a safe geological determination of the rock-type to be made. The position of a square (upper left corner) is given in the x/y-column, where x denotes the vertical, y the horizontal distance in km from the lower left corner of the map-sheet.

Even if the samples for each type of rock are as few as three, the well-grouped results definitely point to a close correlation between statistical anomaly measures and petrography. It is also obvious, that the figures for provinces I, III and IV in Fig. 69 tend to be representative for granodiorite, Lina Granite and Jyryjoki Granite (See geological description.) respectively. In spite of a certain overlap, the above rocks dominate in these provinces (See for example Fig. 2.). The gabbros of Fig. 70 make up only a fraction of province II, which evidently consists mainly of supracrustal rocks. It is interesting to note, however, that the gabbros observed in the Lainio map-sheet are considerably lower in magnetite content than those of the adjoining map 28L Tärendö (Cornwell, in Padget

Rock-type	Square x/y	$\Delta\overline{T}$ γ	S_T γ
Lina Granite	40/36	215	61
	34/42	235	53
	14/46	233	72
Jyryjoki Granite	30/46	320	88
	48/46	605	108
	32/48	473	75
Granodiorite	44/02	–261	127
	44/10	–152	151
	32/06	–131	119
Gabbro	46/00	68	250
	36/06	906	1257
	02/48	614	303

Fig. 70. Comparison between mean ($\Delta\overline{T}$) and standard deviation (S_T) of magnetic anomalies and rock types at selected exposures on 29L Lainio.
Jämförelse mellan magnetiska anomalins medeltal och standardavvikelse för olika bergartstyper inom 29L Lainio.

1970). The observed correlation between anomaly- and rock-types of course only applies to the Lainio map-sheet. In nearby areas, the relation between geology and magnetism may be much more complicated. In the Virrat region (20×40 km) in Finland, Puranen et al (1968) made the interesting observation that the magnetite content in all rock-types changed considerably over a distance of a few km.

Magnetic trend analysis

In an account of geophysical investigations on the adjacent map-sheet 28L Tärendö, Cornwell (in Padget 1970) came to the conclusion that the trends of magnetic anomalies reflect main structural directions. To pursue this idea, anomaly trend directions were compiled for each separate map (See Fig. 71.) and for the whole map-sheet Lainio (See Fig. 72.). The trends are evaluated manually. A line is drawn, if necessary broken in units of length, along the center of every elongated positive or negative

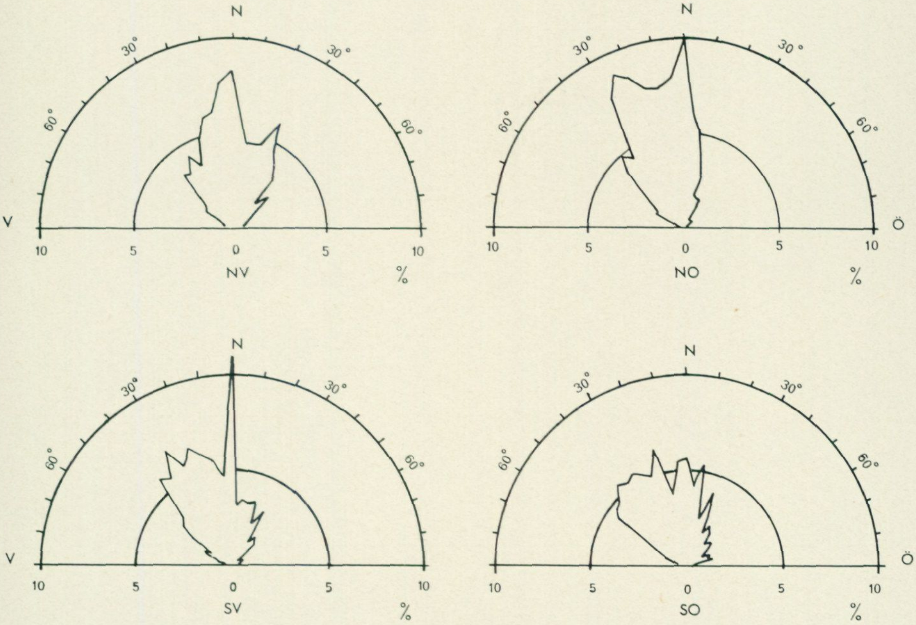

Fig. 71. Anomaly trends on the aeromagnetic maps 29L Lainio NV, NO, SV, SO.
Anomaliriktningar inom flygmagnetiska kartorna 29L Lainio NV, NO, SV, SO.

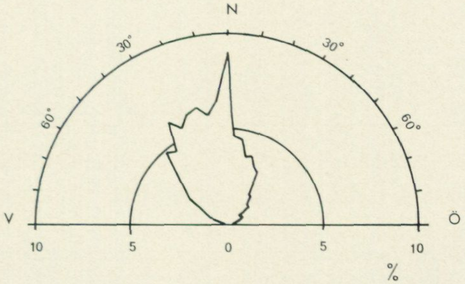

Fig. 72. Anomaly trends on the aeromagnetic map 29L Lainio, whole map-sheet.
Anomaliriktningar inom flygmagnetiska kartorna 29L Lainio, hela kartbladet.

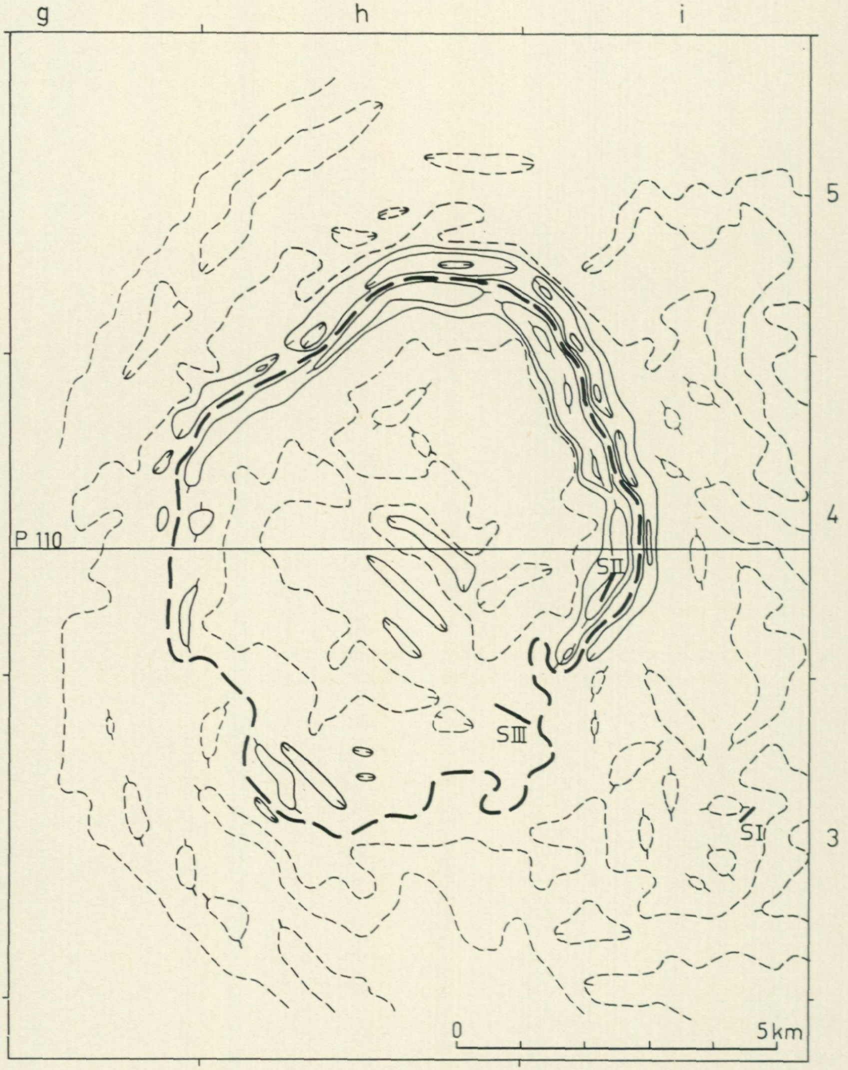

Fig. 73. Second vertical derivative (ΔT_{zz}) of aeromagnetic total-intensity on the Karijärvi anomaly. Dashed lines denote $\Delta T_{zz} = 0$. Heavily dashed zero-line gives the border of the anomalous body. SI–SIII are seismic profiles. *Andra vertikala derivatan av aeromagnetiska totalintensiteten, Karijärvianomalien. SI–SIII seismiska profiler.*

anomaly of the map. The length-units are summed and arranged in a rosette in five-degree intervals of direction. As shown by Cornwell, east-west trends are suppressed due to the east-west flight direction of the aeromagnetic survey.

A strong peak at due N agrees with a dominant structural direction in most of Norrbotten. A broad but pronounced peak at N 30 W appears in all four quadrants, but is most prominent in the NO and SV ones. A weak peak may be discerned around N 40 E. It shows up well in the NV and SV quadrants, but is blurred in the SO and absent altogether in the NO one. Most of these preferred trend directions are equally obvious on the original maps. However, reconsideration of magnetic trend data in appropriate subunits of the maps, may allow the extraction of useful information for the structural interpretation presented in the geological description. Later on, as more map-sheets are treated, the results may prove valuable for large-scale tectonic analysis.

LOCAL MAGNETIC FEATURES

For a number of local anomalies, dip-angles calculated from analog profiles, have been recorded on the geological maps. In most cases the two-dimensional interpretation procedures developed by Gay (1963) or Beskow and Granar (1969) could be used.

The large conspicuous anomaly at Karijärvi (See the ”rounded anomaly” pp. 74, 75.), g-i/3–5, may deserve some supplementary comments. The mean field-intensity (See province V in Fig. 69.) rises to 750 γ above that of province III, which surrounds it. The standard deviation is 160–220 γ, depending on the setting of the boundary, or about the same as for province III (or IV).

The anomaly falls into three different parts. The western part, almost circular with a diameter of 6 km, has sharp, steeply dipping borders to the NE and NW and probably SW, while the gradient to the SE is more gentle. The strong, N-S-striking part of the anomaly in the NE corresponds to a perthite monzonite (See p. 74.). The anomaly ”shadow” to the SE resembles in magnetic character that of province IV.

The heavily marked zero-line of the second derivative map in Fig. 73 nicely delineates the probable contact of the combined western and NE anomaly body. Considering the flight profile P 110 (See Fig. 73.), one possible interpretation is shown in Fig. 74. It must be noted, however,

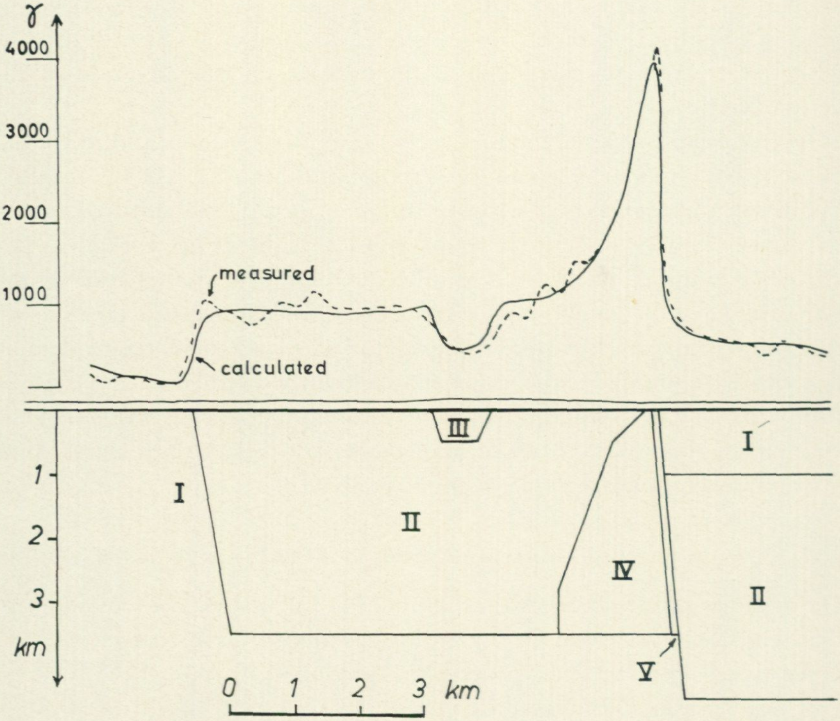

Fig 74. 29L Lainio, aeromagnetic ΔT-profile P 110 over the Karijärvi anomaly. Susceptibilities of model-body: I = 0, II = 3,1, III = 0,8, IV = 8,1 and V = 12,8 × 10^{-3} emu.
Aeromagnetisk Δ T-profil, Karijärvianomalien.

that this is only a two-dimensional approximation. As will appear, this interpretation involves a basin-shaped body (magnetite-contrast 1,1–1,5 %) with a depth of 3,5 km, the eastern border of which is downfaulted about 1 km. In the fault zone, a sheet with a magnetite-contrast of 2–6 % (by volume) accounts for the northeastern magnetic high.

To exclude possible screening from excess overburden, three seismic profiles were run over the anomaly. The position of the profiles is marked in Fig. 73, the results are listed in Fig. 75. The moraine cover has normal thickness, and the velocities are quite reasonable for granites.

Profile	Location x/y km	Basement velocity m/s	Surface depth m
I	19,5/39,6	4000	11–13
II	17,9/43,5	4800	12–19
III	21,4/41,3	4700–5000	8–10

Fig. 75. Seismic measurements in 29L Lainio h–i/3–4.
Seismiska mätningar inom 29L Lainio h–i/3–4.

CONCLUSION

The fact, that some of the most common Pre-Cambrian rock-types occupy large, continuous areas of the Lainio map-sheet, offers opportunities for a study of the basic rules govering the relation between basement mapping by magnetics and geology. An effort to use statistical analysis of large scale magnetic features was initiated too late to be of significance in the geological mapping. Promising results so far have, however, encouraged an attempt to construct a "magnetic interpretation map" of the Lainio area, and to develop further and test the feasibility of extracting more information of direct geological interest from the aeromagnetic maps. Moreover, now that the geological maps are avaiable, it is obviously interesting to recalculate Fig. 69 with a new subdivision into provinces, better adapted to geological evidence. The same applies to other map-sheets of this part of Sweden. We hope to be able to publish later the results of such investigations.

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