Rapport nr. 87.149

Reiserapport IUGG-konferansen
(International Union of Geodesy
and Geophysics)
i Vancouver, Canada

Norges geologiske undersøkelse
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Rapport nr. 87.149	ISSN 0800-3416	Åpen/~~Fortrolig~~

Tittel:
Reiserapport IUGG-konferansen (International Union of Geodesy and Geophysics) i Vancouver, Canada

Forfatter: Jan Reidar Skilbrei Odleiv Olesen	Oppdragsgiver: NGU
Fylke: Nordland Sør-Trøndelag	Kommune: Sortland Roan
Kartbladnavn (M. 1:250 000) Svolvær Namsos	Kartbladnr. og -navn (M. 1:50 000) 1623 III Roan 1232 III Sortland
Forekomstens navn og koordinater:	Sidetall: 35 Pris: kr. 60,- Kartbilag:

Feltarbeid utført:	Rapportdato:	Prosjektnr.:	Prosjektleder:
1985 og 1986	04.11.1987		

Sammendrag:

Rapporten omhandler inntrykk frå konferansen og kva følger desse bør få for utviklinga av den regionale geofysikken ved NGU.

Kopier av to "posters" om magnetiske eigenskapar til høgmetamorfe bergartar frå Lofoten og Nord-Trøndelag er vedlagt.

Emneord		
	Magnetometri	
Geofysikk	Gravimetri	
Petrofysikk		Reiserapport

INNHOLD

BILAG

Bilag 1: Magnetite in high grade and retrogressed rocks in Vestranden, Western Gneiss Region, Central Norway.

Bilag 2: A prograde granulite-amphibolite facies transition zone at Sigersfjord, Lofoten, northern Norway.

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Jan Reidar Skilbrei
Odleiv Olesen

FORMÅL MED DELTAKINGA

IUGG-konferansen (9/8-22/8, 1987) presenterte dei siste arbeida som er gjort innafor geofysikk/geologi og geodesi i form av "posters" og foredrag.
Vi stilte ut to "posters" av arbeider frå Nord-Trøndelag og Lofoten i seksjonen: "Change of magnetic properties with metamorphism and diagenesis" som er arrangert av IAGA (Internation Association of Geomagnetism and Aeronomi). Teksten til desse to utstillingane ligg i bilag 1 og 2.
Vi deltok på foredrag som viste tolking av magnetometri, gravimetri, paleomagnetisme, bruk av personlege datamaskin i geofysikk, tektonikk og kombinerte tolkinger av geofysikk/petrofysikk/geologi.

Tre "abstract"-samlingar og programmet for møtet kan lånast av Olesen eller Skilbrei.

EI VURDERING AV STATUS INNAFOR GEOFYSISKE FAGDISIPLINER

Det kom ikkje fram noko nytt m.h.p. prosessering av potensialfelt data som betyr noko i den målestokk og nøyaktigheit som NGU arbeider.
Eit nytt elektronisk gravimeter er utvikla av Scientex. Det har dårlegare nøyaktigheit enn Lacoste-Romberg gravimeter, og det er større, tyngre og dyrare. Gradiometer er utvikla av NASA der ein

kan gjere målinger frå fly med ein presisjon under 0.1 mGal. Instrumentet er meget dyrt, dvs. fleire mill. kr.

Arbeidet med å samanstille eit flymagnetisk kart for heile Europa er i gang (det same gjeld dei landområda som er flymålt i Afrika). Dette er allereie gjort for Nord-Amerika. Dette magnetiske kartet over Canada og U.S.A. har ført til ny kunnskap om regional geologi.

Dei Geologiske Undersøkelsane i Canada trykker flymagnetiske fargekart som kartbladserier i fleire målestokker. Karta som Geofysisk avdeling ved NGU lager er kvalitetsmessig fullt på høgde med desse. Vi må no utgi eitt flymagnetisk kart over Norge med havområder i M 1:1 mill. og 1:3 mill. Kart i M 1:250 000 000 bør utgis som kartserier av magnetisk residual total felt og relieffkart av desse. Relieffkarta gir betre tolkingsprodukt når ein bruker dei saman med dei vanlege karta. Relieffkarta verkar som "high-pass"-filter (viser horisontalgradienten) og framhever trender i datasettet.

Seismiske regionale data samtolka med potensialfeltdata gav dei beste resultata når det gjalt djupgeologi. Eksempel frå COCORP djup seismikk frå "Appalakkene" samtolka med magnetometri blei vist. NGU er involvert i landseismikk frå Storlien til Trondheimsfjorden. Det er viktig at vi bygger opp kompetanse på tolking av seismikk på NGU siden det er vi som tolker potensialfeltdata.

Magnetotellurikk er eitt felt som det blir gjort mykje forsking på no. Det gir viten om djupe strukturer i jordskorpa spesielt med hensyn på sutursoner. Ein av dei vanlege tolkningene av desse djupe leiarane er hydrert basaltisk skorpemateriale av havbunntype.

For å undersøke lokaliseringa av kaledonske og svekokarelske sutursoner i Finnmark og Nord-Trøndelag burde ein prøve ut magnetotellurikk. I Nord-Trøndelag kan dette gjerast langs profil der ein har gjort gravimetri og seismikk før. Desse målingane har låg kostnad, men tolkinga kan vere komplisert.

Sambandet mellom mineralogi og metamorfosegrad til bergartane og magnetiske- og gravimetriske anomalier er eit forskingsfelt som er i starten av ei utvikling. Problema innan IAGA har dessverre vore at geofysikare i dei to leirane: bergartsmagnetisering (Rock magnetism) og aeromagnetisk tolkning ikkje har samarbeidd om dette fagfeltet.

Vi kom i kontakt med J. Wasilewski (NASA) som har jobba mykje med granulittbergarter. Han skal vere redaktør for ei spesialutgåve av "Tectonophysics". Dei to arbeidene våre blei invitert til å vere med som to artikler i denne.

Vi kan få gjort ein del målinger av magnetiseringseigenskaper på prøver frå Nord-Trøndelag og Lofoten på lab. i NASA. Dette vil bli gjort gratis for oss. Søknad om midler til å sende prøver til Bergen for målinger er tidlegare avslått, men no vil berre fraktutgiftene kome på vårt budsjett. I tillegg ville Fabio Barbian, Université de Genéve, gjere lydhastighetsmålinger på bergartsprøvene våre frå granulitt/amfibolitt overgangssona i Lofoten. Desse prøvene vil bli sendt i haust.

Foredrag om granulittb.a. var av særleg interesse for oss. Mengde og fordeling av CO2-gasser og andre volatiler er av avgjerande betydning for granulitt-amfibolitt facies overganger. Overgangsoner i grunnfjellet kan kartleggjast v.hj.av magnetiske kart.

Paleomagnetisme har hatt ei kraftig utvikling dei siste åra. Saman med U-Pb og Ar-Ar aldersdateringar kan mange kronologiske-, tektoniske- og dynamiske problemstillingar løysast. NGU som landets største geologiske institusjon burde bruke paleomagnetisme som eit hjelpemiddel i geologisk kartlegging av landets geologi. Vi treng ein del nye instrumenter (som t.d. spinner magnetometer) og automatisering av eksisterende instrument på petrofysisk lab.

Vi takker Geofysisk avdeling v/H. Håbrekke, Nord-Trøndelagsprogrammet v/R. Boyd, Finnmarksprogrammet v/S. Olerud og NTNF for finansiering av reisene.

Teksten til bilag 1 er skrive av J.R. Skilbrei, unntatt "abstractet" som T. Skyseth har skrive.
Tekst til bilag 2 har O. Olesen skrive.

Trondheim, 4. november 1987
NORGES GEOLOGISKE UNDERSØKELSE
Geofysisk avdeling

Odleiv Olesen
forsker

Jan Reidar Skilbrei
forsker

MAGNETITE IN HIGH GRADE AND RETROGRESSED ROCKS IN VESTRANDEN, WESTERN GNEISS REGION, CENTRAL-NORWAY

Skyseth, T., Skilbrei, J. and Olesen, O., Division of Geophysics, Geological Survey of Norway, Box 3006, N-7001 Trondheim, Norway

Abstract

A regional aeromagnetic anomaly centred around Roan, Vestranden, is caused by granulite facies orthogneisses and metabasites with 1-2 vol % magnetite. The granulites are surrounded and partially overlain by amphibolite facies rocks which consist of reworked and retrogressed granulitic orthogneisses and bands of metasediment. The magnetite content shows a gradual decrease with increasing degree of retrogression. The metasedimentary rocks show a striking deficiency in magnetite.

The metamorphic history of the area can provisionally be divided into the following phases: A) A prograde metamorphic event resulting in high-P granulite facies is due to depression of the margin of the continent Baltica during Caledonian (Silurian) continent-continent collision. B) An early retrogression with rapid decompression is related to subsequent uplift. C) Later widespread amphibolization was followed by extensive ductile deformation.

The prograde metamorphism (A) from amphibolite to granulite facies led to production of magnetite as a result of the break-down of hydrous (Fe, Mg)-silicates. The magnetite occurs as 0.5-1 mm amoeboid grains surrounded by plagioclase and K-feldspar. Microprobe analysis show that the magnetite is close to the pure end-member with only a negligible content of ulvospinel ($FeTiO_4$) in solid solution (<1-2 mole percent). The Q-value is about 0.1-0.4 which is typical for viscous remanence in this low-coersivity multidomain magnetite.

The early retrogression at low P_{H_2O} (B) was characterized by the breakdown of garnet, producing fine-grained magnetite in almandine-rich variants. This 'secondary' magnetite is common in basic rocks where it can be the dominant type. With grains smaller than 10 um, high coersivity may develop, and this magnetite may be the carrier of remanence in such lithologies. A parallel development of magnetite can be seen in clinopyroxenes where it occurs as 0.1 mm long needles or rods within crystallographic planes. Clinopyroxene which crystallized at high P can hold an excess of Fe in the lattice, but upon decompression will have released this Fe, producing Fe-Ti oxides.

Late retrogression at high P_{H_2O} (C) led to reduction of the magnetite content due to replacement of magnetite by silicates, mainly hornblende and sphene (also leucoxene). Magnetite is still stable into upper amphibolite facies.

Factors other than metamorphism controlling magnetite content and behaviour in these rocks are mainly degree of silica saturation, major element chemistry, oxidation state, migmatization and certain low-temperature alteration processes.

Introduction

Aeromagnetic and gravimetric maps from Trøndelag, central Norway, were interpreted as part of the 'Nord-Trøndelag Programme', a project carried out by the Geological Survey of Norway.

Special attention was paid to aeromagnetic and gravimetric anomalies located around Roan in Vestranden (Fig. 1).

The basement complex of Vestranden consists mostly of gneisses of granitic, granodioritic to tonalitic and dioritic composition. Metabasites and 'Cover'sequences of down-folded metasedimentary rocks are also widespread.

The granulite facies and retrogressed amphibolite facies gneisses, and the metabasites show a striking correlation with positive residual magnetic and gravimetric anomalies.

Few works have dealt with the impact from prograde and retrograde metamorphism on magnetic properties of rocks in Norway.

Schlinger (1985) and Olesen et al. (1987) investigated the magnetic properties of rocks of deep-seated origin in the Lofoten Province, where there is a well defined transition zone between amphibolite and granulite facies gneisses.

This work reports some results from an investigation of magnetic properties, mineralogy, major element chemistry, Fe-Ti-oxide composition and geophysical modelling in a high-grade terrain where the metamorphic facies changes abruptly on a local scale between granulite - and retrograde amphibolite - facies assemblages.

Methods

129 rock samples were measured in the laboratory with respect to magnetic susceptibility, density and Q-values.

At each of 93 localities 10-15 in situ magnetic susceptibility measurements were recorded using an induction coil with a size of 20 cm x 20 cm.

When the interpretation of the petrophysical data obtained was completed, 30 thin sections from selected hand specimens were examined in reflected and transmitted light to study Fe-Ti oxide and silicate mineralogy, with special attention to metamorphic reactions. Microprobe analysis was used to examine Fe-Ti oxides.

Results

The prograde metamorphism into granulite facies assemblages produced magnetite with the breakdown of hydrous (Fe-Mg)-silicates. This magnetite typically occurs as 0.5-1 mm amoeboid grains (Fig. 4).

The main factor other than metamorphism controlling magnetite content in the rocks is major element chemistry.

The correlation between major element chemistry and in situ magnetic susceptibility is illustrated by the frequency distribution diagrams in figs. 5a-c.

An X-Y plot of susceptibility versus density (Fig. 6) separates rock groups well.

The Q-values are around 0.25 on average (Fig. 7). Thus magnetization is parallel to the earth's magnetic field, simplifying modelling of magnetic anomalies. Combined modelling of residual magnetic and gravimetric anomalies indicated that the basement rocks form a dome with relatively steep sides and extending downwards to a depth of at least 12 km (Skyseth, 1987). High T-low P retrogression led to breakdown of garnet and the production of magnetite (Fig. 8). This secondary magnetite can be the dominant type in basic rocks. Secondary magnetite can also be observed as 0.1 mm long needles or rods in clinopyroxenes within crystallographic planes. With alteration of clinopyroxene to hornblende on later retrogression, hornblende inherits the magnetite (Skyseth, 1987).

Retrogression to amphibolite facies led to reduction of magnetite content due to replacement of magnetite by hornblende mainly and sphene (Skyseth, 1987). Thus, the highest susceptibility values measured are generally associated with specimens taken from granulite facies rocks, as illustrated in Fig. 9.

Conclusion

Combined interpretation of mineralogy and petrography, petrophysical data and geophysical data from the Roan area, Central Norway, have revealed new aspects of the regional geology, and verified the previously proposed model for the geological history of the area (Johansson & Möller 1986, Möller 1986).

It is concluded that prograde metamorphism from amphibolite to granulite facies increased magnetite content and consequently magnetic susceptibility. Secondary magnetite produced during early retrogression at low P-high T is observed in basic rocks. Such fine-grained magnetite is possibly the carrier of high remanence. Later retrogression into amphibolite facies led to reduction of magnetite content.

Consequently, the granulite facies gneisses generally have the highest magnetite content, giving rise to magnetic susceptibility values similar to the values that Olesen et al. (1987) and Schlinger (1985) reported from granulite facies gneisses in the Lofoten area, and also comparable to the magnetic properties (Powell, 1970) of high-grade rocks from the Lewisian complex in North-West Scotland.

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Figure captions

Fig. 1 Simplified geological map of Central-Norway.

Fig. 2 Aeromagnetic residual map.

Fig. 3 Bouguer gravity residual anomaly map.

Fig. 4 Magnetite and ilmenite in silicate matrix.

Fig. 5 Percentage frequency distribution of in situ magnetic susceptibility for (a) granitic gneiss, (b) dioritic gneiss and (c) metabasites. Values in SI-units.

Fig. 6 Plot of magnetic susceptibility versus density.

Fig. 7 Percentage frequency distribution of Q-values for quartz monzonitic gneiss.

Fig. 8 Magnetite produced by the breakdown of garnet.

Fig. 9 Percentage frequency distributions of susceptibility for quartz monzonitic and granitic gneiss. The vertical lines separate values measured on specimens taken from granulite facies rocks from values measured on rocks of lower grade.

Fig 1

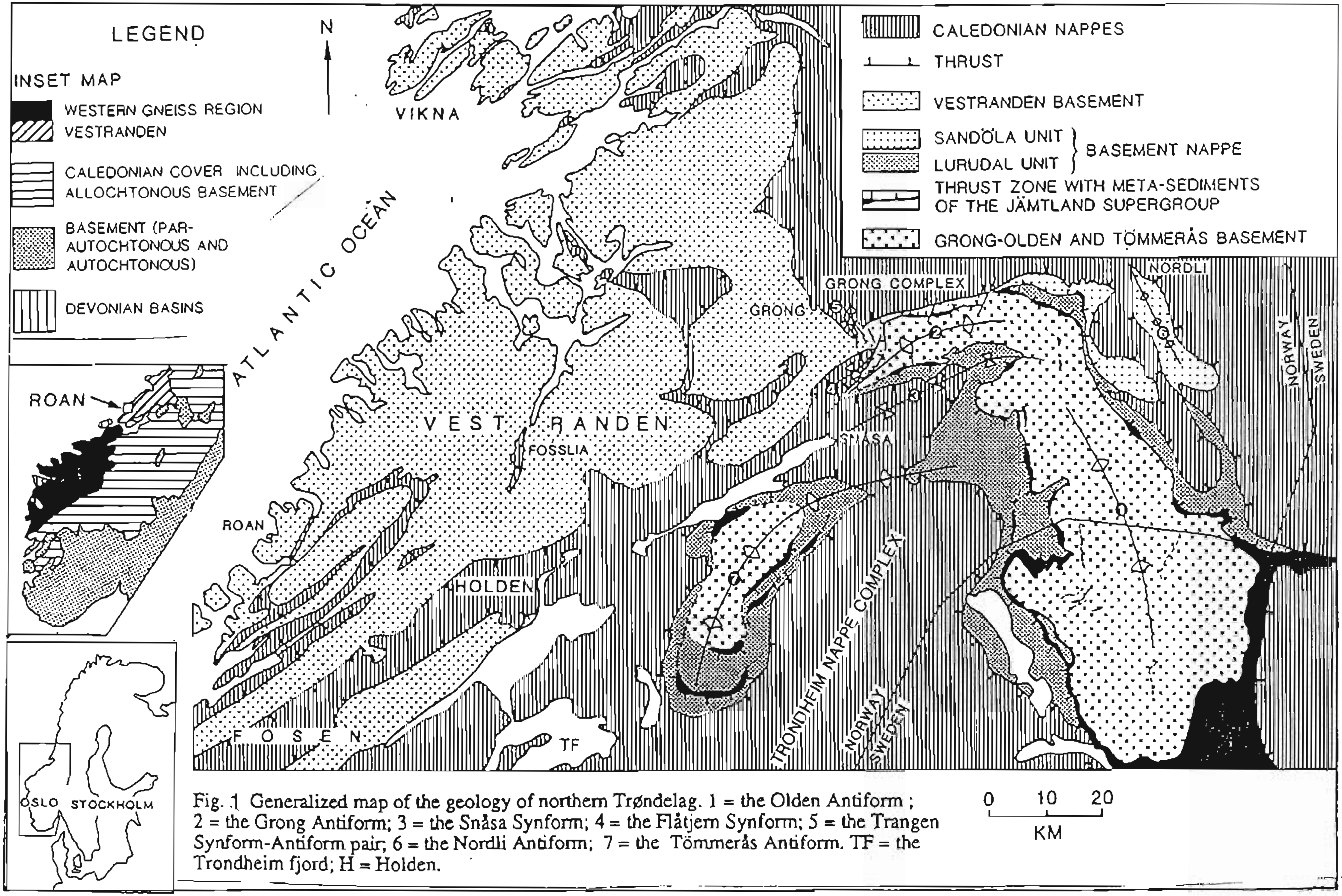

Fig. 1 Generalized map of the geology of northern Trøndelag. 1 = the Olden Antiform ; 2 = the Grong Antiform; 3 = the Snåsa Synform; 4 = the Flåtjern Synform; 5 = the Trangen Synform-Antiform pair; 6 = the Nordli Antiform; 7 = the Tömmerås Antiform. TF = the Trondheim fjord; H = Holden.

(From Leif Johansson - 1986)

Fig. 2

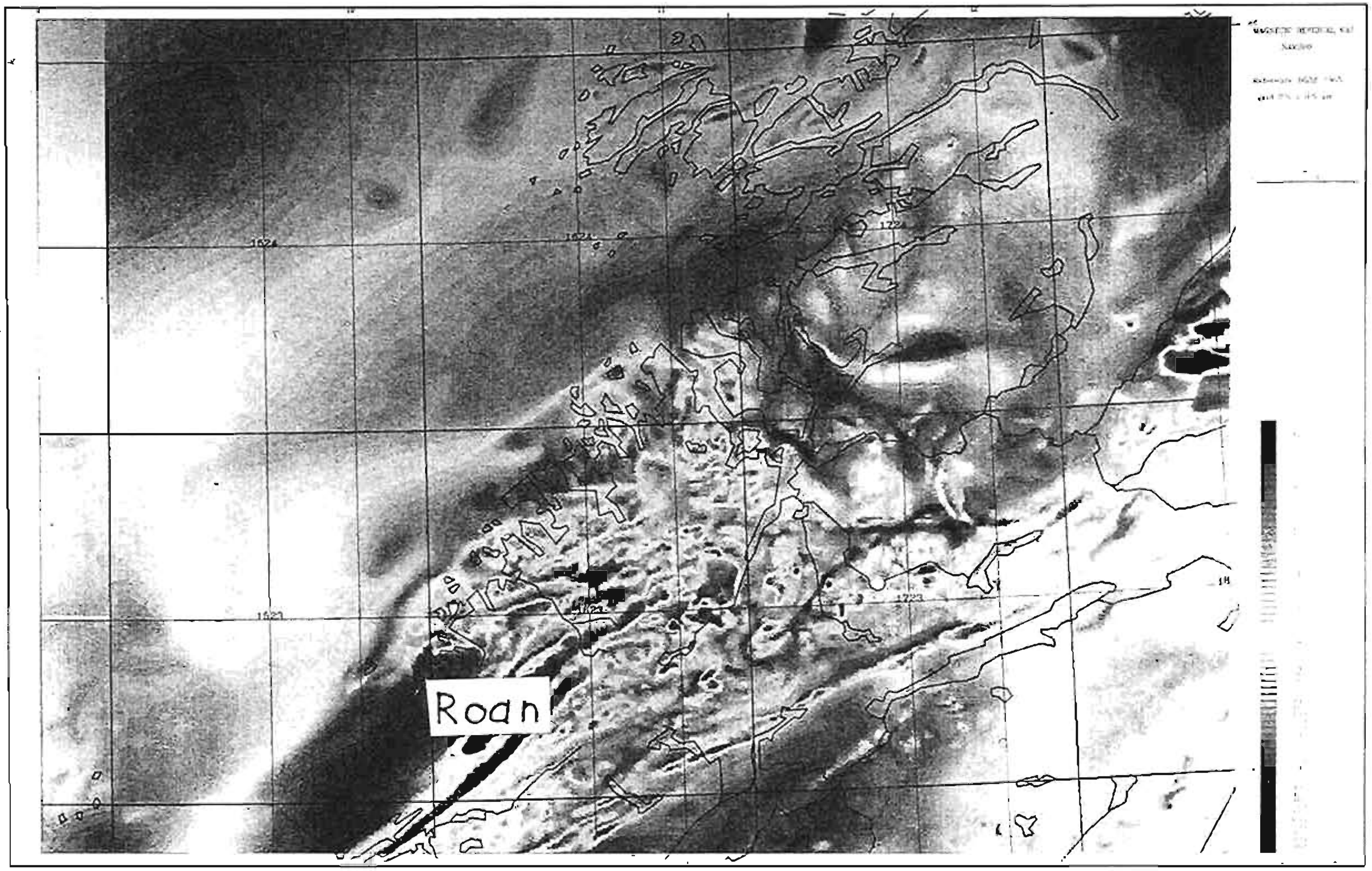

Fig 3

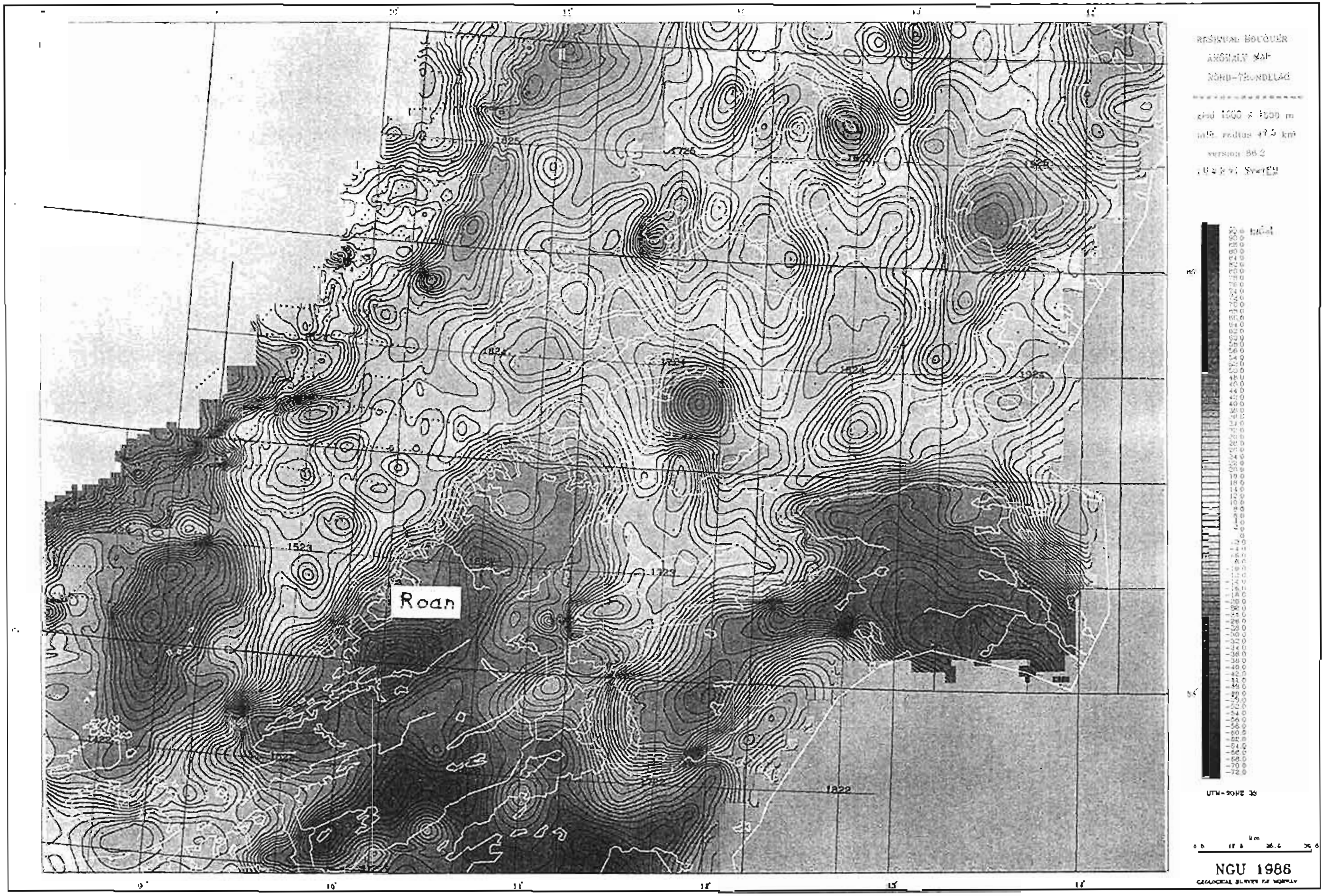

Fig. 8

Fig. 4

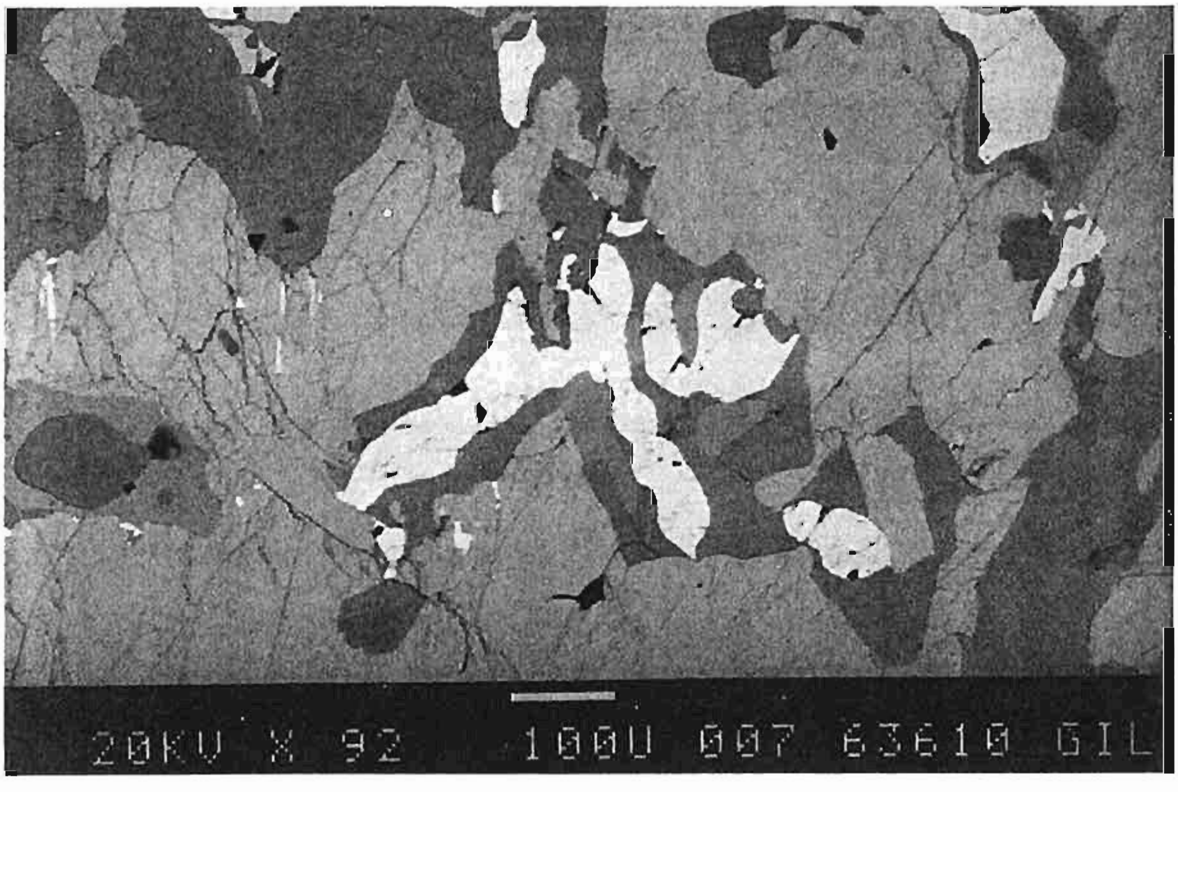

Fig. 5 a-c

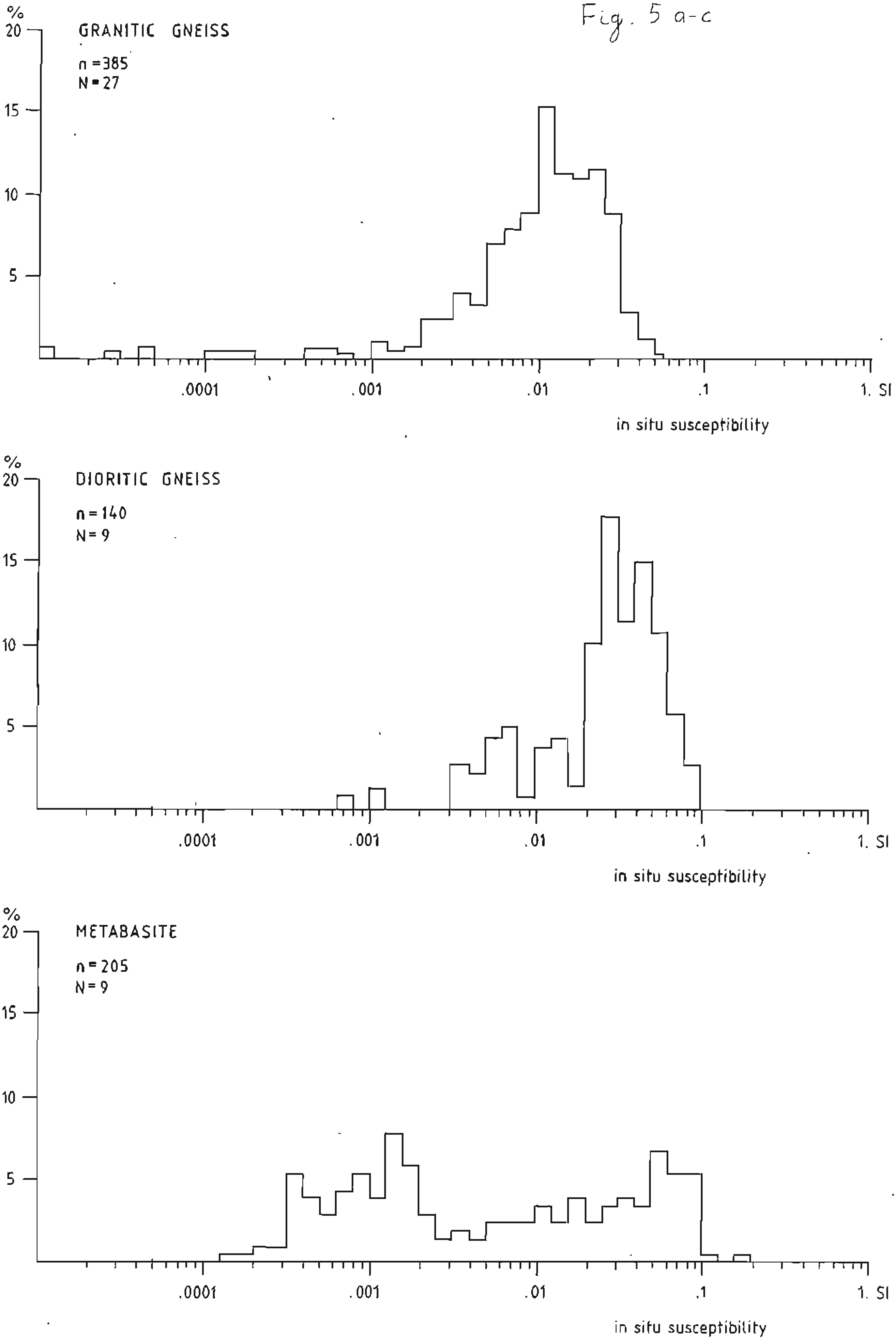

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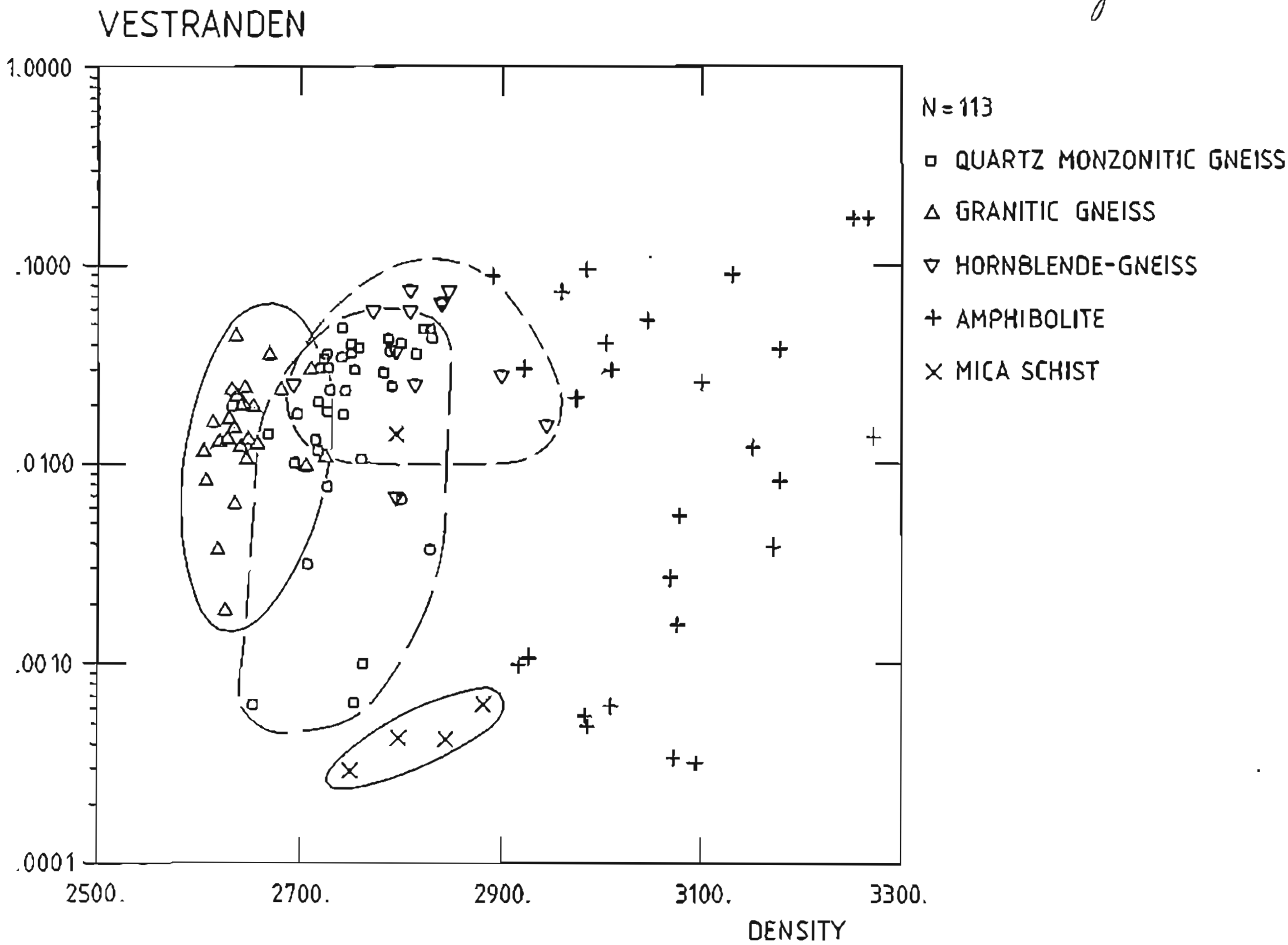
Fig. 6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MICA SCHIST

Fig. 7

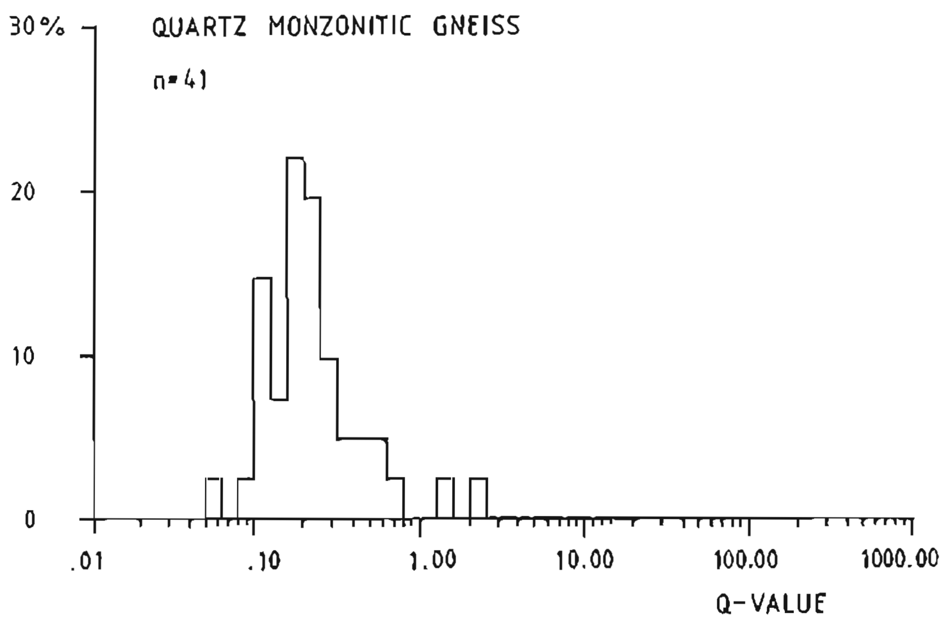
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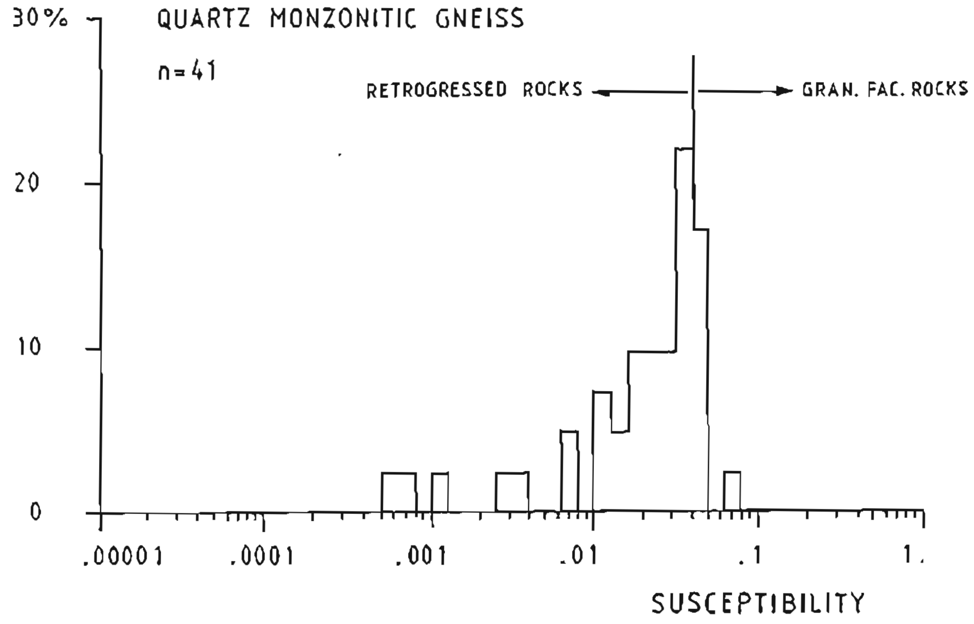
Fig. 9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SUSCEPTIBILITY

Manuscript date June 18th, 1987

A prograde granulite - amphibolite facies transition zone at Sigersfjord, Lofoten, northern Norway.

ODLEIV OLESEN, HERBERT HENKEL, KJETIL KAADA & EINAR TVETEN

Olesen, O., Henkel, H., Kaada, K. & Tveten, E. 1987: A prograde granulite - amphibolite facies transition zone at Sigersfjord, Lofoten, northern Norway. *Poster session, International Union of Geodesy and Geophysics (IUGG), XIX General Assembly, Vancouver, Canada, Aug. 9-22,* xx pp.

The Lofoten area in northern Norway is a province of deep-seated origin with associated regional magnetic and gravimetric anomalies. With regard to interpretation of aeromagnetic and gravimetric data in northern Fennoscandia, a regional transition zone between amphibolite and granulite facies gneisses has been examined in detail. The exact location of this petrographical border is defined by the first appearance of orthopyroxene in the intermediate gneisses. This orthopyroxene isograd is situated within an approximately 1.4 km wide magnetic transition zone where the average magnetite content is increasing fairly gradually from approximately 0.05 % in the amphibolite facies to 1.0 % in the granulite facies. These estimates are based on in situ susceptibility measurements which show an increase from $150 \cdot 10^{-5}$ SI to $3000 \cdot 10^{-5}$ SI. Magnetite is by far the most common Fe-oxide. The orthopyroxene isograd is situated approximately 500 m from the point where the susceptibility starts increasing. A few of the samples in the granulite facies have garnet occurring as coronas around Fe-Ti oxides and pyroxenes, indicating high-pressure retrograde metamorphism. Prograde textures are however predominant.

The density shows a moderate increase across the profile, from $2.76 \cdot 10^3$ kg/m^3 in the amphibolite facies rocks through $2.78 \cdot 10^3$ kg/m^3 in the transition zone to $3.81 \cdot 10^3$ kg/m^3 in the granulite facies rocks. The Q-values are 1.5 for the amphibolite facies, 0.34 for the transition zone and 0.27 for the granulite facies. The remanence is predominantly viscous.

Based on susceptibility measurements and examination of thin sections it is concluded that the prograde metamorphism occurred along weakness-zones in the rocks where fluids like CO_2 had easily access and H_2O could escape. The frequency and the width of these zones increase through the steeply dipping transition zone. A few cases of retrograding along the profile seem also to take place in weakness-zones due to later supply of H_2O.

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Introduction

In a Nordic cooperation project between the geological surveys of

Finland, Norway and Sweden, interpretation of aeromagnetic and gravimetric maps in northern Fennoscandia have been performed. Special attention was drawn to the Lofoten area in northern Norway (Fig. 1) because of the associated large magnetic and gravimetric anomalies (Fig. 2 and 3). These are believed to reflect an up-warping of the Mohorovičić discontinuity (Kjenes 1970, Svela 1971) and a consequent exposure of rocks formed in the deep crust.

The Lofoten Province is composed predominantly of Precambrian polymetamorphic granulite facies migmatite gneisses and intrusives both of intermediate (andesitic) composition. The migmatites are thought to be formed essentially by moderate anatexis of volcanic and volcanoclastic rocks (Griffin et al. 1978). An orthopyroxene isograd runs through the eastern part of the area (Fig. 1). West of this line the migmatites are in granulite facies and to the east they are in amphibolite facies. This isograd represents a prograde reaction. There is no obvious difference in the structures or the major element chemistry of the migmatites on the two sides of the isograd (Heier & Thoresen 1971). The observed granulite facies assemblage was therefore most probably superimposed on already migmatized rocks.

In the past two decades a number of thorough investigations have been carried out in the Lofoten area. Schlinger (1983, 1985) showed that the main cause of the increase in magnetic properties in the rocks is the progressive breakdown of hydrous, iron-rich (Fe,Mg) silicates such as biotite and amphibole toward magnesium rich orthosilicates such as pyroxene. Griffin & Heier (1969) suggested the generalized retrograde reaction

Fe-biotite + pyroxenes + plagioclase ± magnetite/sulphides + O_2 → hornblende + K-feldspar + Mg-biotite + garnet ± magnetite/sulphides + quartz

for the consumption of pyroxene and introduction of garnet and amphibole and secondary biotite during the retrogression to amphibolite facies. This reaction from right to left is also representative for the prograde metamorphism of the intermediate gneisses.

Methods

The main goal of this study is to examine the orthopyroxene isograd. Sigersfjord on West Hinnøy (Fig. 1) was chosen as an appropriate location for this study because the granulite/amphibolite facies contact in this area is interpreted not to be tectonic. In addition there is an abundance of fresh roadcuts along a line almost perpendicular to the orthopyroxene isograd.

At each of 29 locations along a 9 km long profile, 10-15 in situ magnetic susceptibility measurements were carried out 3-10 m apart in addition to collection of one hand specimen. The distance between the locations varied from 100 to 800 m and is shortest in the vicinity of the orthopyroxene isograd. The size of the induction coil for the in situ susceptibility measurements was 20 by 20 cm. The susceptibility, Q-values and density were measured in laboratory (Kaada 1987). Three representative samples were selected for measurements of the Curie-temperature. In addition to the 29 rock samples, we oriented another twelve from the granulite facies part of the profile for measurements of the NRM-directions.

The data are illustrated as a susceptibility profile (Fig. 4), susceptibility frequency distributions (Fig. 5), X-Y plots of susceptibility versus density (Fig. 6a) and susceptibility versus Q-value (Fig. 6b). The curved continuous lines in the susceptibility versus density diagram (Fig. 6a) represent the effect of the magnetite content on density (Henkel 1976). By extrapolating the density measurements along these curves down to the axis of abscissas an estimate of the silicate density can be achieved.

Polished thin sections of 15 rock-samples were examined in reflected and transmitted light to determine the Fe-Ti oxide mineralogy and the metamorphic mineralogy (Kaada 1987).

Results

The susceptibility profile (Fig. 4) indicates an approximately 1.4 km wide transition zone where the average susceptibility increases gradually from $150 \cdot 10^{-5}$ SI in amphibolite facies to $3000 \cdot 10^{-5}$ SI in granulite facies. This represents an increase in magnetite-content from approximately 0.05 % to approximately 1 % which is representative for the magnetite-content in the rest of the Lofoten granulite facies terrain (Schlinger 1983). The orthopyroxene isograd is situated within the transition zone, 500 m from the point where the susceptibility starts to increase. Sample site no. 14 and 15 show lower values due to fracture zones where magnetite is oxidized to hematite.

The susceptibility histograms in Fig. 5 show unimodal distributions for the amphibolite and the granulite facies gneisses. The distribution of the granulite facies measurements is however negative skewed and shows signs of bimodal character due to the low value measurements in the retrograded and oxidized zones. In the frequency distribution diagram the measurements from the transition zone occupy the area between the peaks of the granulite and amphibolite facies measurements. The distribution of the data from this transition zone is bimodal. The samples from the transition zone also show a tendency to plot within two groups in the susceptibility versus density plot (Fig. 6a). One of the groups, however, contains only two samples.

The first occurrence of orthopyroxene is found in sample no. 92. The mineralogical border is consequently between location no. 92 and 74 (Fig. 4). Magnetite grains were found in all thin sections. Fig. 7 shows typical occurring magnetite grains in the granulite facies gneisses. The magnetite grains are usually in close contact with iron-rich biotite and have a secondary biotite phase as a rim around the grain. The size of the Fe-Ti oxides in the thin sections for both facies varied between 0.1 and 0.7 mm with an average of approximately 0.3 mm. In addition to a relatively smaller amount of opaque minerals in amphibolite facies, the thin sections showed that the size in average was somewhat smaller than in granulite facies. Titanomagnetite and hemoilmenite are also occurring, especially in the granulite facies rocks. A few of the granulite facies samples showed sign of retrograding where garnet occur in corona-structures around Fe-Ti oxides and pyroxene (Fig. 8). The occurrence of this secondary garnet is interpreted to be a result of late stage cooling at high temperature associated with the granulite facies metamorphosis 1830 Ma ago (Griffin & Heier 1969, Schlinger 1985).

Curie-temperature measurements show that the rocks contain magnetite on both sides of the isograd. The amphibolite facies gneisses contain sulphides.

In the susceptibility versus density diagram (Fig. 6a) 62 % of the samples are within the intermediate area, 31 % within the acid and 7 % in the basic. The density shows a moderate increase across the profile, from $2.76 \cdot 10^3$ kg/m^3 in the amphibolite facies rocks through $2.78 \cdot 10^3$ kg/m^3 in the transition zone to $3.81 \cdot 10^3$ kg/m^3 in the granulite facies rocks. Approximately half of this increase is caused by the increase of magnetite content and the other half is most probably related to the alteration of amphibole and biotite to pyroxene.

The Q-values are 1.5 for the amphibolite facies rocks, 0.34 for the transition zone and 0.27 for the granulite facies. Amphibolite facies rocks have consequently the highest Q-values, which is consistent with observations in other Precambrian shields (Grant 1985). This phenomenon is also responsible for the observed negative susceptibility - Q-value correlation (Fig. 6b). The higher coercive force is probably caused by small magnetite grains within amphibole-grains and/or occurrence of titanomagnetite and ilmenite. The NRM-measurements showed no stable direction and the remanence is therefore believed to be viscous. This is also previously shown for the Lofoten area by Schlinger (1983, 1985).

Conclusions

Based on susceptibility measurements and study of thin sections it is concluded that there is a gradual change in metamorphic grade across a 1.4 km wide transition zone from amphibolite facies to the east to granulite facies in the west. The first prograde metamorphism in this transition zone has taken place along small scale fractures where fluids like CO_2 have easy access to the rocks and H_2O can escape. The frequency and width of these prograde bands increase across the transition zone. Retrograding seems also to occur along the same type of fractures due to supply of H_2O. This type of process can account for the quite wide range of the susceptibility within each site in the transition zone (Fig. 4), and a gradual increase of the median value of the susceptibility from site to site occurs across the zone. The process can also explain the apparent bimodal character of the susceptibility distribution within the transition zone. The value of susceptibility will depend on whether the induction coil includes or does not include a prograde metamorphosed zone.

Kaada (1987) interpreted the dip of the amphibolite/granulite facies contact to be approximately 80° to the west based on aeromagnetic data. At the moment it is not possible to decide if this almost vertical dip indicate the original position of the orthopyroxene isograd or if it is due to later emplacement.

Acknowledgements

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Figure captions

Fig. 1. Geological map of the Lofoten - Vesterålen area. The dashed line is the orthopyroxene isograd modified after Griffin et al. (1978) with pluses on the upgrade side.

Fig. 2. Aeromagnetic residual map.

Fig. 3. Bouguer gravity anomaly map.

Fig. 4. Susceptibility profile (9 km long) from the Sigersfjord area.

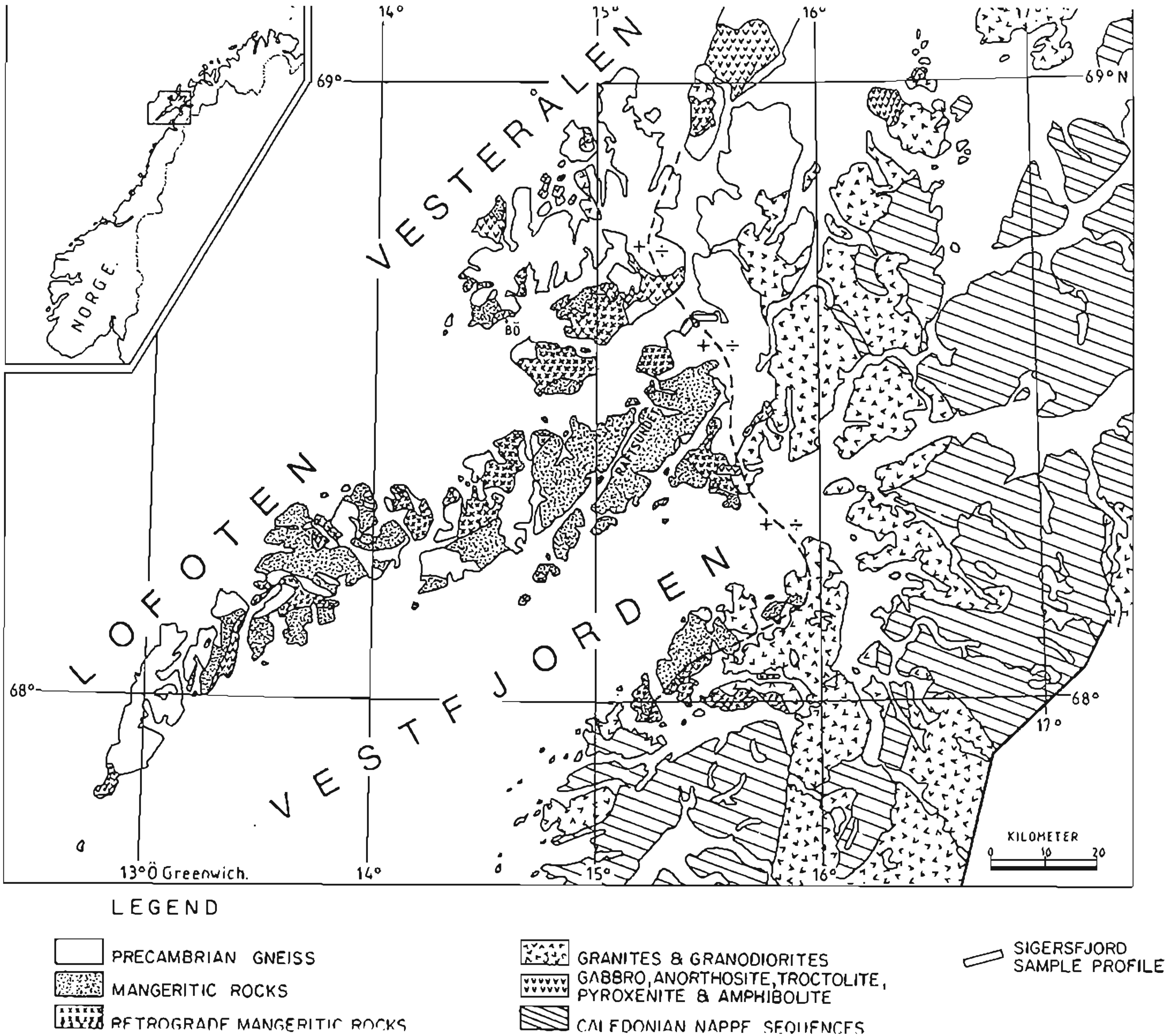
Fig. 5. Susceptibility spectra of rocks in the transition zone and of the granulite and amphibolite facies rocks to the west and east respectively.

Fig. 6. Plot of a) susceptibility versus density and b) susceptibility versus Q-value. The curved continuous lines represent the effect of the magnetite content on density (Henkel 1976). By extrapolating the density measurements along these curves down to the axis of abscissas an estimate of the silicate density can be achieved.

Fig. 7. Typical occurring magnetite grain in the intermediate granulite facies gneisses from Sigersfjord, Hinnøy. a) Transmitted light. b) Reflected light.

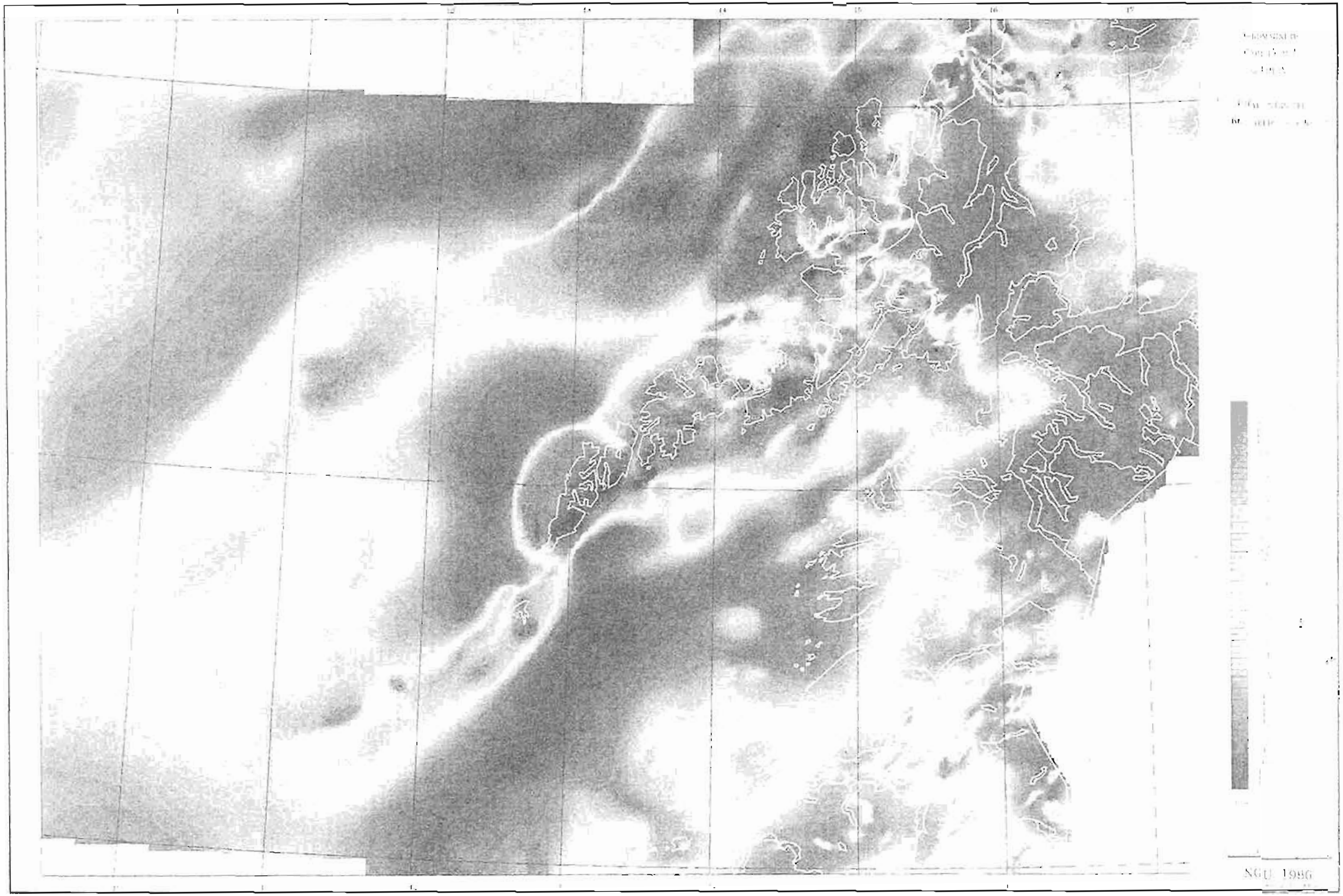
Fig. 8. Garnet coronas around a magnetite grain. Outside the garnet is a rim of radial biotite. a) Transmitted light. b) Reflected light.

Fig. 1



NORGE.
VESTERÅLEN
LOFOTEN
VESTFJORDEN
BÖ
RAFTSUNDET
69°
69° N
68°
68°
14°
15°
16°
17°
13° Ö Greenwich.
14°
15°
16°
17°
KILOMETER
0
10
20
LEGEND
PRECAMBRIAN GNEISS
MANGERITIC ROCKS
RETROGRADE MANGERITIC ROCKS
GRANITES & GRANODIORITES
GABBRO, ANORTHOSITE, TROCTOLITE, PYROXENITE & AMPHIBOLITE
CALEDONIAN NAPPE SEQUENCES
SIGERSFJORD SAMPLE PROFILE

Fig 2



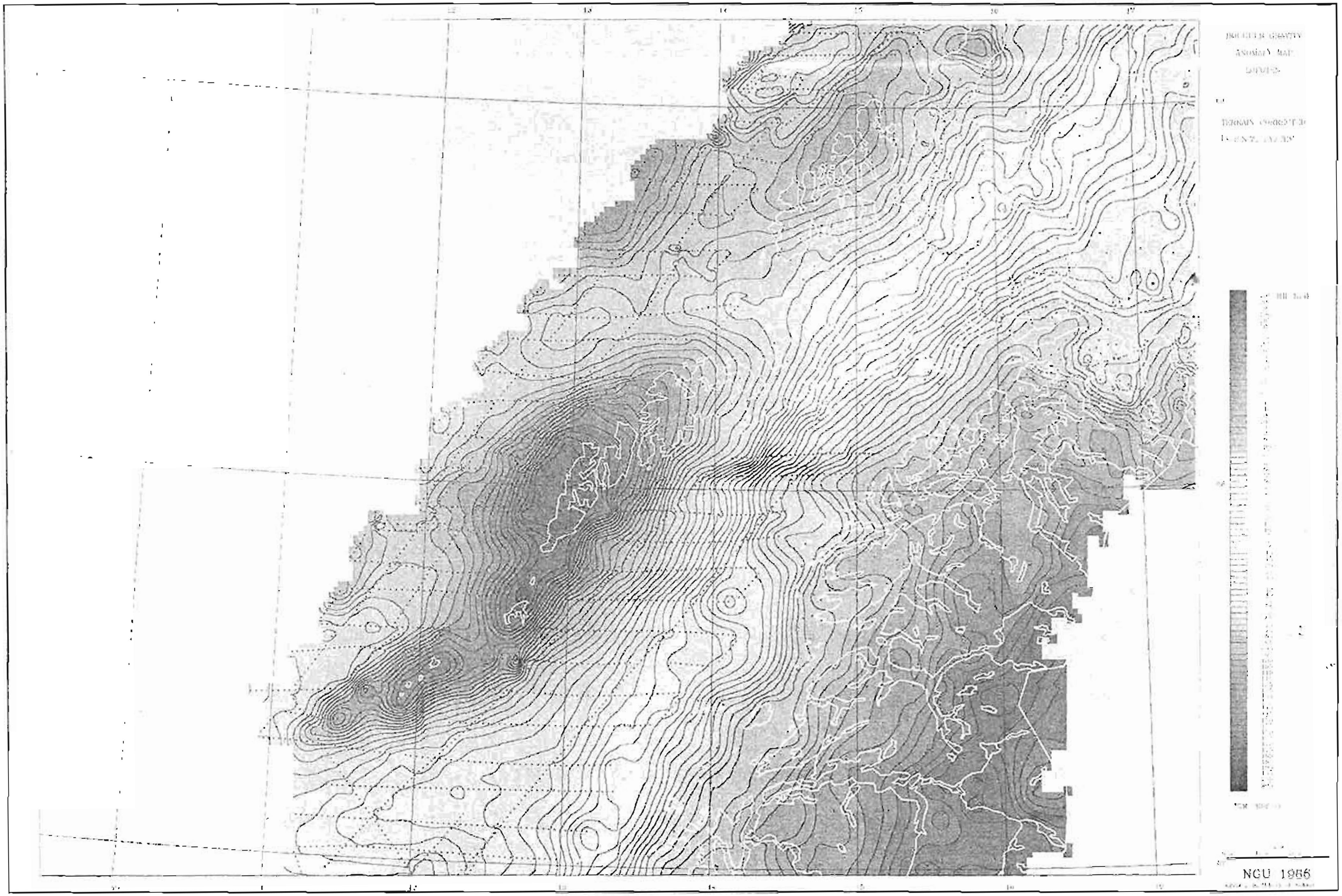
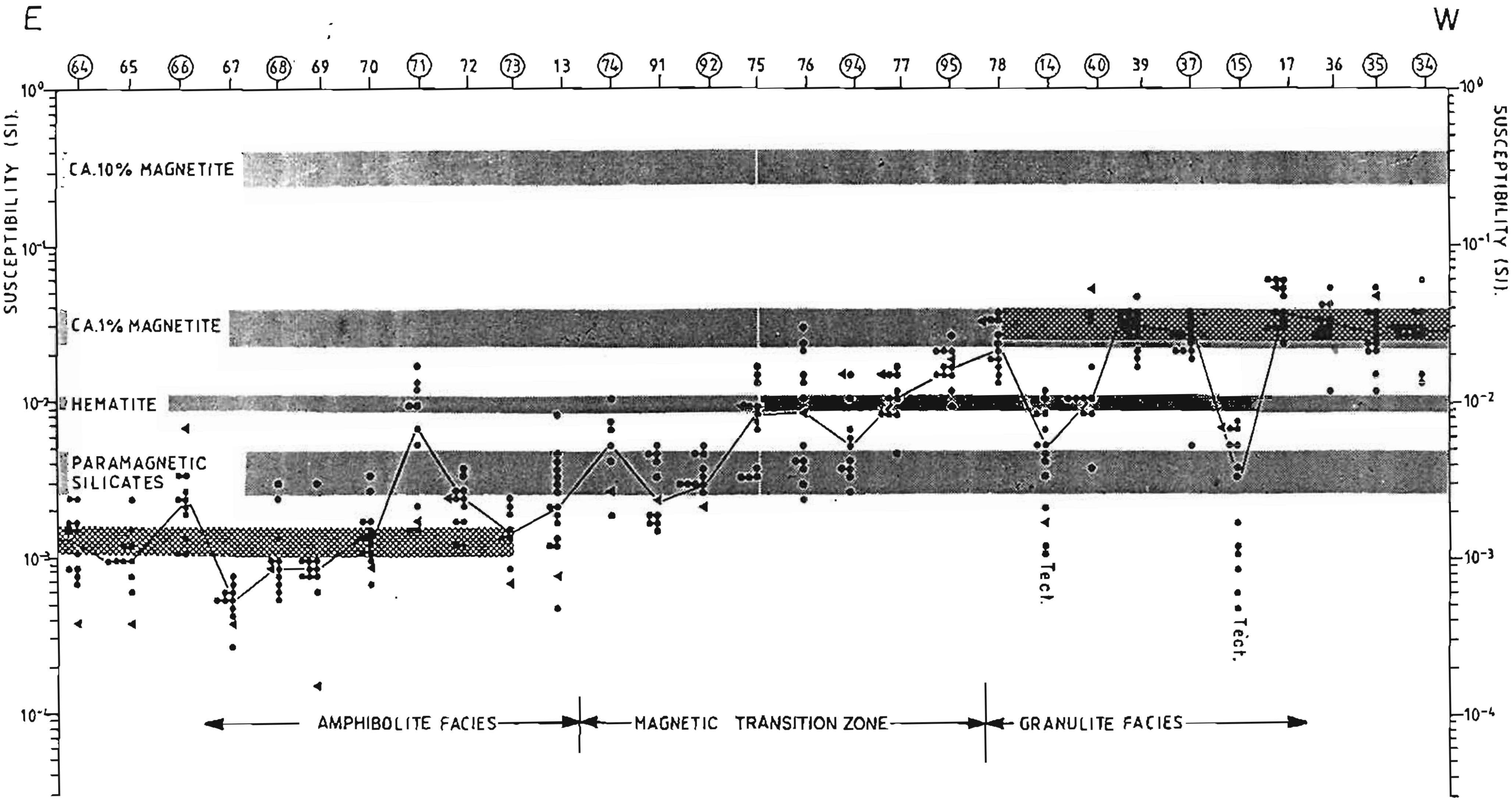

NGU 1986

Fig 4



LEGEND

94 LOCALITY / SAMPLE NO.

(74) THIN SECTION SAMPLE

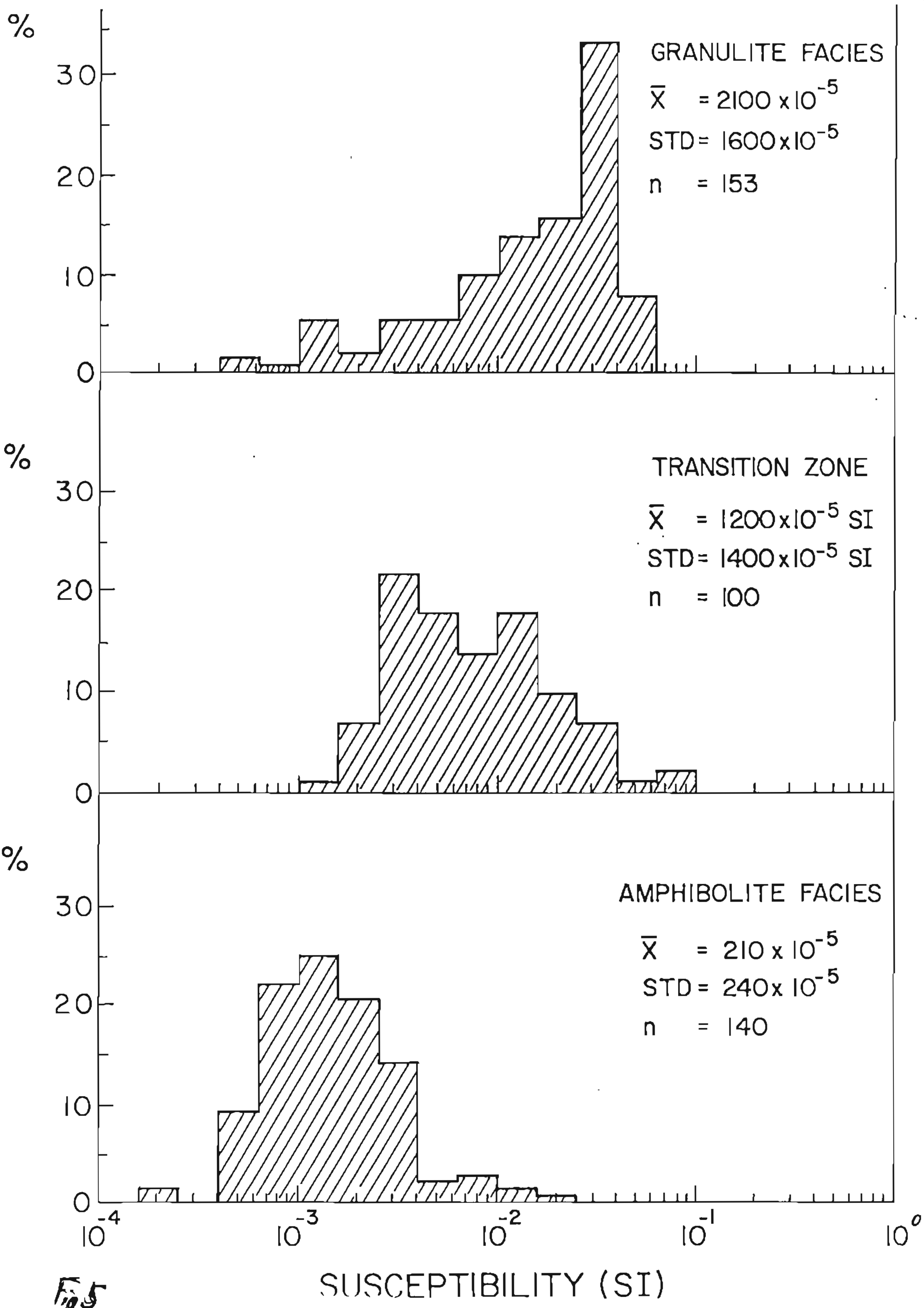
Tect. TECTONIZED ZONE

● IN-SITU SUSCEPTIBILITY MEASUREMENT

◄ SUSCEPTIBILITY OF SAMPLE

— MEDIAN VALUE

▓ SUSCEPTIBILITY TREND


%
GRANULITE FACIES
$\bar{X}$ = 2100 x 10^{-5}
STD = 1600 x 10^{-5}
n = 153
TRANSITION ZONE
$\bar{X}$ = 1200 x 10^{-5} SI
STD = 1400 x 10^{-5} SI
n = 100
AMPHIBOLITE FACIES
$\bar{X}$ = 210 x 10^{-5}
STD = 240 x 10^{-5}
n = 140
0
10
20
30
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
SUSCEPTIBILITY (SI)
Fig 5

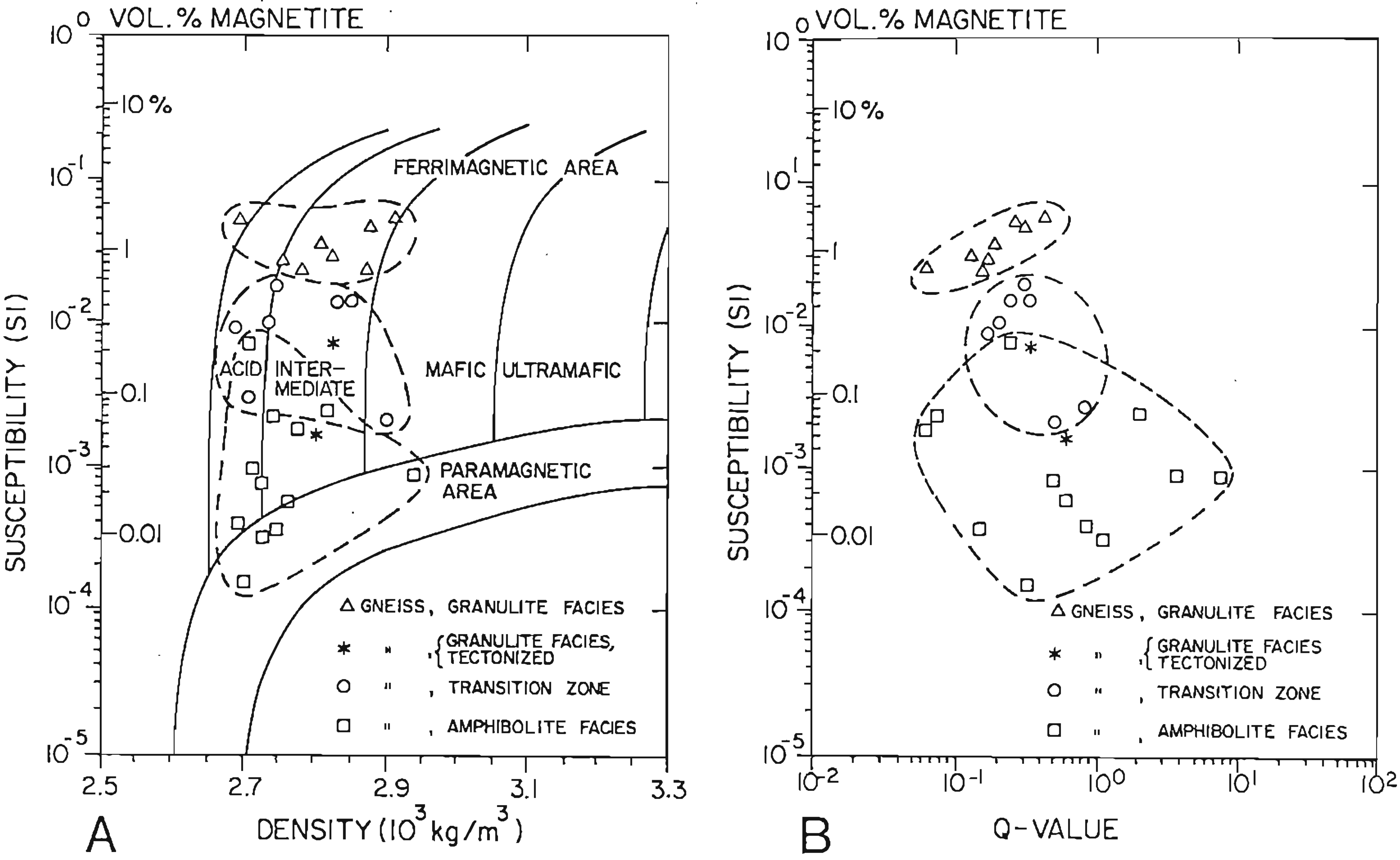

VOL.% MAGNETITE
10%
1
0.1
0.01
FERRIMAGNETIC AREA
ACID
INTER-MEDIATE
MAFIC
ULTRAMAFIC
PARAMAGNETIC AREA
SUSCEPTIBILITY (SI)
DENSITY (10^3 kg/m^3)
A
Q-VALUE
B
△ GNEISS, GRANULITE FACIES
* " , {GRANULITE FACIES, TECTONIZED
○ " , TRANSITION ZONE
□ " , AMPHIBOLITE FACIES

Fig 6

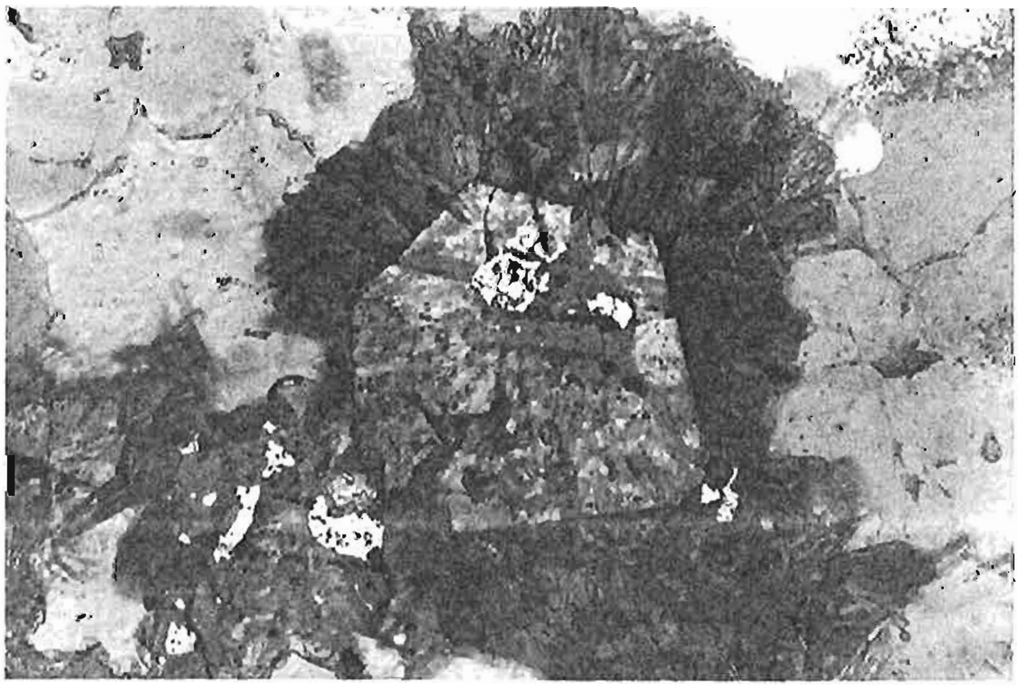
A

B

0.2mm.

Fig 7

A



B

0.1mm

Fig 8