UNIVERSITE DU QUEBEC A CHICOUTIMI

PETROGRAPHY OF LEUCOCRATIC SEGREGATIONS IN THE MIGMATITIC OLD GNEISS COMPLEX EAST OF CHICOUTIMI, QUEBEC

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ABSTRACT

PETROGRAPHY OF LEUCOCRATIC SEGREGATIONS IN THE MIGMATITIC OLD GNEISS COMPLEX EAST OF CHICOUTIMI, QUEBEC

Possible mechanisms and conditions of polyphase migmatization have been determined for quartzofeldspathic segregations in the migmatitic Old Gneiss Complex east of Chicoutimi, Quebec. Rocks of three age groups have been identified:

1) Paragneisses, related concordant amphibolite, granite I, and rare amphibolite I dykes contain thin leucocratic veins (mobilizate I) outlining S1 schistosity.

2) Charnockitic granite IIa, granite IIb augengneiss, and rocks of age group I were intruded by four generations of felsic to mafic dykes emplaced in a regional-scale tensional environment. Subsequent compression (deformation IIa) formed a dominant S2a schistosity, which controls localization of leucocratic segregations generated early in migmatization II (mobilizate IIa). These have been folded (F2b) during deformation IIb, subsequently refolded by deformation IIc, during which mobilizate IIb veins segregated along F2c strain slip axial plane surfaces. Late leucosomes generated during migmatization II cross cut F2b folds, F2c axial planes, and earlier formed leucosomes. Leucosomes generated during migmatization I and complex migmatization II are in situ: leucosome mineralogy is controlled by paleosome type and melanosomes consisting of paleosome mafic minerals are present. Migmatization I leucosomes consist of subanatectic mineral assemblages, and are considered to be products of metamorphic segregation tentatively under conditions of 650 to 700 C, at 3.5 to 4.5 kb. Migmatization II leucosomes exhibit fluid behaviour, and leucosome plagioclases (An 12-15) are considerably more albitic than melanosome plagioclases (An 28) in granite I paleosomes, therefore an anatectic origin is indicated. The paragneiss mineral assemblage garnet-cordierite (Fe:Mg~4:6) -potash feldspar, retrograding to biotite-sillimanite-quartz, indicates anatectic conditions of 750 to 800 C, at about 5.5kb (15 to 20 km), given that $P(H_2O) = (?)\ P$ total. Dehydration reactions instigated partial melting in all rocks except amphibolites, where migmatization occurred largely within the stability fields of biotite and hornblende (very locally breaks down to clinopyroxene + (?) melt). Amphibolites for the most part segregated mobilizate II leucosomes by the process of metamorphic segregation, whereas granitic rocks and paragneisses suffered partial melting during migmatization II.

3) Following deformation IIc, trondhjemitic to granitic pegmatites and granitoids (mobilizate III) were injected into rocks of age groups I and II, and, west of the study area, syenitic granite III plutons. Multiple pegmatite injection in part coincided with deformation III shearing; some pegmatites follow S3 shear surfaces, subsequently reactivated, shearing the enclosed pegmatite vein.

RESUME

PETROGRAPHIE DES SEGREGATIONS LEUCOCRATES DU COMPLEXE MIGMATITIQUE A L´EST DE CHICOUTIMI, QUEBEC

Les mécanismes et les conditions de migmatisation polyphasée ont été déterminés pour les ségrégations quartzo-feldspathiques du complexe migmatitique à l´est de Chicoutimi, Quebec. Chronologiquement, trois groupes lithostructuraux sont distingués:

1) Les paragneiss, les amphibolites concordantes associées, le granite I et localement des dykes d´amphibolite I. Toutes ces roches contiennent des veines leucocrates minces (mobilisat I), qui suivent la schistosité S1.

2) Un gneiss charnockitique (granite IIa) et le granite gneissique oeillé IIb. Toutes les roches des groupes I et II ont été injectées par au moins 4 générations de dykes felsiques à mafiques. La mise en place de ces dykes coincide avec une periode d´extension régionale. Une compression subsequente (déformation IIa) a crée une schistosité dominante (IIa) qui contrôle la localisation des segregations leucocrates (mobilisat IIa) generées tôt pendant la migmatisation II. Ces mobilisats ont été plissés (F2b) durant la déformation IIb, et peu après replissés par la déformation IIc. Durant cette déformation, le mobilisat IIb s´est accumulé le long des surfaces de "strain slip" (S2c), parallèles aux plans axiaux des plis F2c. Les leucosomes générés pendant les stages tardifs de la migmatisation II recoupent les plis F2b, les plans axiaux de F2c et les leucosomes antérieurs.

Les leucosomes génerés pendant les périodes de migmatisation polyphasés I et II le furent in situ. La minéralogie des leucosomes est contrôlée par le type de paleosome et les minéraux mafiques des mélanosomes presents sont les mêmes que ceux du paleosome correspondant. Les veines du mobilisat I consistent en assemblages minéralogiques subanatectiques qui sont considerés comme un des produits de ségregation métamorphiques qui se sont formés sous des conditions estimées à 650-700 C; 3.5-4.5 kb. Les leucosomes generés durant la migmatisation polyphasée II montrent des comportements de fluide. Les plagioclases dans ces leucosomes (An 12-15) sont plus albitiques que les plagioclases dans le mélanosome (An 28) du granite I adjacent. Ainsi, une origine anatectique est indiquée pour le mobilisat II. L´assemblage minéralogique grenat-cordierite (Fe:Mg$\sim$4:6)-feldspath potassique, qui se transforme par rétrogression en biotite-sillimanite-quartz dans le paragneiss, indique des conditions d´anatexie >750 C, a 5.5 kb (15-20 km). Des réactions de déshydratation amorcent l´anatexie dans toutes les roches sauf les amphibolites, où la migmatisation s´est produite largement dans les champs de stabilité de la biotite et de la hornblende, ce deuxième minéral se transforme localement en clinopyroxene + (?) liquide. La presence des veines de mobilisat II dans les amphibolites est dûe largement au processus de ségregation métamorphique. Par contre, les roches granitiques ainsi que les paragneisses on subit une anatexie lors de la migmatization II.

3) La mise en place de pegmatites et de granitoides (mobilisat III) qui suivent la deformation IIc. Ces roches de composition trondhjemitique à granitique se sont mis en place dans les roches du groupe I et II et à l´ouest de la région étudiée, dans les plutons syénitiques (granite III). La mise en place polyphasée des pegmatites coincide en partie avec le cisaillement de la déformation III. Quelques pegmatites suivent les surfaces de cisaillement "S3" qui sont subsequemment reactivées, cisaillant ainsi la pegmatite.

DEDICATION

This study is respectfully dedicated to the memory of Goronwy Owen, Welsh bard, who would have understood.

Coffadwriaeth am y prydydd annwyl
Diweddar o′r Môn, Gwynedd
Bu farw 1780 i mewn Brunswick Newydd
Er mwyn Cymru

"Ail i′r ar ael Eryri
Cyfartal hoewal a hi"
Cywydd y Farn

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I. INTRODUCTION

The migmatitic Old Gneiss Complex contains cross-cutting leucocratic segregations indicative of polyphase migmatization (Owen et al, 1980). The study area, east of Chicoutimi, Quebec, lies within the Central Granulite Terrain (Wynne-Edwards, 1972) of the Grenville Province of the Canadian Precambrian Shield.

The region may be chronologically subdivided into 1) migmatitic supracrustal rocks and granitic gneisses; 2) massifs of the anorthosite-mangerite suite, and 3) late to post-kinematic calcalcaline plutons (Fig. 1) (Woussen et al, 1980; Dimroth et al, 1980). The present study area (Fig. 2) lies within part of unit 1, the migmatitic para- and orthogneisses of the so-called Old Gneiss Complex, constituting the basement complex for unit 2, subsequently intruded by unit 3 plutonites. Unit 1 is characterized by polyphase deformation, migmatization, and igneous activity. The paragneisses have been Rb/Sr age dated at ~1482 m.y. (Frith and Doig, 1973), reinterpreted by Doig (personal communication, 1980) to represent a metamorphic updating of Aphebian (>1800 m.y.) sediments. Dimroth et al (1980, Table 1) relate early deformational features and migmatization within this unit to the Hudsonian orogeny (~1800 m.y.), therefore the sediments probably are pre-Hudsonian.

The geology of the Chicoutimi area is dominated by the Lac St. Jean anorthosite complex, covering an area of some 20,000 sq. km. The regional structural influence of the massif on the host gneisses is as yet incompletely understood. However, certain deformational elements within the gneisses are spatially related to the anorthosite at present exposure levels, and the variability of the attitudes of other structural elements within the gneisses on a regional scale may be interpreted within the context of temporally staggered anorthosite plutonism (Dimroth et al, 1980). The presence of cumulus textures, and a parallelism of structural fabrics in the anorthosite and enveloping host gneisses lead Woussen et al (1980) to ascribe a diapiric mode of emplacement for the anorthosite, after initial crystallization at a depth of some 25-30 km. As such, structural patterns within the gneisses straddling the anorthosite may be expected to demonstrate further evidence of vertical tectonism, as previously described in other smaller anorthosite bodies within the Grenville Province (Martignole and Schrijver, 1970a,b) and in certain granitic plutons (Berger and Pitcher, 1970). Complex lobe geometry may complicate structural patterns.

Emplacement of the anorthosite complex postdated the Hudsonian Orogeny, probably occurring between the latter and the Grenville Orogeny (ca. 1050 m.y.). The anorthosite itself, owing to its composition, may not be directly age dated by isotopic means. However, a syenite-one of a series of late felsic intrusives cutting the anorthosite complex-has been K/Ar age dated at ~896-937 m.y. (Doig and Barton, 1968), placing a minimum age on the final emplacement of the complex. Rb/Sr age dating of the mangerites cutting the anorthosites vary from 1,000 to 1,700 m.y., rendering their interpretation hazardous (Frith and Doig, 1973).

The post Grenville Saguenay graben was the last major tectonic event in the region. Associated with the graben is alkaline magmatism, including Nb-bearing carbonatite (St. Honore) with an associated alkaline igneous ring complex and lamprophyre dykes (Gagnon, 1979). After partial karstification of the carbonatite, the area was blanketed with Cambro-Ordovician limestones and shales, since largely eroded by Quaternary glaciation.

A. STATEMENT OF THE PROBLEM

Stratigraphic and structural aspects of the migmatitic gneisses constituting the Old Gneiss Complex have not previously been described. Given evidence of several generations of mobilizates in these gneisses, the fundamental problem considered by this study concerns the conditions and mechanisms of polyphase migmatization of early Grenville Province gneisses in the Chicoutimi area. The significance of polyphase migmatization becomes apparent only after cross-cutting mobilizate segregations are categorized in a stratigraphic and structural framework. Mechanisms and conditions of migmatization are indicated by the morphologies and mineral parageneses constituting each generation of mobilizate. Systematic documentation of these various features yields estimates of the upper limits of PT conditions related to polyphase migmatization. Within a stratigraphic and structural context, the method broadly indicates the metamorphic and tectonic evolution of early Grenville supracrustal and plutonic rocks.

As a basis for this interpretation, detailed field mapping established the chronology of these segregations and the structural controls of their localization. Petrographic techniques, in particular modal analysis, provided quantitative compositional data, which, coupled with field data, indicate possible migmatization mechanisms responsible for the different generations of mobilizates.

B. FIELD WORK AND SAMPLE COLLECTION

Field work was largely conducted along the shoreline of the Saguenay river at St. Fulgence, and adjacent to Rang St. Martin (Fig. 2). Since the foliation in the rocks is at a high angle to the shoreline, a cross section was thereby established. For comparative purposes, some field work was conducted at Cap Jaseux and at Ha ! Ha! Bay.

Section ON at St. Fulgence (Fig. 2) is one kilometre long; section OS along the Rang St. Martin shoreline is 3.1 km long. Each section is divided into 100 m wide divisions, consecutively numbered from west to east. Samples and detailed maps are numbered according to their location along the shoreline, and with respect to the number of samples taken, and maps drawn, within that division. Samples whose location is noted on a detailed map are denoted by an "F" suffix, corresponding to that identifying the map.

Large samples were taken to provide sufficient material for chemical analyses, performed by M. Hervet and M. Tremblay under the supervision of E. Dimroth and G. Woussen. Petrographic work was performed on the same individual leucocratic segregations and host rocks as were analysed.

Field relations were documented by photographs and detailed maps and sketches. The scale of mapping generally ranged from 1:10 to 1:100, depending upon the feature being documented. A generalized field map, which should serve to locate typical exposures of the different stratigraphic units, is presented as Fig. 2; a copy of the original 1:10,000 map is provided at the end of the present work.

FIGURE 1.

Regional geology of the Saguenay-Lac St. Jean area. From Dimroth et al, 1980. Draughting by A. Wawrzkow.

FIGURE 2.

Simplified geology of the Old Gneiss Complex, as exposed within the study area. Refer to Table 2 and text for description of structural/stratigraphic relations. Note that granite III within the study area consists of unfoliated granitoids, probably related to polyphase mobilizate III pegmatite/granitoid injection, and can not be correlated with syenitic granite III (Woussen et al, 1980; Dimroth et al, 1980) plutons outcropping near Chicoutimi. A copy of the original 1:10,000 map, of which the present figure is a reduction, is provided at the end of the report.

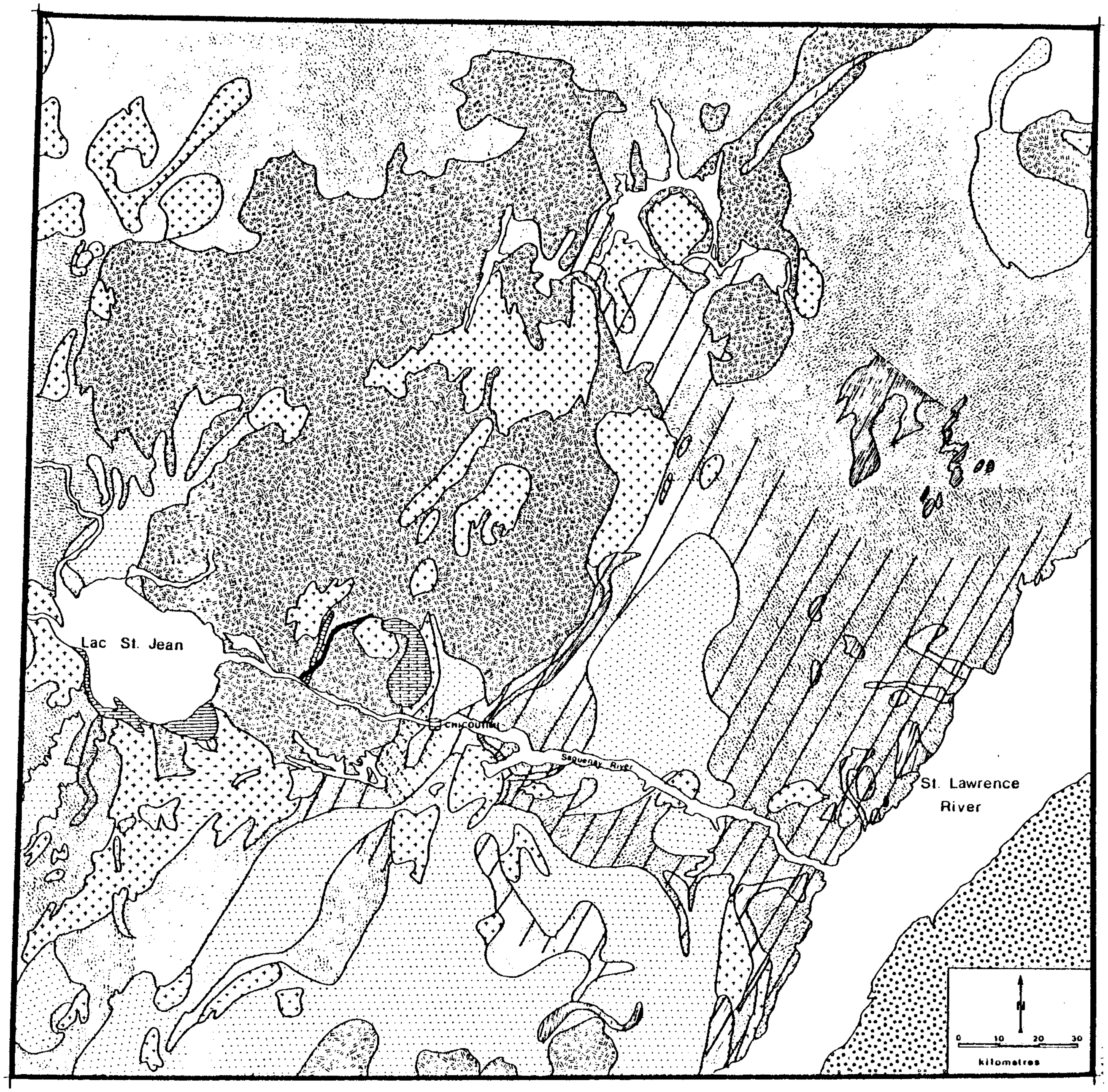

LEGEND
Palaeozoic
Ordovician limestone
Cambro-Ordovician sediments
PreCambrian
Late granites
Troctolite dyke
Diorite dyke
Mangerite-monzonite
Anorthosite
Extent of amphibolite III dykes as presently known
Extent of amphibolite II dykes as presently known
Undifferentiated gneiss (mainly granitic)
Paragneiss
Lac St. Jean
Chicoutimi
Saguenay River
St. Lawrence River
N
0 10 20 30
kilometres

FIGURE 1.

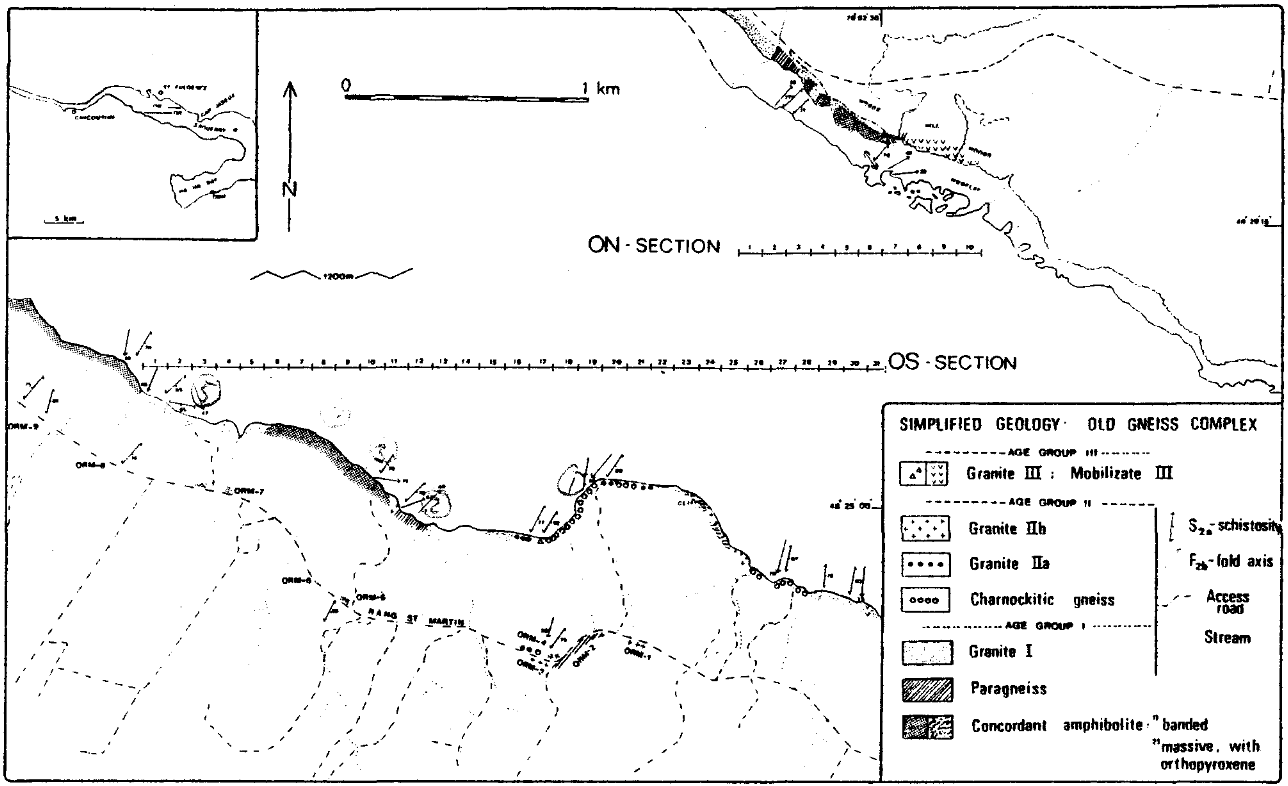

0
1 km
N
1200m
ON - SECTION
OS - SECTION
ORM-1
ORM-2
ORM-4
ORM-5
ORM-6
ORM-7
ORM-8
ORM-9
RANG ST MARTIN
SIMPLIFIED GEOLOGY · OLD GNEISS COMPLEX
AGE GROUP III
Granite III : Mobilizate III
AGE GROUP II
Granite IIb
Granite IIa
Charnockitic gneiss
AGE GROUP I
Granite I
Paragneiss
Concordant amphibolite : " banded
" massive, with orthopyroxene
S2a - schistosity
F2b - fold axis
Access road
Stream
5 km

FIGURE 2.

PLATE 1.

Evidence for polyphase migmatization in migmatitic pelitic paragneiss from the Old Gneiss Complex. A fine grained, tightly folded leucocratic segregation (mobilizate I) is cross-cut by a coarser grained segregation (mobilizate II). These cross-cutting relationships provide a basis for chronologic classification of mobilizate generation. Definition of the petrographic characteristics of each mobilizate, and the relationship of mobilizate localization to paleosome structural features, allow consistent recognition of different generations of leucocratic segregations in the migmatites east of Chicoutimi. The sample is sketched and described in detail in Fig 25.

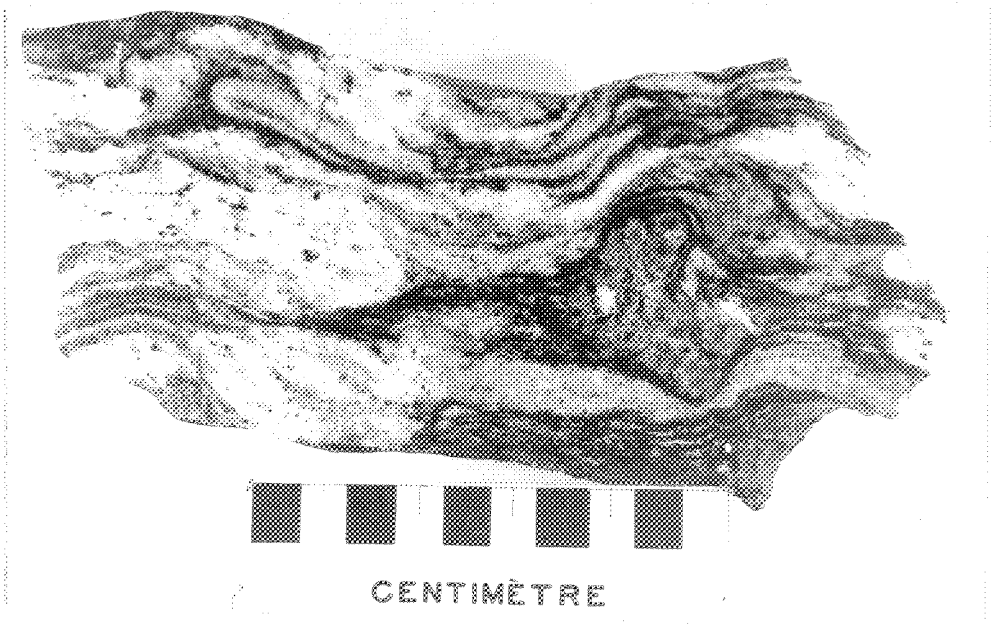


PLATE 1.

II. STRATIGRAPHY AND STRUCTURAL GEOLOGY OF THE STUDY AREA

The stratigraphy of the study area is presented in Table 1. Stratigraphic units are defined chronologically by their relation to three postulated episodes of deformation and migmatization, and by intrusive cross-cutting relationships. Cross-cutting relationships permit chronological classification of different generations of leucocratic segregations (products of polyphase migmatization); the relations of these to tectonic structures permit evaluation of the relative age of migmatization to each particular phase of deformation.

For convenience, rock units outcropping in the study area are subdivided into three age groups, each subdivision being separated by a migmatization and/or deformational episode (Table 1).

A. STYLE OF DEFORMATION

Before describing the petrography and field aspects of the different stratigraphic units, it is opportune to describe the structural elements shown by rocks of different age groups. Folding patterns are best displayed by dyke amphibolites, and by heterogeneities, in particular products of migmatization, seen in otherwise homogeneous host rocks. Different products of migmatization will be referred to in establishing the forthcoming structural schema; their detailed description will be presented in Section IV.

Referring to Table 2, all rocks of age group I are seen to contain mobilizate I leucocratic veins, outlining S1. These veins are thrown into isoclinal folds (F2a) having S2a as axial plane. No relicts of F1 folds having S1 as axial plane have been recognized, due to strong structural overprinting during deformation DIIa. Figure 3 (inset) shows mobilizate I veins thrown into small-scale isoclinal F2a folds

STRATIGRAPHY OF THE OLD GNEISS COMPLEX

(----> : read "producing")

Saguenay graben faulting, mylonitization, and related events.

- - - - - - - - - - - - - -

Déformation III -----> S_3 shearing

- - - - - - - - - - - - - -

Mobilizate III pegmatites: pre/syn deformation III

Granite III

- - - - - - - - - - - - - -

Regional Compression

Mobilizate IIc: coarse grained discordant pods

Complex Migmatization II
- Mobilizate IIb: syn-deformation IIc (-----> S_{2c} - strain slip cleavage surfaces, axial planar to F_{2c})
- Deformation IIb -----> F_{2b} folding; no axial plane schistosity
- Mobilizate IIa: pre/syn-deformation IIb. S_{2a} controls leucosome localization.

Mobilizate II material filling interstices between DIIa-boudinaged dyke amphibolites was probably generated syn-DIIa

- - - - - - - - - - - - - -

Deformation IIa: -----> S_{2a} (axial plane schistosity to F_{2a} folds)

Regional extension

- - - - - - - - - - - - - -

Dyke amphibolite II
- IIc: dioritic dykes
- IIb: even-grained amphibolite dykes, locally plagioclase-phyric
- IIa: amphibole – phyric amphibolite dykes
- uncorrelated fine grained granitic dykes (pre-dykes I

Granite IIb
Granite IIa
Charnockitic gneiss

- - - - - - - - - - - - - -

Deformation I -----> S_1
Migmatization I: mobilizate I veins define S_1 surface

- - - - - - - - - - - - - -

Dyke amphibolite I
Granite I
Paragneiss, concordant amphibolite, calc-silicate

in granite I, and the effects on these of subsequent folding episodes and mobilizate generation. With the exception of compositional banding (bedding = So) in the pelitic paragneiss, the S1 surface delineated by mobilizate I veins is the oldest foliation identified in the Old Gneiss Complex.

Following deformation I, rocks of age group I were intruded by large volumes of granitic rocks, constituting granite II. A period of regional extension followed, and is marked by the intrusion of large volumes of amphibolite II dykes, which outcrop from west of the study area to the St. Lawrence river, a distance of some 150 km. The majority of amphibolite II dykes are concordant to the dominant foliation (S2a) in their host rocks. This foliation is also present in the amphibolite dykes, indicating that S2a-formation postdates dyke injection. S2a presumably formed during a period of regional compression, representing a closing of the tensional environment operative during dyke injection. As such, the formation of the regional S2a-foliation in rocks of age groups I and II marks the initial effects of the complex deformation II (Table 1). S2a formed during deformation IIa and folds related to this deformation are termed F2a-folds. These folds are probably represented by local internal folding seen in some amphibolite II dykes, which have since been refolded (Plate 1). These F2a-folds formed in some dykes during slippage along dyke-host rock interfaces during S2a development. The S2a-schistosity is seen axial planar only to these internal folds , to some F2a-folded discordant dykes (Plate IIf; Fig. 16) and to tightly folded mobilizate I veins (Fig. 3).

Migmatization IIa postdated F2a-folding, with mobilizate IIa veins being preferentially localized in flexural openings of the S2a-schistosity (Fig.3) These veins and their host rocks have been subsequently folded. This deformation (IIb) is responsible for most decimetre to metre scale folds in the study area. F2b-folds (Fig. 4) have a height/width ratio (Hansen, 1971) of about 0.5 to 5.0. No axial plane schistosity to F2b folds has been identified in the study area, and layering (eg. dykes) indicate folds, but doesn't actively control the folding mechanism. Thus, F2b folds are not flexural shear folds, as are F2a-folds, but are passive flow folds (Donath and Parker, 1964). F2b-related drag folds commonly developed within folded amphibolite II dykes, refolding F2a-fold folds (Plate 2). Amphibolite dykes in the study area show evidence of having been ductile during deformation. Individual dykes vary widely in thickness over short distances with 1 m thick dykes commonly being 'smeared out' by folding (Figs. 5, 6). Despite this, individual folded dykes may be followed for some distance, thereby outlining folding patterns in some detail (Fig. 4). The amplitude of F2b-folds ranges from about 10 cm to over 5 m, perhaps averaging between 50 and 200 cm. At OS-30 (Fig. 2) amphibolite II dykes about 10 cm thick are separated by similar thicknesses of host granite I, giving the unit a regularly banded appearance. This banding is not, however, due to a particularly close spacing of injected dykes, rather, it represents isoclinal folding of an extreme nature, wherein the noses of many folded dykes have been detached. In some cases, however the complete isoclinal fold may be followed, as seen in Fig. 6. Axial planes of F2b-folds are steeply dipping, typically trending N45E, more northerly in the eastern part of the OS-section (Fig. 6), axes plunging moderately to the NE or SSW (Fig. 2).

Locally, F2b-folds are refolded. These folds are termed F2c, and have a weak axial plane schistosity S2c. This schistosity parallels strain slip cleavage surfaces along which mobilizate IIb has segregated (Figs. 3, 7, 8, 26)., indicating that deformation IIc is synchronous with migmatization IIb. As such, these strain slip cleavage surfaces, where present, may serve to distinguish F2c-folds from F2b-folds, which lack an axial plane schistosity (Fig. 8). F2c-folds are of a small scale, with wavelengths and amplitudes typically less than 50 cm. In the study area, S2c strain slip cleavage surfaces trend from N10E to N60E, however, within a given outcrop where these surfaces are abundantly developed (ex. OS-3,4), their attitude rarely varies more than ten degrees. F2c-refolding of F2b-folds may be related to anorthosite and mangerite (Fig. 1) diapirism, representing a regionally heterogeneous vertical tectonism, explaining the variability of orientation of the refolding in the general region (Dimroth et al, 1980).

Following the termination of complex deformation II, rocks of age group III were emplaced. These granite III and dyke amphibolite III. In the present study area, no amphibolite III dykes outcrop, and the unit described as granite III may not be correlated with the syenitic granite III intrusions near Chicoutimi (Dimroth et al, 1980). Rather, the "granite III" described in Table 1 and located in Fig. 2 includes quartz-rich, non-foliated biotite granites, likely related to multiple pegmatitic mobilizate III injection, constituting the "migmatization III" event (Table 1). Migmatization III is in part synchronous with deformation III. Excluding Saguenay graben-related shearing (see below), any internal shear fabric seen in mobilizate III pegmatites and their host rocks in the study area is a product of deformation III. Deformation III is represented by a shear cleavage, termed S3, which typically deforms the regional schistosity S2a in rocks of age groups I and II. Figures 9 and 26 show mobilizate III pegmatites with S3 shear cleavage. Effects of deformation III are seen only locally within the study area. These effects increase in intensity and in frequency toward the Lac. St. Jean anorthosite some 15 km northwest of the study area, indicating that deformation III is related to the emplacement of this massif (Fig. 1).

Deformation III shearing may be distinguished from Saguenay graben-related structures insofar as the latter invariably are represented by small scale brecciated fault zones infiltrated by secondary pore space material, chiefly carbonates, crystalline quartz (Plate 3), and hematite. Here and there, cm-thick graben-related mylonite bands are seen (Fig. 10, Plate 4). Saguenay graben-related structures are the last structural elements seen in the region, and are of negligible importance in the study area.

Criteria useful in distinguishing different generations of structural elements are presented in Table 2.

TABLE 2: CRITERIA FOR DISTINGUISHING DIFFERENT GENERATIONS OF STRUCTURAL ELEMENTS IN THE OLD GNEISS COMPLEX

Elements related to Deformation III

S3: Shear cleavage developing within, and partly granulating, mobilizate III pegmatites, which often in part are concomitant with deformation III (S3 is often seen only in the pegmatite, indicating that the pegmatite filled an S3 shear zone, crystallized, and suffered partial shearing due to reactivated S3 movement)

Elements related to Deformation IIc

F2c: Small-scale (cm to decimetre) refolding of F2b folds. Have S2c as axial plane, which hosts mobilizate IIb. S2c surfaces are often closely spaced (usually 15 to 50 cm), as a result of the small scale of F2c folds. S2c is a shear cleavage: mobilizate IIb veins are partly granulated, quartz forms strained plates, and mafic clots are similarly oriented, paralleling the S2c surface.

Elements related to Deformation IIb

F2b: Intermediate-scale (dm to m), tight to isoclinal folds, predominant in the study area. Fold geometry is outlined but not controlled by heterogeneities (ex. dykes). This, and the absence of an axial plane schistosity, identifies the folding mechanism as passive flow. Migmatization IIa preceeds and overlaps deformation IIb, as evidenced by the localization of mobilizate IIa in DIIb-related flexural zones, seen deforming S2a, and the subsequent F2b folding of these mobilizate IIa veins.

Elements related to Deformation IIa

F2a: Small (cm) to intermediate (m) scale folding of dyke amphibolites and host rocks, with S2a (dominant schistosity) as axial plane. Mobilizate IIa veins are localized along S2a, accumulating in flexural openings of S2a produced during DIIb. Amphibolite II dykes at a high angle to S2a may outline F2a-folds, and have a biotite-amphibole axial plane schistosity paralleling S2a. Dykes concordant to S2a in the host rocks also contain S2a, and have been boudinaged by this same deformation (DIIa), here and there containing small scale internal folds due to slippage along the dyke-host rock interface. Mobilizate IIa material accumulates in DIIa-related interboudin zones, indicating that migmatization II commenced during DIIa. F2a-folds are controlled by rock layering. This fact, along with the presence of axial plane schistosity indicating shear or slip, identifies the folding mechanism as flexural slip.

Elements related to Deformation I

S1: Relicts of F1 folds have not been identified in the Old Gneiss Complex. Mobilizate I veins outline S1 schistosity, formed during deformation I. The tight small-scale (10 cm) folds shown by some mobilizate I veins has S2a as axial plane, thus these folds are termed F2a.

Note: attitudes of structural elements are too variable within the study area to be of consistent use in distinguishing different generations of deformation and folding. Rather, folding episodes should be distinguished using the criterion of the presence/absence of an axial plane schistosity, and the control structural elements have on the localization of different generations of mobilizates (c.f. Table 3 for criteria useful in distinguishing leucosomes).

FIGURE 3.

F2c-refolding of F2b-folded S2a-schistosity, outlined by mobilizate IIa veins and by the strong biotite foliation, in granite I. Slip-cleavage surfaces (S2c) bearing mobilizate IIb leucosomes are axial planar to the F2c folds. Inset at "A" shows an F2a-folded mobilizate I vein, pale grey in colour, and highly granulated, which parallels the S2a biotite foliation in the granite I paleosome, along with which the vein was folded by F2b and subsequent folding episodes. Note the absence of possible F2a folds; these are folds formed during S2a-formation, with S2a as axial plane. F2b folds have no axial plane schistosity.

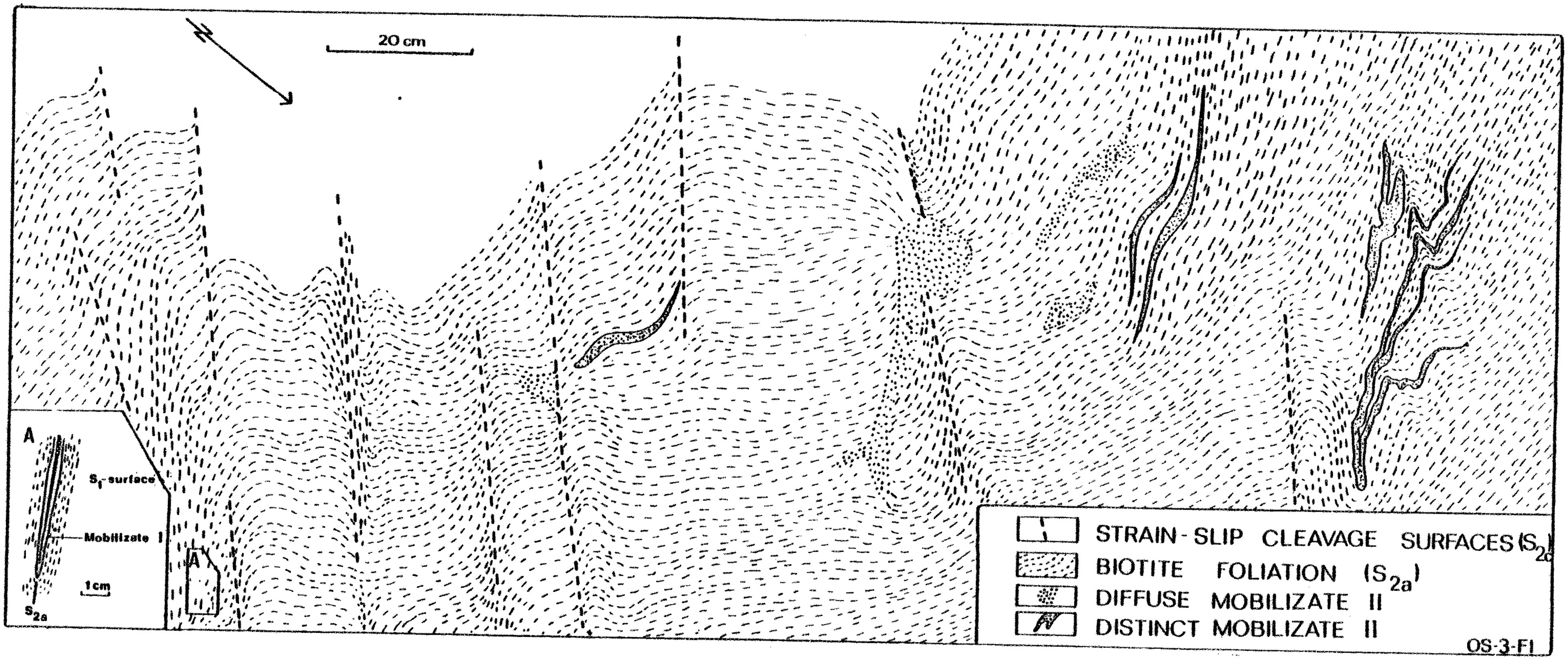

20 cm
A
S_1-surface
Mobilizate I
1cm
S_{2a}
A
STRAIN-SLIP CLEAVAGE SURFACES (S_{2c})
BIOTITE FOLIATION (S_{2a})
DIFFUSE MOBILIZATE II
DISTINCT MOBILIZATE II
OS-3-F1

FIGURE 3.

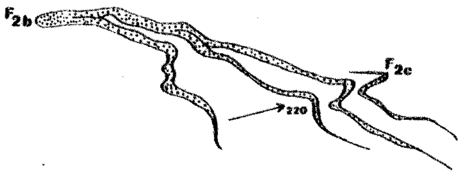

F_{2b}
F_{2c}
F_{220}

FIGURE 4.

F2b-folding of amphibolite II dykes, concordant to the dominant S2a biotite foliation in the granite I host rock.

PLATE 2.

Possible relicts of F2a folds, refolded by F2b, within a concordant amphibolite IIb dyke. Relict F2a folds are here represented by small scale asymmetrical folds outlined by the thin leucocratic "vein" , top centre of photo, on the left limb of the F2b fold (axial plane parallels long direction of photo). These small scale folds are asymmetric with respect to the larger scale F2b folds, suggesting that these are earlier folds, ie F2a. In this case, the F2a folds are internal drag folds within the amphibolite II dyke. Photograph taken within 2 m of the nose of the F2b folded dyke. Host rock of the dyke is granite IIa, the source of much of the leucocratic material (mobilizate II) within the dyke. F2a folding is also seen in some discordant amphibolite II dykes which have S2a as axial plane (Fig. 18; Plate 11f). The same deformation, while folding discordant dykes, has boudinaged concordant dykes (Figs. 17, 18). Location: OS-20.

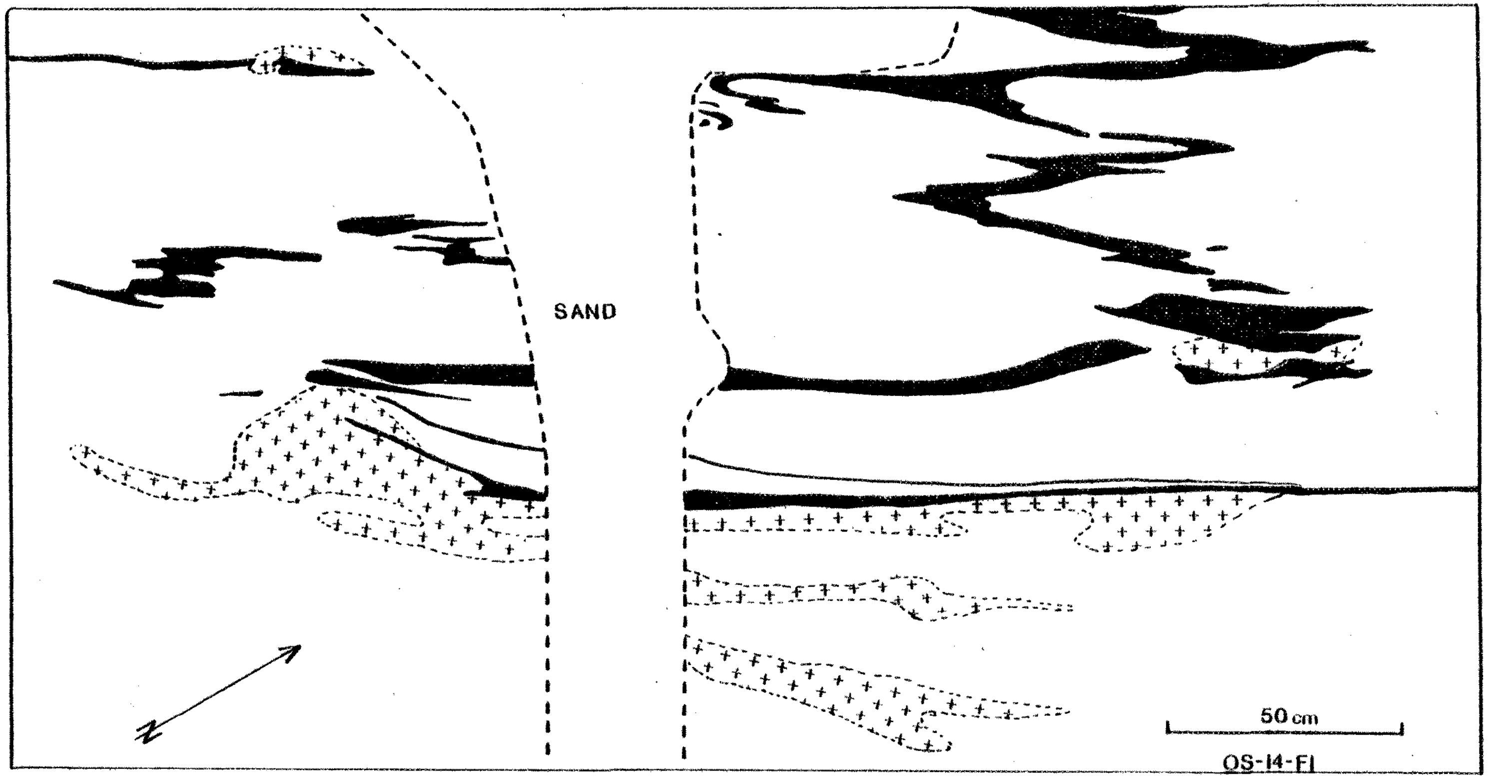


FIGURE 4.

■ DYKE AMPHIBOLITE II

⊞ MOBILIZATE II

☐ GRANITE I

FIGURE 5.

"Smearing out" of amphibolite IIb dykes in streaky-textured charnockitic granite IIa, especially pronounced near the hinges of F2b-folds. Note the mobilizate II vein cutting the dyke.

FIGURE 6.

F2b isoclinal folding of a concordant amphibolite IIb dyke. Although paralleling the dominant biotite-(hornblende) S2a foliation in the granite I host, this type of folding is rarely visible in the absence of dyke amphibolite (or in situ mobilizate) markers.

FIGURE 7.

F2b isoclinally folded amphibolite IIb dyke, refolded about a N35E-trending axis by F2c, paralleling strain slip cleavage surfaces (S2c) along which mobilizate IIb has segregated. At upper right is the continuation of a N135E-trending Saguenay graben-related fault, which truncates the dyke (out of figure).

FIGURE 8.

F2c refolding of F2a folded mobilizate I veins, in granite I. Sample OS-3-6.

a.) Symbols: dashing=biotite foliation (S2a); fine stippling=mobilizate I (grey, fine grained); black dots=mobilizate IIa (pink, medium grained); white=diffuse band of mobilizate IIb. At right is a late quartz stringer cutting mobilizate IIb.

b.) Explanation: folding of S2a schistosity, axial planar to flattened F2a folds, by F2c. Evidence: refolding has an axial planar schistosity (S2c) along which mobilizate IIb accumulated. Therefore the folding is not F2b, which is pervasive elsewhere in the outcrop, but which cannot be expressedly identified in the sample.

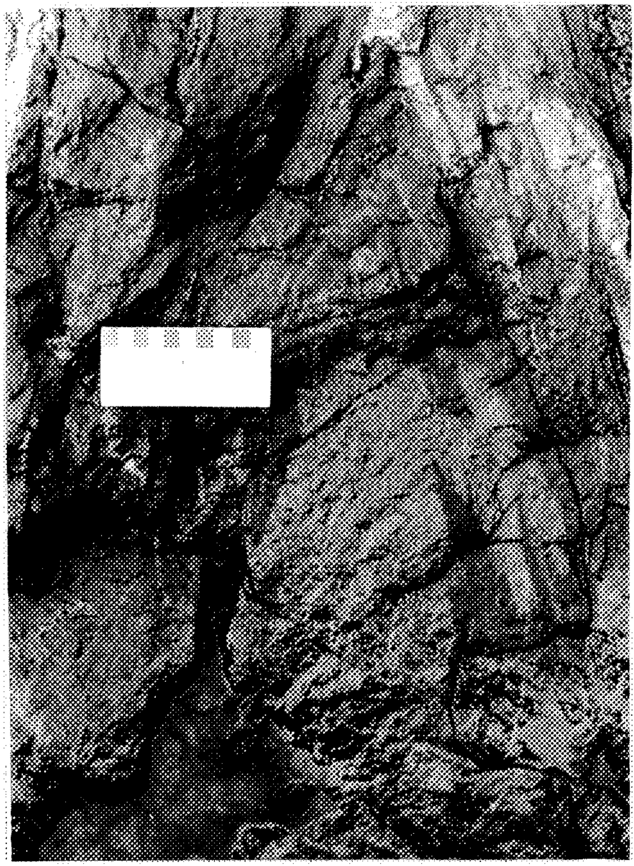


PLATE 2.

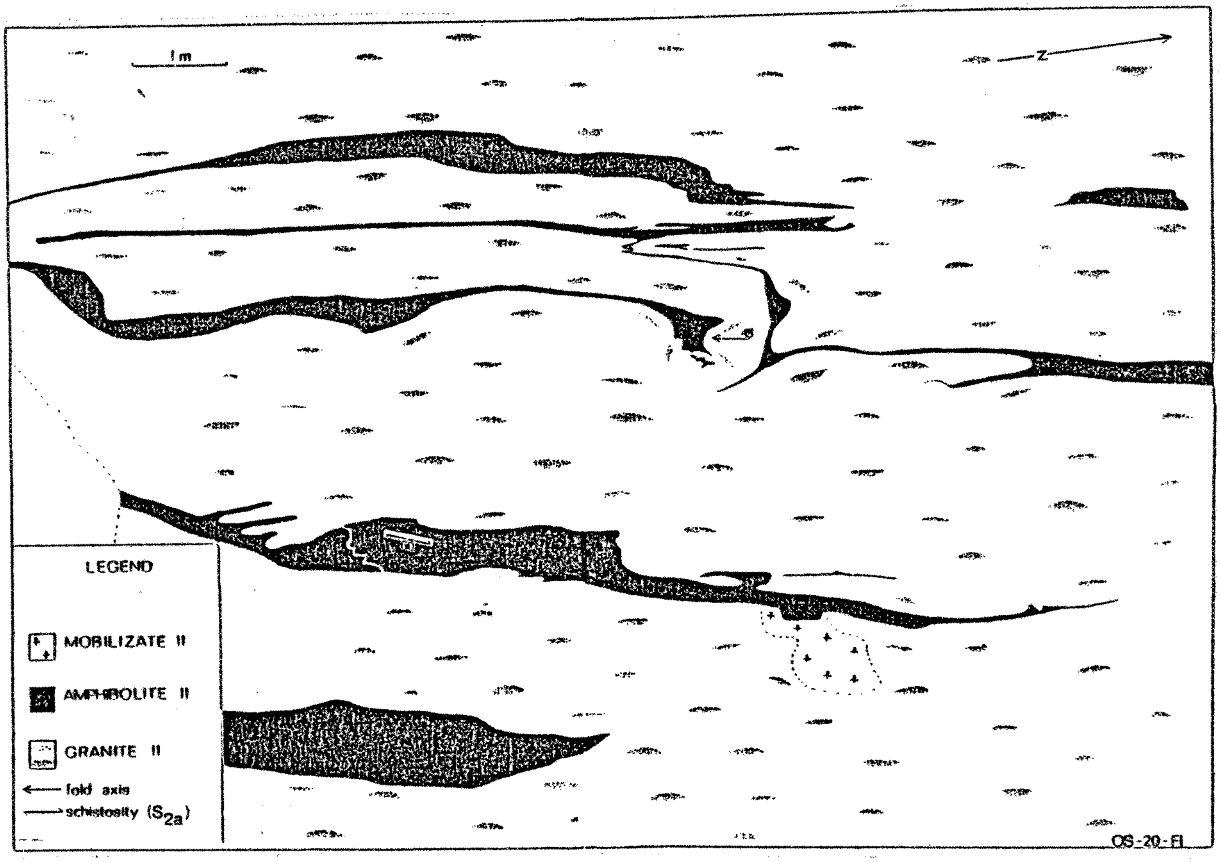

1m
Z
LEGEND
MOBILIZATE II
AMPHIBOLITE II
GRANITE II
fold axis
schistosity (S_{2a})
OS-20-FI

FIGURE 5.

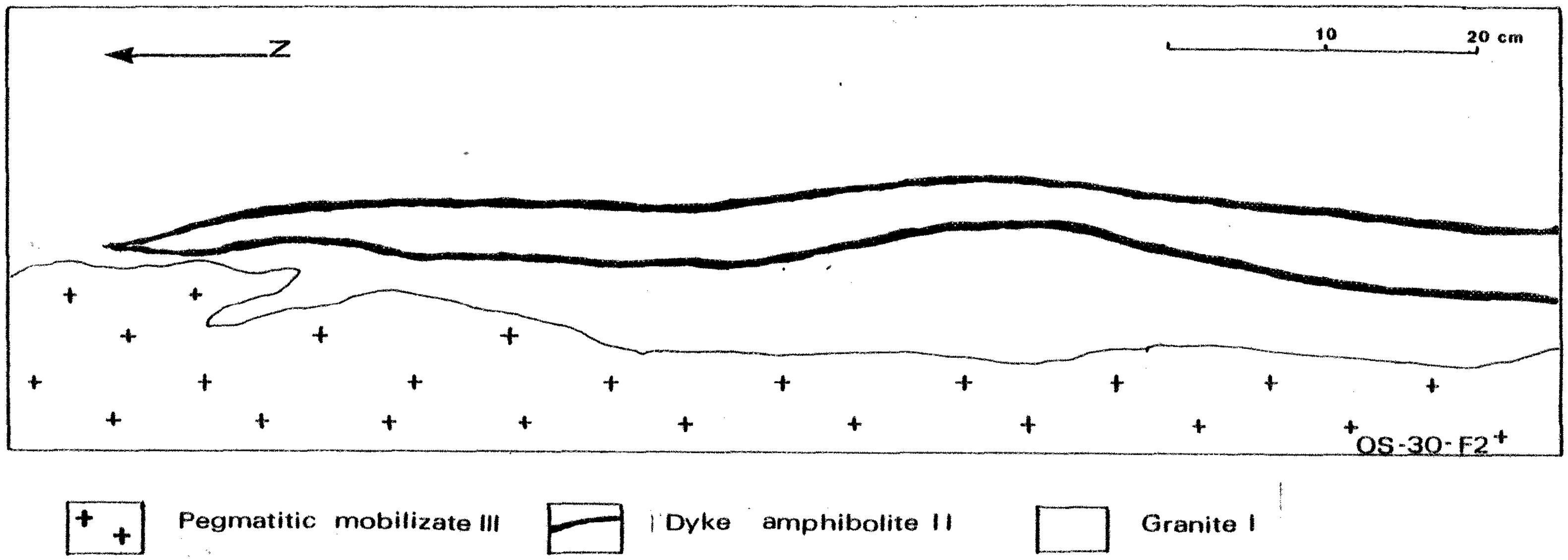

Z
10
20 cm
OS-30-F2
Pegmatitic mobilizate III
Dyke amphibolite II
Granite I

FIGURE 6.

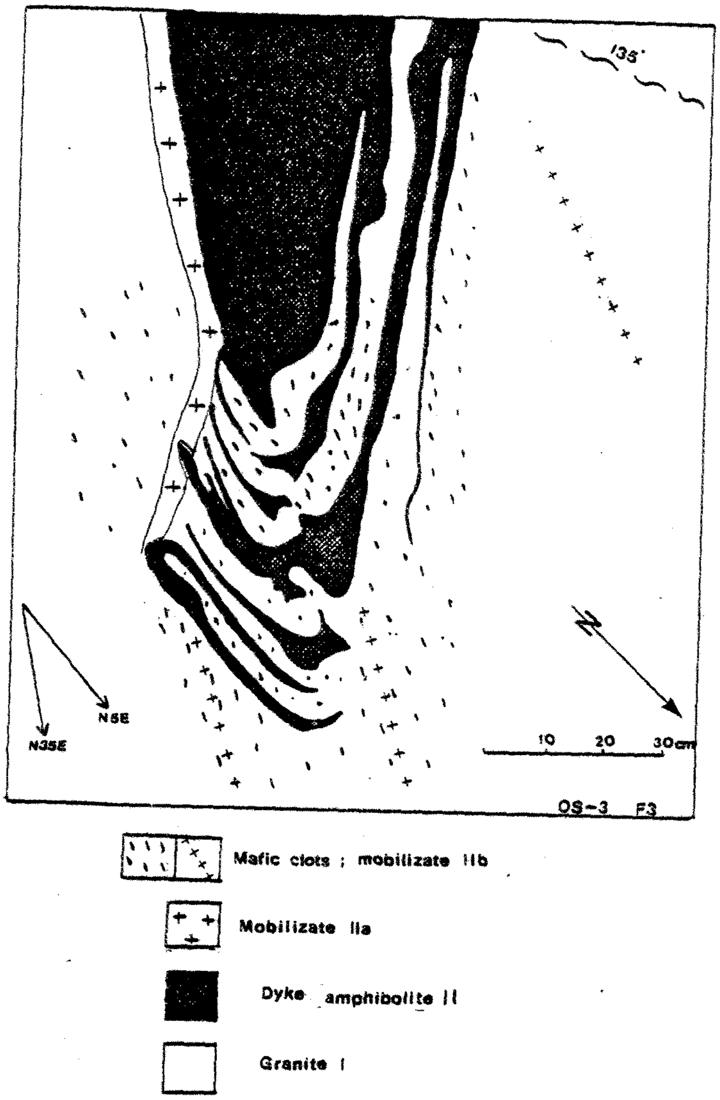


FIGURE 7.

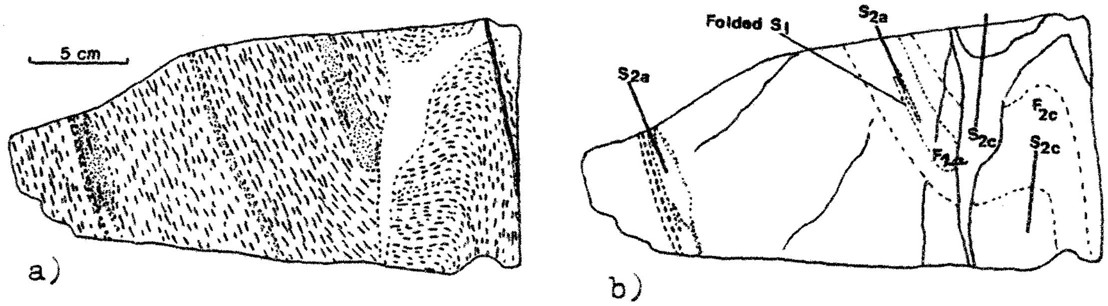


FIGURE 8.

FIGURE 9.

Mobilizate III pegmatite, sheared by deformation III, in concordant amphibolite. The concordant amphibolite contains large volumes of mobilizates I and II, and is cut by amphibolite II dykes (ex. amphibolite IIa), outlining F2b folds. Although not indicated in the figure, the S3 shearing of the pegmatite has deformed layering in the host concordant amphibolite in a manner similar to that shown in Fig. 26. Since shearing is localized within the pegmatite, we may conclude that the pegmatite intruded S3 shear zones, crystallized, and was subsequently sheared by further S3 movement. Location: highway at St. Fulgence, 5 km west of the ON-section. Mapping by M. Elgner and C. Schroeder. Draughting by A. Wawrzkow and B. Tremblay.

Figure 10.

Saguenay graben related cataclasis along thin, closely spaced shear planes, cutting coarse grained mobilizate III and host granite I and amphibolite II dykes.

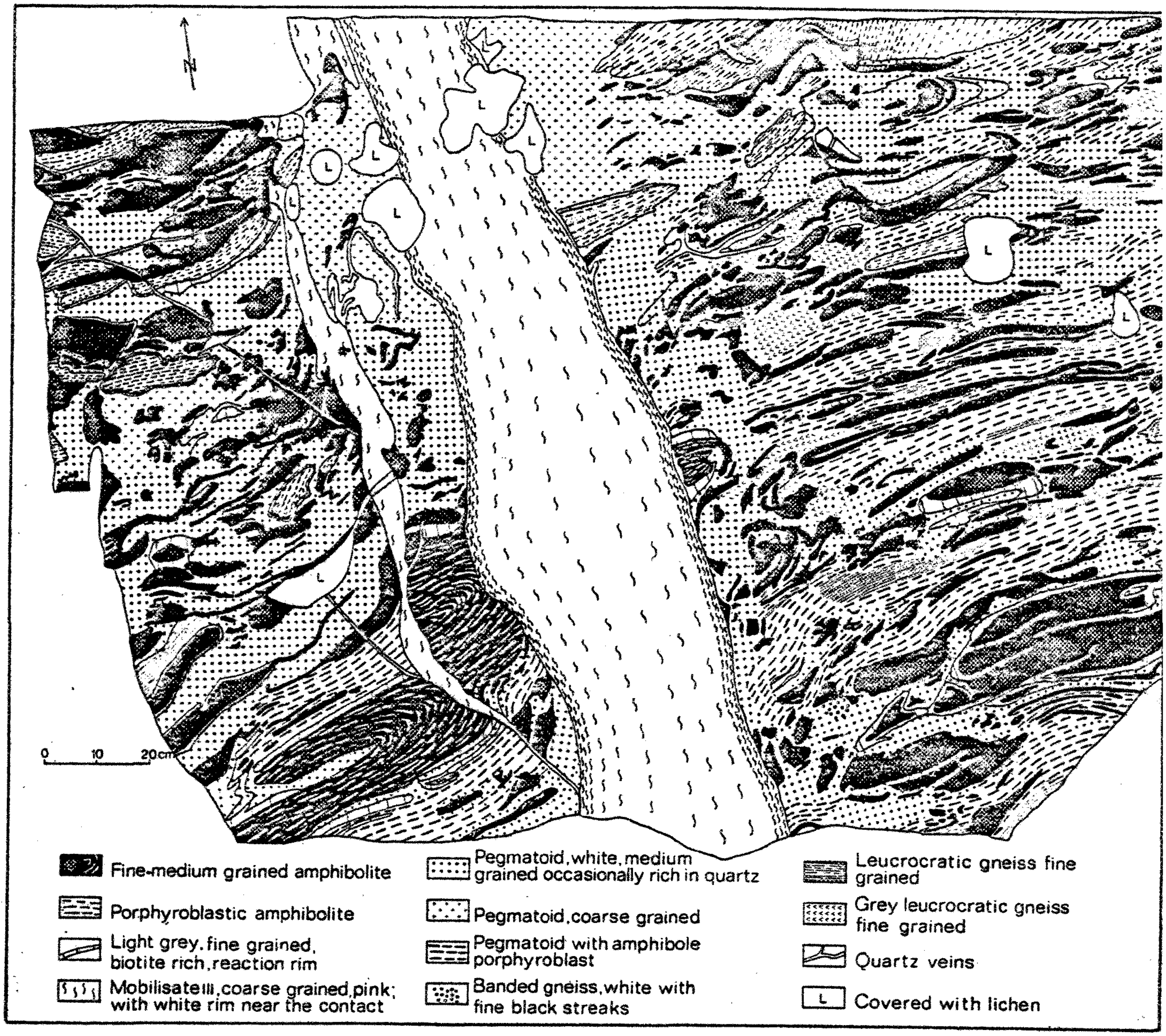

N
0
10
20cm
L
Fine-medium grained amphibolite
Porphyroblastic amphibolite
Light grey, fine grained, biotite rich, reaction rim
Mobilisate III, coarse grained, pink; with white rim near the contact
Pegmatoid, white, medium grained occasionally rich in quartz
Pegmatoid, coarse grained
Pegmatoid with amphibole porphyroblast
Banded gneiss, white with fine black streaks
Leucrocratic gneiss fine grained
Grey leucrocratic gneiss fine grained
Quartz veins
Covered with lichen

FIGURE 9.

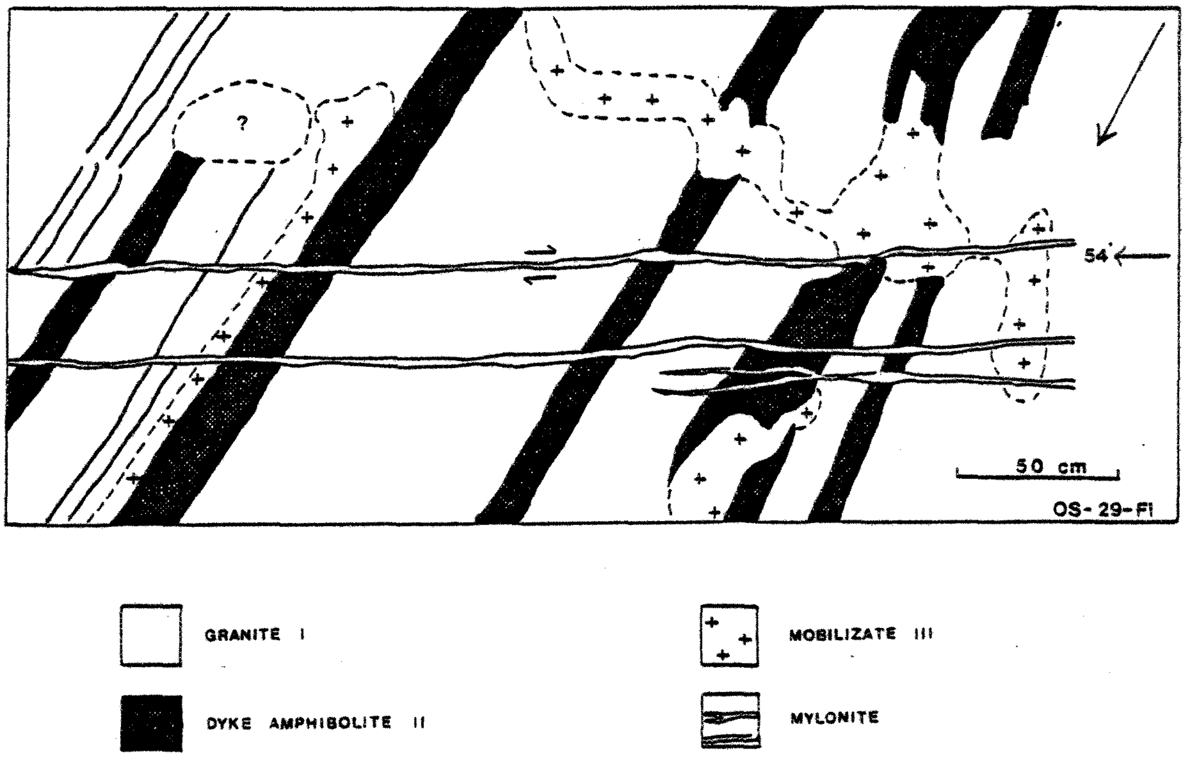

?
54
50 cm
OS-29-FI
GRANITE I
DYKE AMPHIBOLITE II
MOBILIZATE III
MYLONITE

FIGURE 10.

PLATE 3.

Bull quartz filling a Saguenay graben-related breccia zone, in granite I, at OS-3. Note dislodged fragments of the granite I host. This material should not be mistaken for pegmatitic mobilizate III; the latter always contains significant quantities of potash feldspar and/or plagioclase.

PLATE 4.

Photomicrograph of the "mylonite" shown in Fig. 10, transecting coarse grained mobilizate (top). The lack of a well defined internal fabric identifies this microbreccia as being the product of cataclasis rather than true mylonitization. Bar: 1 mm. Thin section GP 011 (sample donated to E.H. Chown, taken from OS-29).

PLATE 3.

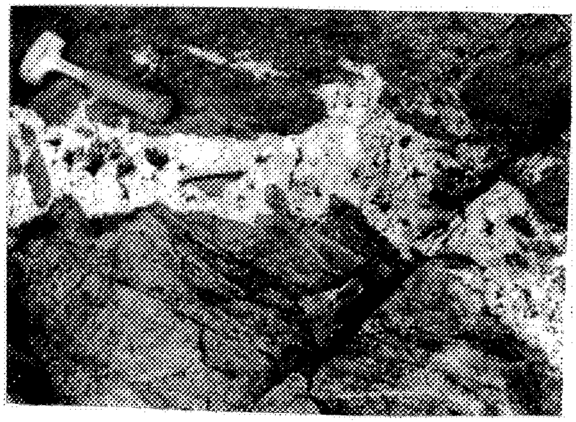
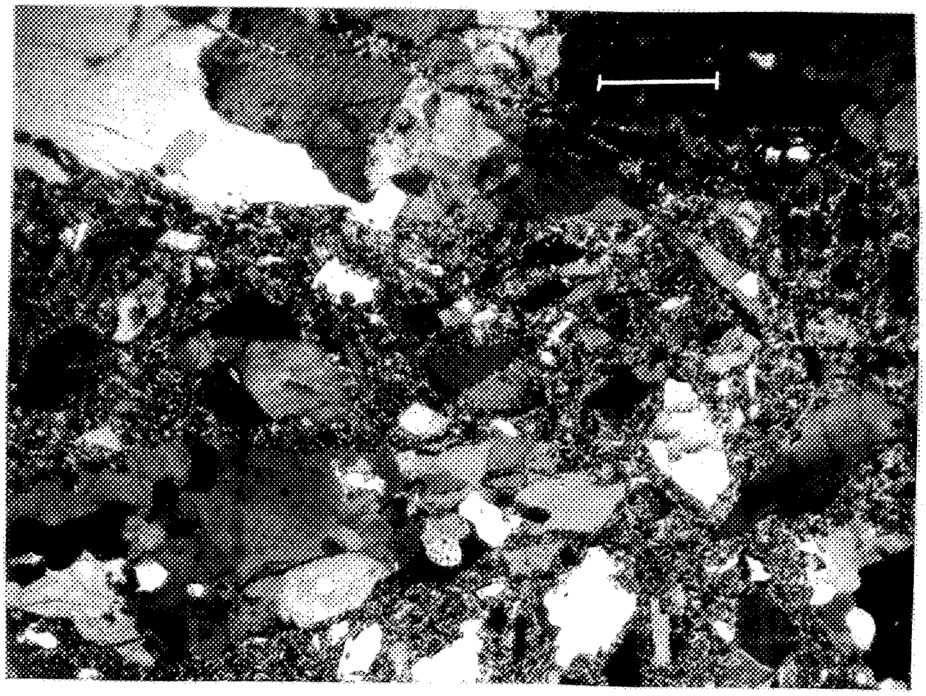


PLATE 4.



B. STRATIGRAPHY.

1-Rocks of Age Group I

The oldest rocks of the Old Gneiss Complex (Table I) have been subjected to the first phase of migmatization, the resulting leucosomes (mobilizate I) having been thrown into flattened isoclinal F1-folds. These rocks include paragneisses, and thick sequences of heterogeneous concordant amphibolite, and have been intruded by large volumes of finely even grained granite I, and lastly, by sporadically occurring amphibolite I dykes.

The paragneiss sequence outcrops for about 125 m along the ON and OS sections (Fig. 2). It consists of strongly folded intercalated garnet-sillimanite-(cordierite)-biotite quartzofeldspathic gneisses, quartzites, arkosic quartzites, and sillimanitic quartzites. representing pelites and semipelites, quartz arenites, feldspathic quartz arenites , and argillaceous quartz arenites, respectively. Mineral asemblages indicate that the unit has been metamorphosed to at least the sillimanite-potash feldspar subfacies of the upper amphibolite facies.

The metapelites, as a result of migmatization, and, probably, primary compositional layering (bedding) are very heterogeneous and are true migmatitic gneisses. Generally speaking, leucocratic layers (neosomes) are rich in quartz and microcline, with lesser quantities of plagioclase. Melanocratic layers are biotite-quartz-sillimanite rich, with garnet porphyroblasts up to 5 cm across occurring sporadically in both leucocratic and melanocratic layers. Larger garnets not uncommonly show helicitic structure, with the rotation axis possibly paralleling F2b-fold axes. Sillimanite in particular tends to be concentrated adjacent to leucocratic layers, consisting of streaks and thin (<1 mm) marginal seams of very finely divided grains, outlining the folded neosomes. In thin section, these same neosomes may contain tightly folded internal sillimanite-rich flasers, separated by sillimanite-biotite microlithons, representing F1 intrafolial folds, and identifying the neosome as a product of migmatization I (Dimroth et al, 1980). Cordierite occurs sporadically within mobilizate II leucosomes, often forming a paragenesis with garnet, quartz, microcline and sillimanite.

Within the metapelites are quartzite interbands up to 4 m thick. The quartzites contain 0 to 5 % plagioclase and potash feldspar, rarely with up to 5% sillimanite, and traces of biotite. Biotite flakes parallel the axial planes of folded quartzite layers. Quartz in the quartzites has sutured borders, and individual grains frequently are stretched, and partly rimmed by finely recrystallized quartz polygons.

Concordant amphibolite is typically layered on a cm- to m-scale, however a massive subvariety outrops along part of the OS-section. Layering is represented by varying hornblende-(biotite):plagioclase-(quartz) ratios. Concordant amphibolite typically consists of a medium to coarse grained (0.5 to 5 mm), granoblastic-polygonal textured hornblende-plagioclase rich assemblage. The percentage of mafic minerals ranges from about 25 to 50%, although cm-scale bands containing in excess of ~60% hornblende occur locally.

Massive concordant amphibolite contains ~20 to 40% hornblende, often poikilitic, containing numerous quartz inclusions, and may contain orthopyroxene, or be cut by orthopyroxene-bearing leucosomes (Plate 5).

In both the layered and massive concordant amphibolites, the proportion of biotite is highly variable, usually less than 8%, but locally surpassing 30%, particularly where the amphibolite contacts paragneiss, or has been metasomatized by pegmatite dykes.

Folded (Plate 6) and boudinaged (Fig. 11) decimetre-thick calcsilicate layers seen here and there in the layered concordant

FIGURE 11.

Boudinaged, fine grained, pale green calcsilicate layers in banded concordant amphibolite. The coarse grained pegmatoid is quartz-rich, bears small amounts of pink microcline, and metasomatizes (biotitizes, silicifies) amphibolite inclusions. Consequently, it is believed that the thin networks of pegmatoid in the outcrop are mobilizate III. Irregular hornblende clots appear to be recrystallization products related to pegmatoid intrusion. These hornblendes are coarser grained than amphibolite hornblendes, and form clots consisting almost wholly of amphibole.

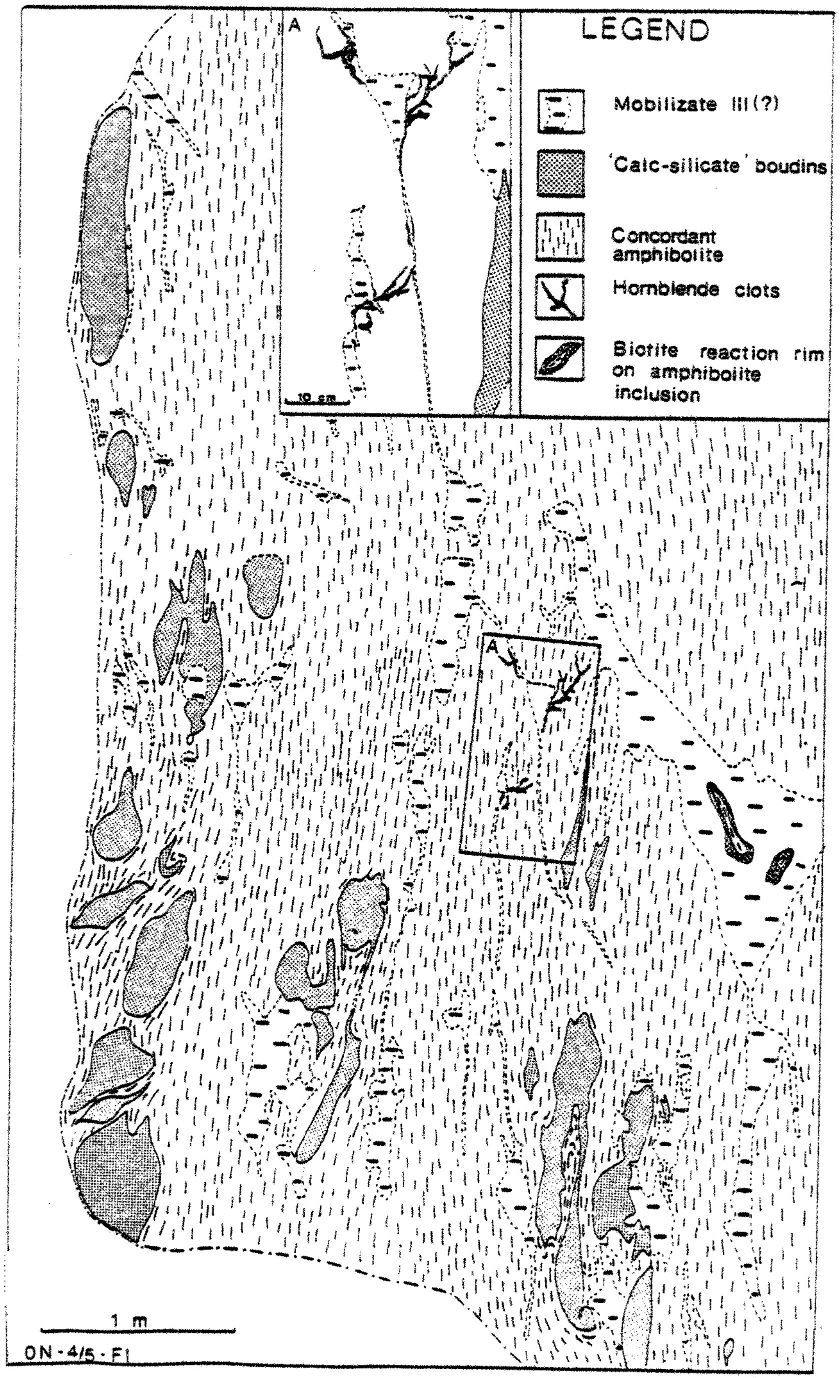

A
10 cm
LEGEND
Mobilizate III(?)
'Calc-silicate' boudins
Concordant amphibolite
Hornblende clots
Biotite reaction rim on amphibolite inclusion
A
1 m
ON-4/5-F1

FIGURE 11.

PLATE 5.

Coarse grained orthopyroxene rich networks of leucosomes cutting massive concordant amphibolite, at OS-24. Leucosomes were generated during migmatization II.

PLATE 6.

Folded calcsilicate layer in banded concordant amphibolite. Location: ON-5.

PLATE 7.

Photomicrograph of clinopyroxene (c) in granite I. The rock is rich in quartz (q) and microcline (m), This is the only sample of granite I seen to contain clinopyroxene: it does so at the expense of hornblende, a common mafic mineral of granite I in the study area. Thin section ON-2-6. Bar: 0.5 mm. X-nicols.

PLATE 5.

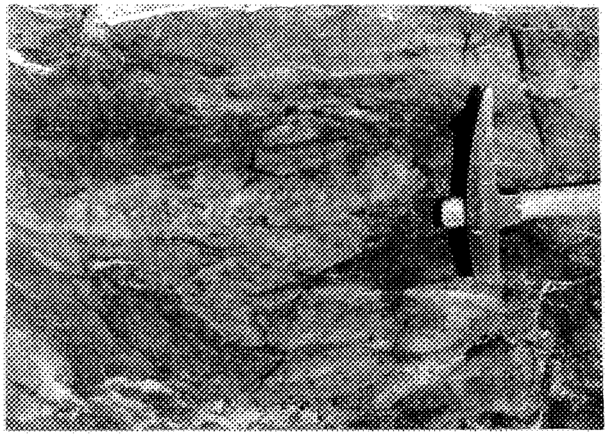


PLATE 6.

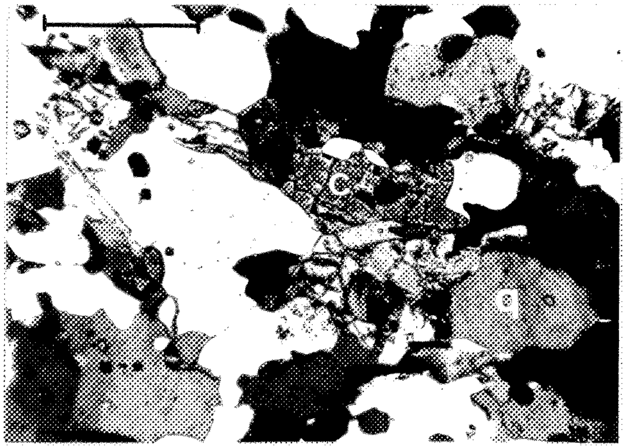


PLATE 7.

amphibolite sequence have a granoblastic texture, consisting of fine grained (average about 0.25 mm) subhedral, moderately to strongly sericitized plagioclase (35%), polygonal quartz (20%), pale green diopside (40%) with minor amounts of sphene, typically mantling opaques. Locally, fine grained aggregates of orange brown garnet (grossularite?) occur in the calcsilicate. A few green hornblende crystals are found in the calc-silicate where it contacts the concordant amphibolite, however, this contact is invariably sharp and well defined, in thin section as well as on the outcrop.

Granite I is a homogeneous, rose to grey coloured, fine grained (~0.5 mm) granoblastic biotite and hornblende-biotite leucogranite. Locally the granite is clinopyroxene-bearing (Plate 7). The homogeneity of the unit renders it an ideal candidate for quantitative study of neosome morphology, insofar as a well defined paleosome is always present. The homogeneity of the rock also precludes the possibility that the unit is a meta-arkose, insofar as no gradational contacts between granite I and quartzites have been seen within the study area. Dimroth et al (1980) indicate that intrusive contacts have been seen in at least one locality. Approaching the paragneiss sequence along both the ON- and OS- sections, granite I and paragneissic rocks may be intercalated on a centimetre (Fig. 12) to a decametre (Fig. 2) scale. This may represent thin granite I sills intruding the marginal borders of the paragneiss sequence, the interlayered effect possibly being accentuated by folding.

The youngest rocks of age group I consist of rare, thin amphibolite dykes, here termed amphibolite I dykes. Probable examples of these include a) thin subconcordant dykes in an inclusion of granite I within charnockitic gneiss (age group II) wherein the amphibolite dykes are terminated at the inclusion-charnockite host interface (Fig. 13); and b) tightly folded (F1) relict dykes (?) containing abundant mobilizate I material (Fig. 14, Plate 8), in granite I host rock, cut by simply folded (F2b) amphibolite II dykes devoid of mobilizate I material (Fig. 15).

Although these may represent dyke amphibolites , they may, particularly in the latter case (Figs. 14, 15) consist of stretched inclusions of concordant amphibolite.

An interesting observation regarding Fig. 13 is the high angle of the schistosity of the granite I inclusion (marked by the concordant dykes) to the schistosity within the charnockitic gneiss host. According to the model presented in section IIA, the dominant schistosity (S2a) in rocks of age groups I and II formed "simultaneously", following injection of amphibolite II dykes. This, in light of Fig. 13 and the local occurrence of intersecting "S2a" (?) schistosities in the granitic rocks of age group II (Plate 9b) indicates that this explanation of S2a-formation is an oversimplification of the actual process. However, bearing in mind the marked and consistent parallelism of the dominant schistosities (S2a) within all rocks (including amphibolite II dykes) of age groups I and II, the present model supporting "simultaneous" schistosity-formation proves to be a pragmatic , albeit incomplete, compromise. Local, contradictory observations may indicate the very plausible existance of relicts of pre-S2a foliations, possibly primary (ex. igneous), in the intrusive rocks, since largely overprinted by the S2a schistosity.

2. Rocks of Age Group II

A major group of granitic intrusive rocks and felsic to mafic dykes constitutes the rocks of age group II. None of these rocks contain products of migmatization I, nor do they show effects of deformation I. Unlike rocks of later age groups (age group III, and younger), rocks of age groups I and II suffered the effects of migmatization IIa,b and deformations IIa,b,c (Table 2).

FIGURE 12.

Thin interbands of paragneiss within granite I, as seen approaching the paragneiss sequence along the OS-section (c.f. Fig. 2). Note the minor displacement of Saguenay graben-related faulting.

FIGURE 13.

Truncation of probable amphibolite I dykes, concordant within a granite I inclusion, at contact of the inclusion with the streaky textured charnockitic gneiss host rock.

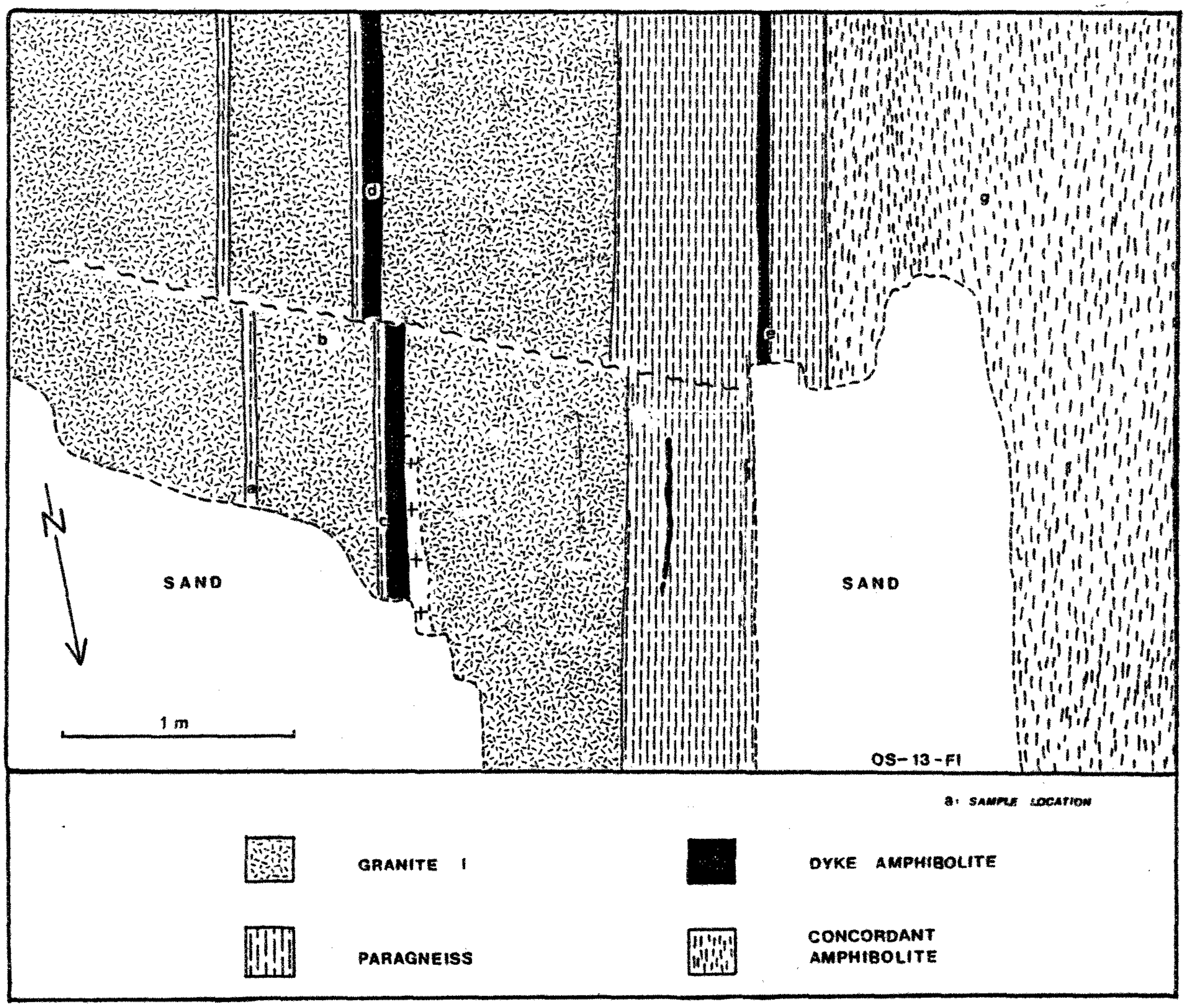


FIGURE 12.

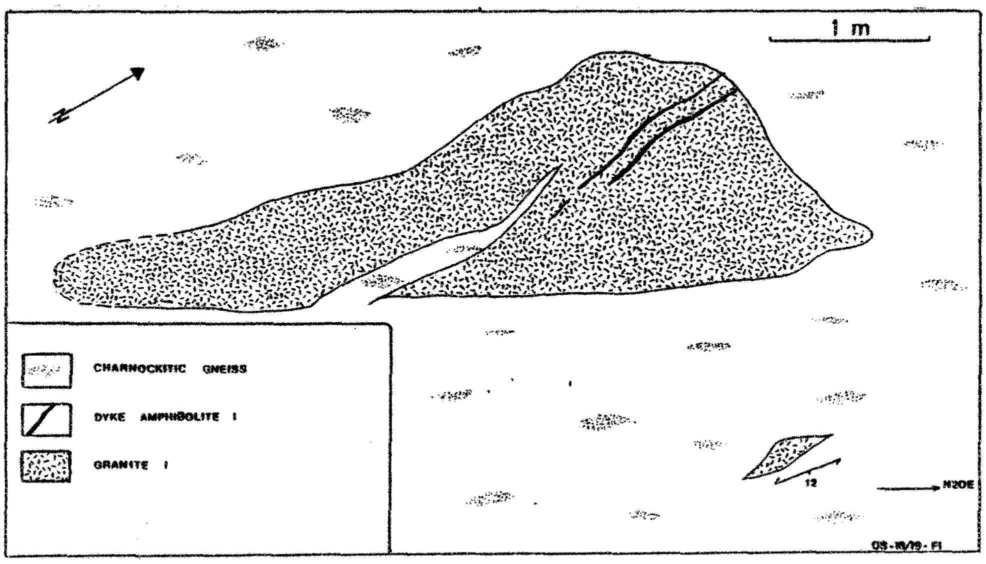


FIGURE 13.

FIGURE 14.

Possible dyke amphibolite I material in granite I. This material contains abundant mobilizate I leucosomes (enlargement, and Plate 8), showing isoclinal F2a-folds, here refolded by F2b. The dyke (?) amphibolite I is cross-cut by the amphibolite II dykes (c.f. Fig. 15), which are entirely devoid of mobilizate I leucosomes. Although this may be a dyke amphibolite, it cannot be excluded that this material is an inclusion of concordant amphibolite within the granite I, subsequently injected by amphibolite II dykes after migmatization I.

PLATE 8

Photograph of a thin offshoot of dyke (?) amphibolite I material represented in Fig. 14. Note tight F2a-folded mobilizate I veins (grey), and the notable sparsity of leucosomes in the granite I host.

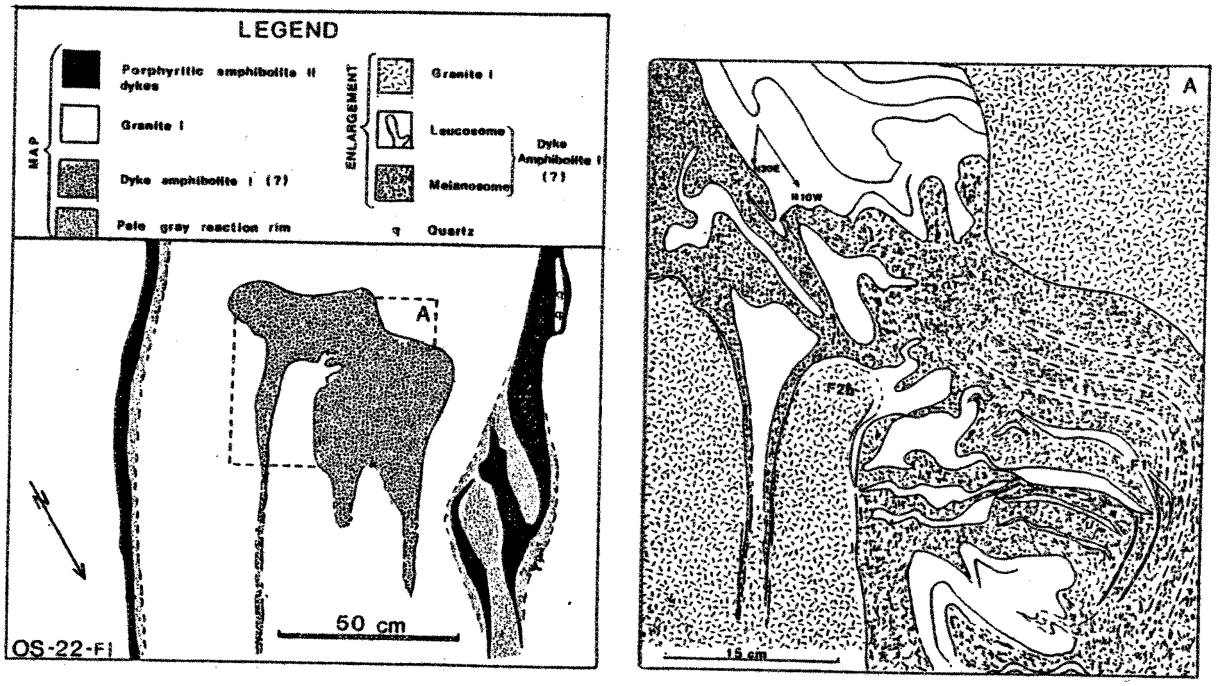


FIGURE 14.

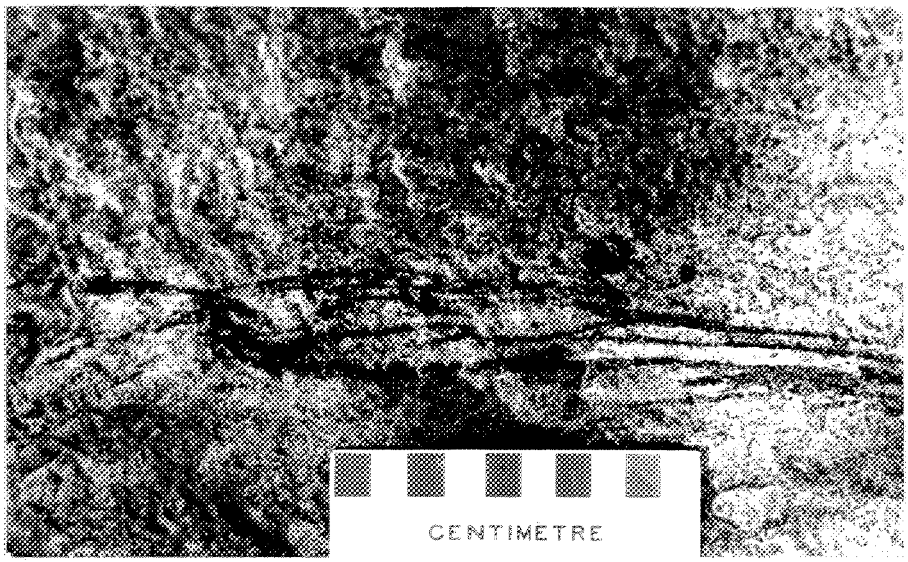


PLATE 8.

FIGURE 15.

Possible amphibolite I dyke cross-cut by an amphibolite IIb dyke, in granite I host. Irregular shape of the amphibolite I dyke (?) near intersection reflects F2a folding in the dyke (?), as outlined by mobilizate I veins, which are absent in the amphibolite II dykes. Note the accumulation of mobilizate II material, stemming from granite I, near the "sink" formed at the intersection of the dykes. See also Fig. 14 and Plate 8.

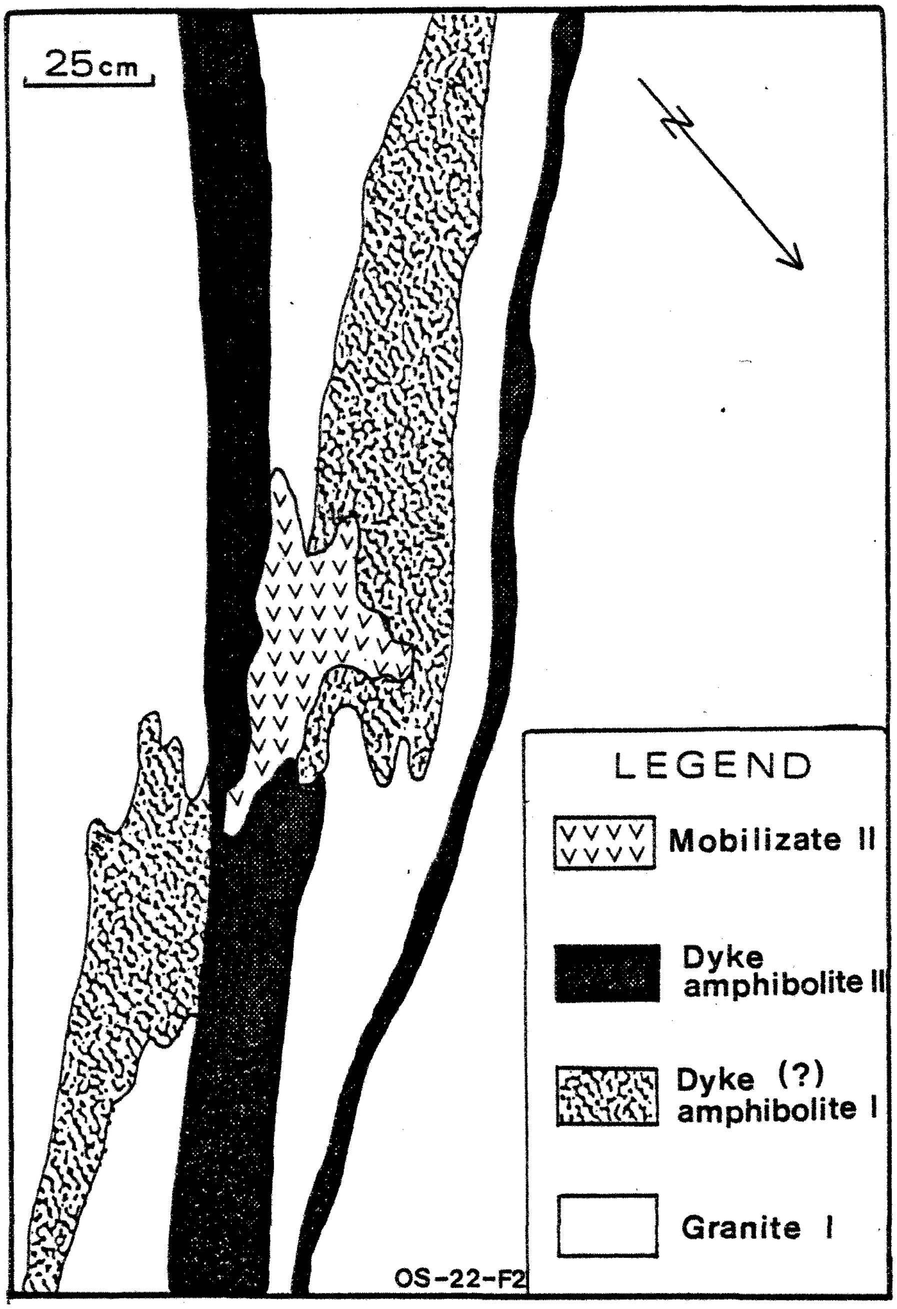

25cm
N
LEGEND
Mobilizate II
Dyke amphibolite II
Dyke (?) amphibolite I
Granite I
OS-22-F2

FIGURE 15.

Three varieties of medium grained subsolvus granitic rocks are recognized. Granite IIa consists of pink coloured, streaky textured granite gneiss. The streaky texture is defined by 1 to 3 cm long, 1 to 3 mm wide aggregates of biotite or biotite-hornblende, not uncommonly with hypersthene, and by elongated potash feldspar (microcline, perthite)- and strained quartz- rich aggregates of similar dimensions. The rock is leucocratic; total mafics do not exceed 7%. The streaky texture represents the S2a schistosity, prevalent in all rocks of age groups I and II.

Here and there, decimetre to metre scale greenish coloured bands occur within granite IIa, both concordant and discordant to the S2a foliation (Plates 9a,). These bands also are streaky textured granitic rocks, compositionally similar to granite IIa, however, hypersthene is usually present in small (<1 to 5%) quantities. Consequently, these bands, which are, volumetrically, the most important rocks of age group II within the study area (Fig. 2), are classified as charnockitic gneiss. Considering the textural and mineralogical similarity of the charnockitic gneisses to granite IIa, they may represent volatile-transformed equivalents of granite IIa, or, more likely, precursors of granite IIa, the latter being the oxidized member. Concordant interbanding of the two rock types is common along the OS-section (Plate 9a); "discordant" bands are not intrusive, since the S2a schistosity passes unhindered through the banding. Rather, discordant color banding indicates local reducing (or oxidizing for pink bands in charnockite gneiss) metasomatizing fronts, whose migration locally disregards schistosity.

The charnockitic gneiss locally contains hypersthenes up to 6 mm across, lending a spotted rather than streaked appearance to the rock. These hypersthenes may be partly mantled by retrograde green hornblende (Plate 10).

PLATE 9. Features of Granite IIa.

a. Concordant contact between rose coloured streaky-textured granite IIa (above) and greenish coloured streaky-textured orthopyroxene-bearing charnockitic gneiss (below). Location: OS-20.

b. Apparent discordant relationship between streaky granite IIa (Below, scale follows S2a) and granite IIb augengneiss (above). However, the intrusive contact, indicated by S2a in granite IIb "cutting" (?) S2a in granite IIa is, as such, ambiguous. The contact itself is sheared, therefore it is likely that this is a tectonic contact, not an intrusive relationship. Location: OS-20.

PLATE 10.

Photomicrograph of the retrograde mantling of orthopyroxene (o) by hornblende (h), in charnockitic gneiss. Microcline (m) and quartz (q) occur as matrix minerals. Thin section ORM-3-8. X-nicols. Bar: 1 mm.

PLATE 9a.

PLATE 9b.

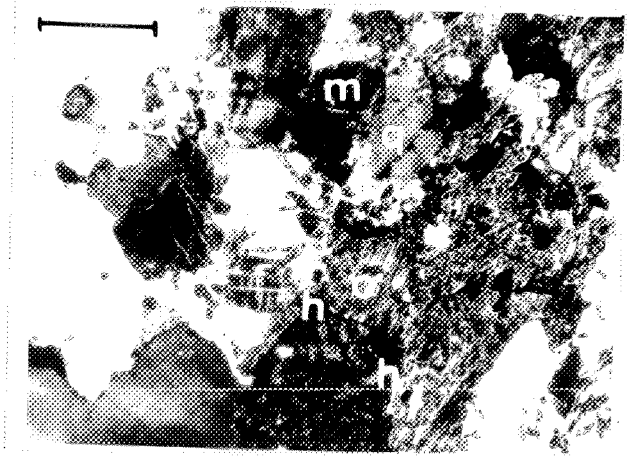


PLATE 10.

Granite IIb is a rapákivi-textured, potash feldspar rich biotite (-hornblende) augengneiss. Augen structures are tabular to lens-like in shape, averaging about 20 mm long and 7 mm wide; stretched augen-structures are longer and thinner. These consist of perthite, quartz, and plagioclase, with mafic minerals (hornblende, biotite) and plagioclase separating and rimming augen. Since no definite intrusive contacts between granite IIb and granite IIa/charnockite gneiss have been observed, granite IIb may only tentatively be placed above granite IIa in the stratigraphic column. Evidence supporting this tentative chronology is presented in Plate 9b, where granite IIb apparently truncates S2a-schistosity in the streaky granite IIa. This relationship returns us to the problematical timing of formation of the dominant schistosity (S2a), in rocks of age groups I and II, as discussed in section II-A,B(fig. 13). The apparent cross-cutting relationship shown in Plate 9b may be misleading insofar as the contact between the two lithologies shows evidence of shearing, so this may be a tectonic rather than intrusive contact.

Granite IIb commonly contains hypersthene metacrysts, consequently, it may be stated that all granitic rocks of agegroup II in the study area locally are charnockitic.

All rock types described above have been intruded by large volumes of felsic to mafic dykes, ranging in thickness from a few centimetres to 5 m. These dykes with few exceptions are concordant to subconcordant to S2a in their host rocks. However, since the dykes themselves contain a strong S2a cleavage, it is deduced that F2a postdates dyke injection. That dykes of age group II antedate migmatization II is indicated by the accumulation of mobilizate II material, derived from the dyke's host rocks, in interstices between boudinaged dykes, less commonly by the presence of in situ neosomes within the dykes themselves.

A chronology of dyke injection has been established from cross-cutting relationships. Since even-grained amphibolite dykes are volumetrically the most important dykes within the study area, in general, all compositions of dykes of age group II are referred to as amphibolite II dykes. A "dyke" prefix distinguishes the intrusive amphibolites from the "concordant" amphibolites of age group I.

Amphibolite II dykes most frequently parallel host rock schistosities, dominantly S2a, and compositional layering. However, cross-cutting relationships are not unknown, even where primary compositional layering might be expected to provide preferred control of intrusion (Figs. 16, 22).

The oldest documented dykes of age group II within the study area are hornblende-phyric amphibolites. The thin section examined of this material juxtaposes perthite-rich mobilizate IIa material in granite I host rock (thin section OCJ-F1b; c.f. Fig. 17) and contains greenish-brown hornblende phenocrysts (Plate 11a), representing uralitized pyroxene, partly altering to chlorite. The groundmass of the amphiboles consists of string perthite, with lesser quantities of quartz and plagioclase. These dykes are termed "amphibolite IIa dykes" (Table 2), and are cut by even-grained amphibolite IIb dykes (Fig. 17).

Even-grained amphibolite dykes are volumetrically the most important dykes within the study area. They are granoblastic, hornblende (-biotite)-plagioclase rich assemblages, in which the total mafic content varies from about 25 to 65%, averaging perhaps 40% (Plate 11b). Locally, amphibolite IIb dykes contain saussuritized plagioclase phenocrysts (Plate 11c). An interesting feature observed at ON-3 is the occurrence of garnetiferous lineations, apparently paralleling F2b-fold axes, formed along the contact between amphibolite IIb dykes and host paragneiss. Garnets form along the contact interface, and within the dyke, from 2 to >15 cm from the interface. The garnetiferous marginal zone of these dykes contains biotite at the virtual exclusion of hornblende; the hornblende/biotite ratio increases toward the centre of the dyke. Some of the garnets in this zone contain sillimanite (Plate 11d).

Amphibolite IIb dykes are cross-cut by dioritic dykes, rich in quartz and plagioclase, with lesser amounts of orthoclase, and mafics (biotite, hornblende, traces of clinopyroxene-Plate 11e) totalling ~15%. In the case of thin section OS-26-F1a (Fig. 18), the biotite (Plate 11f) defines a strong axial plane schistosity, paralleling both the biotite/hornblende S2a schistosity in the granite I host rock, and concordant amphibolite IIb dykes, cut here by the dioritic dyke. These relations identify the folding of the discordant dyke, and the boudinaging of the concordant IIb dykes, as being the result of F2a-folding. As such, the axial plane schistosity in the folded IIc dyke (Plate 11f) corresponds with S2a, which normally is itself folded by F2b.

A series of consistently fine grained granitic dykes outcrop within the study area, particularly along the OS-section. The age of these dykes relative to dykes IIa,b,c is unknown, however, their grouping among rocks of age group is justified insofar as these dykes have been folded by F2b Fig. 19), and locally are cross-cut by mobilizate II veins originating from host gneisses ((Fig. 20). It is likely that these dykes antedate amphibolite IIb dykes, since in at least one case the granitic dyke appears to have had an amphibolite IIb dyke injected along the contact of this dyke with its host granite IIa (Plate 12). In another case, a dark weathering even-grained amphibolite IIb dyke intersects a pale weathering, leucocratic granitic dyke (Fig. 21). In this case, the dyke contains biotite, not hornblende as the major mafic mineral.

In thin section, these granitic dykes are seen to be rich in potash feldspar (perthitic orthoclase and microcline) and quartz, with

FIGURE 16.

Discordant amphibolite IIb dykes in paragneiss.

FIGURE 17.

Amphibolite-phyric IIa dykes cross-cut by even grained amphibolite IIb dykes, in granites I and IIa. The contact between the granites is concordant (parallels S2a in both units), and the boudinaged/brecciated IIb dykes are concordant. The anomalous relationship seen in the concordant dyke near the contact between the two granites is the result of "smearing" of the IIa dyke across the IIb dyke. Inset shows mobilizate I veins cut by mobilizate II veins following the IIa dyke. Note the intersecting mobilizate IIa veins, indicating that products of migmatization IIa were not all concomitantly fluid. Note also that the mobilizate II material migrating into brecciated/boudinaged IIb dykes has as its source the granite immediately enclosing the dykes. Thus, the mobilizate found within the IIb dyke within the granite I (left) is different from that found in dykes within the granite IIa. These differ insofar as the mobilizate stemming from granite IIa is finer grained, and locally recrystallizes the dyke amphibolite, producing melanocratic, recrystallized hornblende-rich margins on some brecciated dyke fragments. The mobilizate within granite IIa is coarser grained, resembling mobilizate III, and recrystallizes the amphibolite also, yielding pale grey thin (5 mm) recrystallized margins surrounding amphiblite fragments. Both mobilizates are rich in potash feldspar. The granite IIa material, although pegmatitic, is demonstrably <u>not</u> mobilizate III, despite the absence of melanosomes in veins within the granite, since this material forms cm-thick, metre-long concordant (less commonly discordant) veins widespread throughout the granite IIa exposure. No similar material was noted within granite I, as would be expected if the material was allochthonous (ie pegmatite injections would not discriminate between the two lithologies.) Furthermore, mobilizate II leucosomes in granite II exposures elsewhere within the study area are not seen to be bounded by melanosomes.

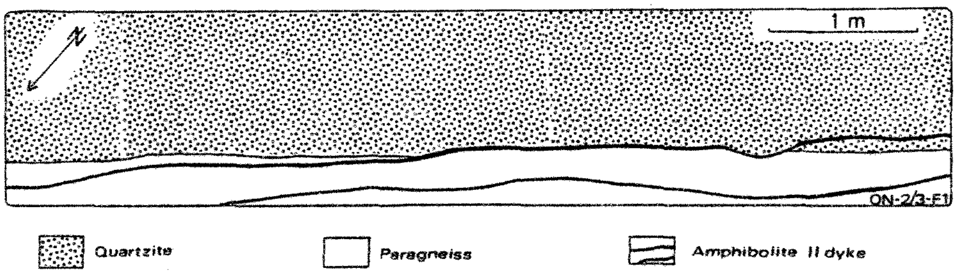


FIGURE 16.

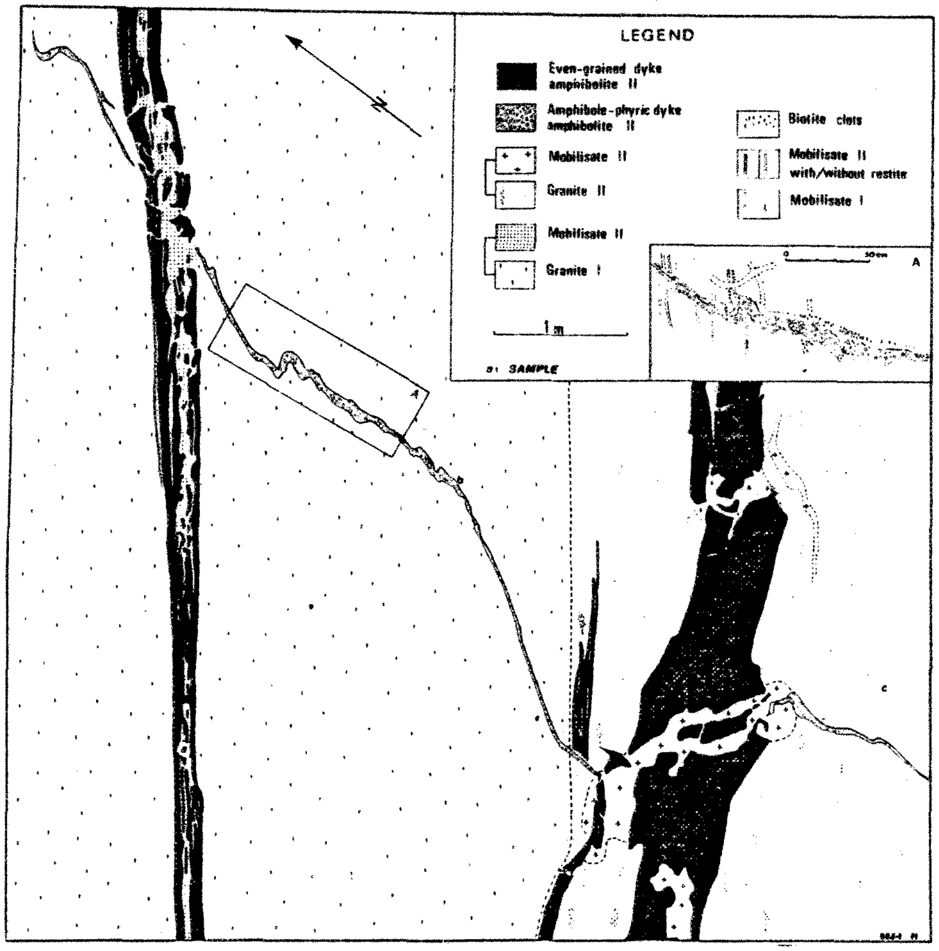


FIGURE 17.

FIGURE 18.

Folded leucocratic (dioritic) IIc dyke cross-cutting concordant, even grained amphibolite IIb dykes in granite I. The dioritic dyke contains a strong axial planar schistosity (marked by biotite-c.f. Plate 11f) paralleling the S2a schistosity in the granite I and boudinaged amphibolite IIb dykes. Since S2a is axial planar to these folds, they are F2a folds. Boudinaged concordant IIb dykes were deformed concomitantly with F2a folding. Note the axial planar orientation of mobilizate II veins in the IIc dyke, indicating S2a control on neosome localization.

FIGURE 19.

F2b folded evenly fine grained granitic dykes of age group II, within streaky textured granite IIa.

FIGURE 20.

Uncorrelated evenly fine grained granitic dyke of age group II, discordant within the paragneiss sequence along the OS section. The dyke traverses the contact between biotite-garnet paragneiss and a band of granite I (?) (possibly a quartzofeldspathic biotite paragneiss). Note that a vein of garnetiferous, medium grained pink coloured mobilizate II cuts the dyke, demonstrating its age relative to migmatization II.

FIGURE 21.

Concordant evenly fine grained granitic dyke of age group II, being cross-cut by a probable even grained dyke amphibolite IIb. Note the products of migmatization II in the granitic dyke (feldspathic streaks and mobilizate vein).

PLATE 12.

Uncorrelated evenly fine grained granitic dyke of age group II, with a thin even grained amphibolite IIb dyke intruded along one contact. Note how the amphibolite dyke bifurcates within the granite IIa host. Location: OS-21.

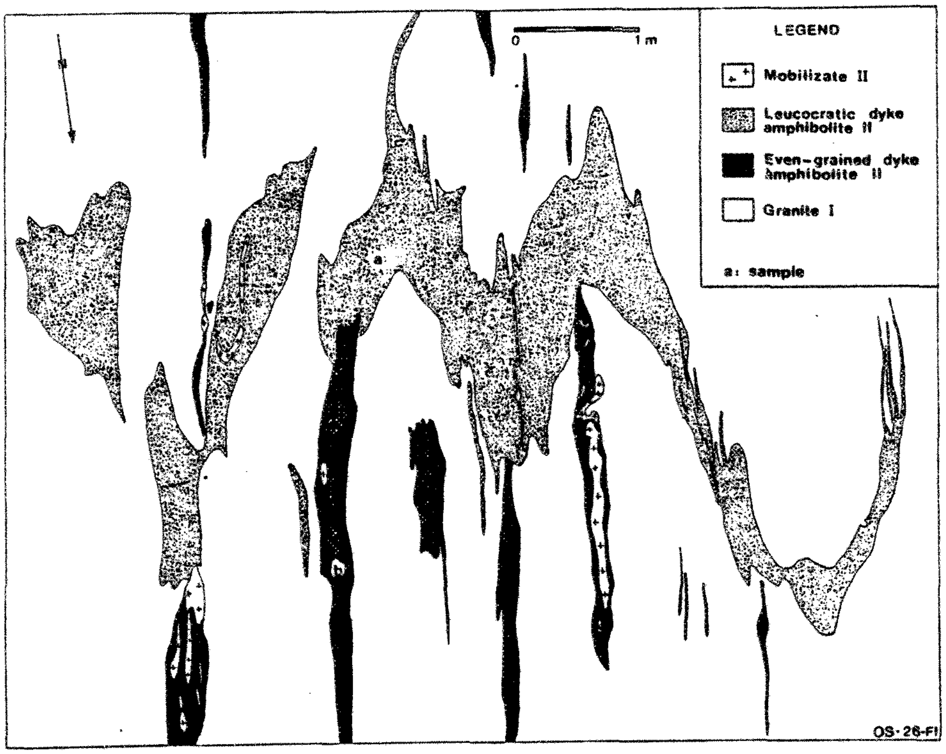


FIGURE 18.

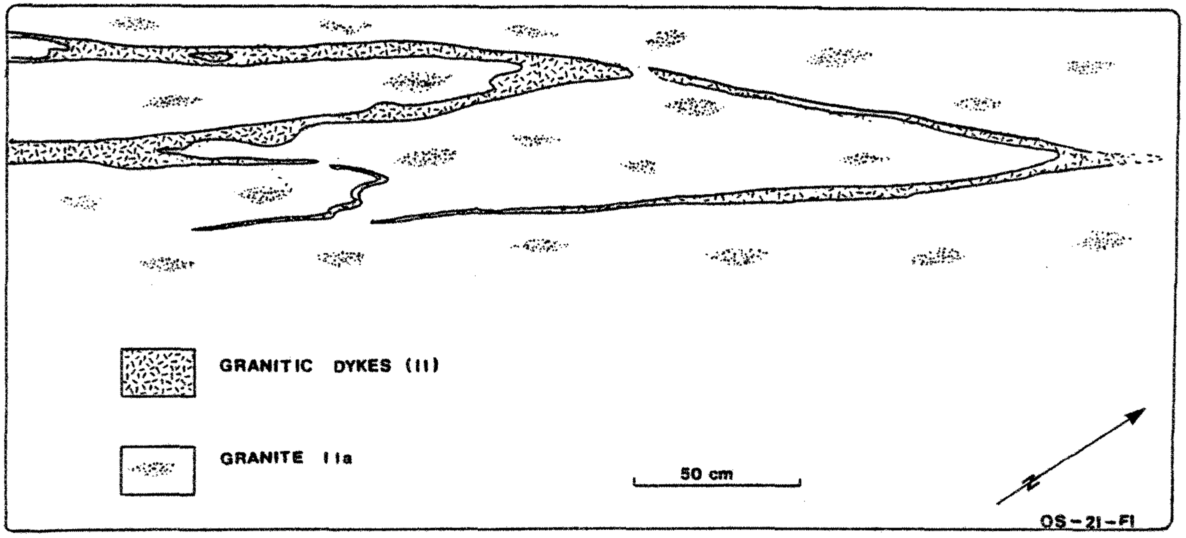


FIGURE 19.

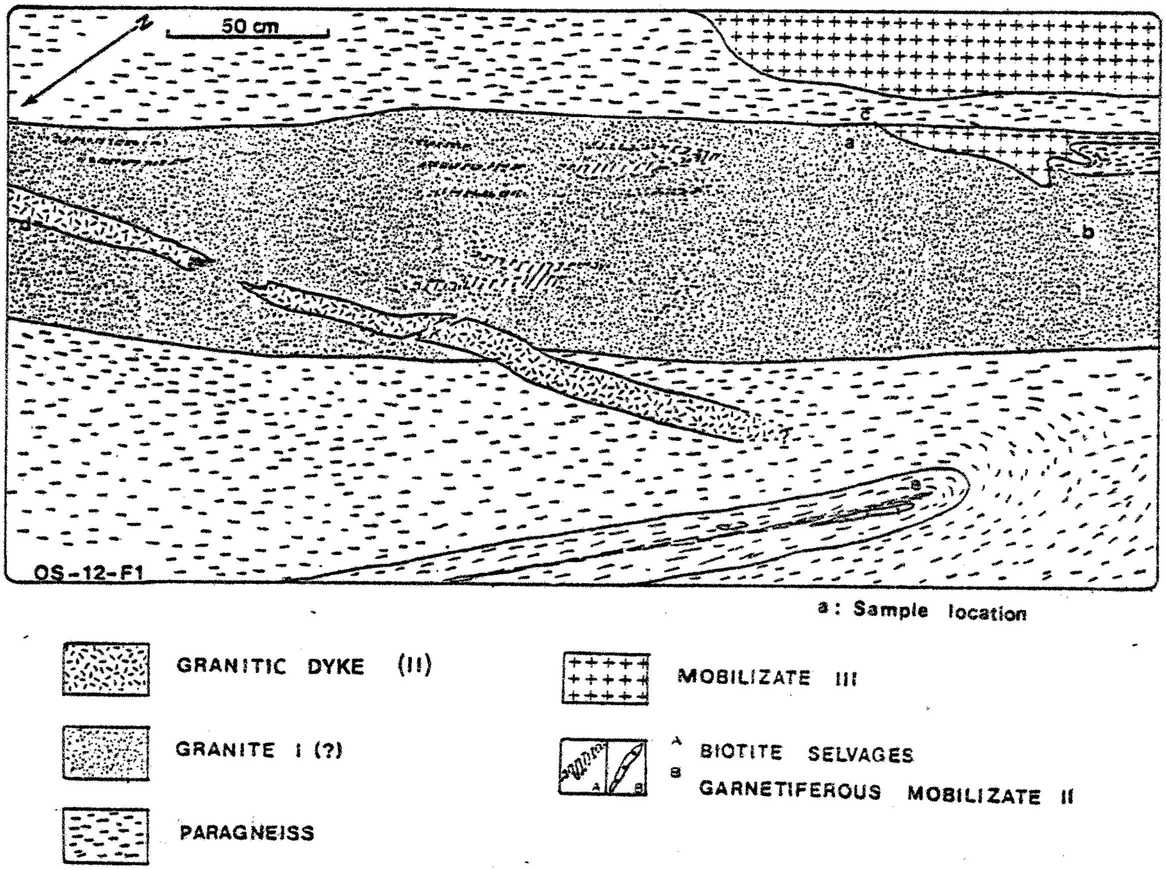


FIGURE 20.

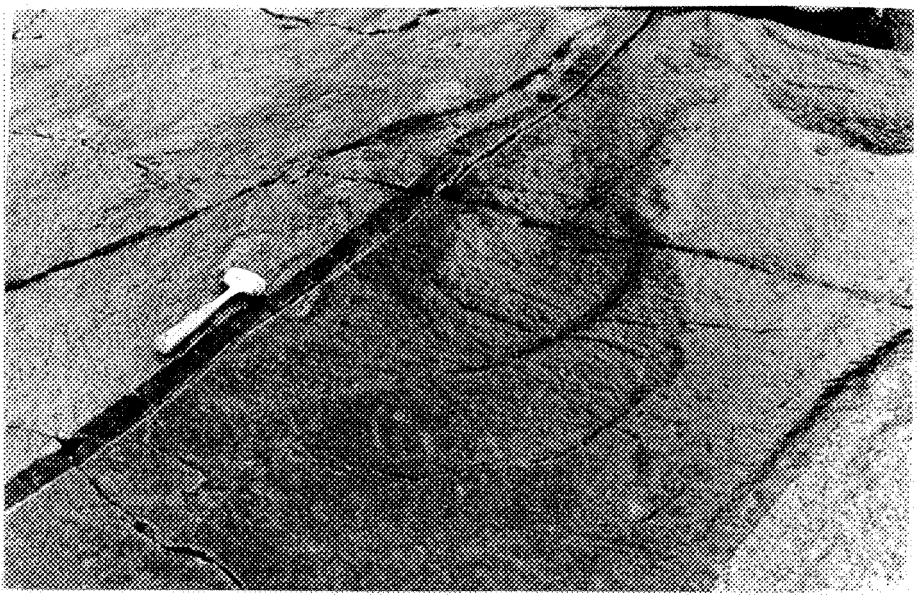


PLATE 12.

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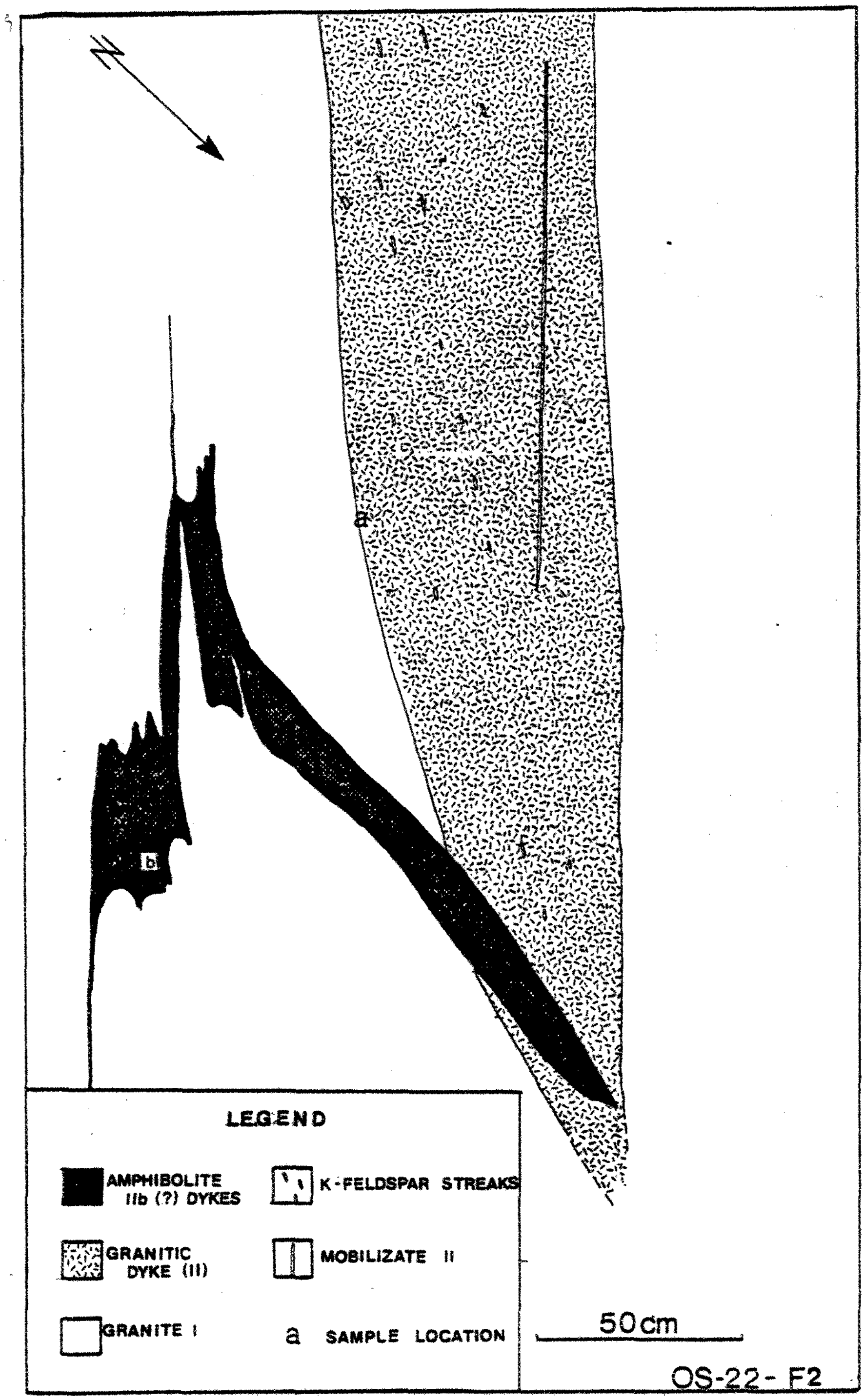

N
a
b
LEGEND
AMPHIBOLITE IIb (?) DYKES
K-FELDSPAR STREAKS
GRANITIC DYKE (II)
MOBILIZATE II
GRANITE I
a SAMPLE LOCATION
50cm
OS-22- F2

FIGURE 21.

PLATE 11. Features of dyke "amphibolites".
(All bar scales are 1 mm except as indicated)

a. Perthitic microcline (m) in groundmass of hornblende (after pyroxene)-phyric dyke amphibolite (IIa). Sampled from dyke depicted in Fig. 17: this thin dyke has been "granitized" by the adjacent mobilizate II material during migmatization. Thin section OCJ-F1b. X-nicols.

b. Typical even-grained amphibolite (IIb), with hornblende (medium grey, two cleavages) and biotite (pale grey, basal cleavage) defining S2a schistosity. Thin section ON-4-2 (i). Plane polarized light.

c. Plagioclase-phyric variety of dyke amphibolite IIb. Note groundmass hornblende and plagioclase wrapping about the phenocryst aggregate. The phenocrystic aggregate is heavily sericitized. Thin section OS-3-F1a. Plane polarized light. Bar: 1 cm.

d. Poikiloblastic garnet (gt) forming in dyke amphibolite IIb near contact with garnetiferous biotite-sillimanite paragneiss. Sillimanite (white, fibrous) is enclosed in the garnet, as are pale green patches (grey in photo) consisting of serpentinized and biotitized former hornblendes, with opaques, carbonate and quartz (?) as residues of the transformation. The garnetiferous marginal zone of the dyke, contacting the paragneiss, is biotitized: the hornblende:biotite ratio reaches a maximum toward the non-garnetiferous dyke centre. Thin section ON-3-2. X-nicols.

e. Dioritic dyke (IIc), with biotite (medium grey, basal cleavage), clinopyroxene (dark grey, irregular cleavages), and opaques in a plagioclase-quartz rich groundmass. Thin section OS-26-F1a.

f.(i) Dioritic dyke showing parallelism of biotite schistosity and trondhjemitic leucosome (right, coarse grained). Note slight enrichment of mafic minerals at the interface between the two components (melanosome?). This schistosity (S2a) is axial planar to the F2a-folded dyke (Fig. 18). Thin section OS-26-F1a. Plane polarized light.

f.(ii) Detail of "melanosome" section shown in f.(i). Biotite (b), opaque (o).

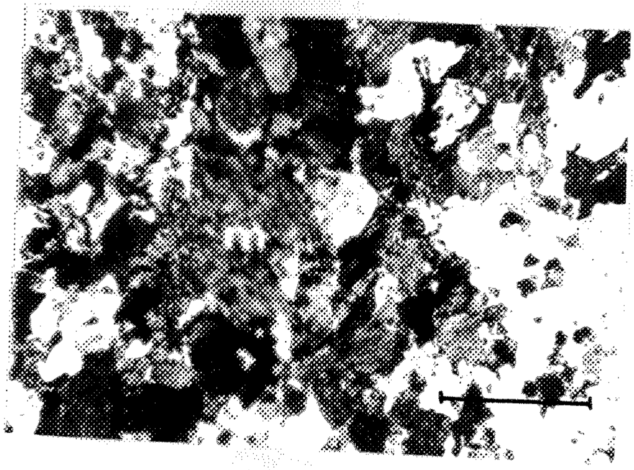


PLATE 11a.

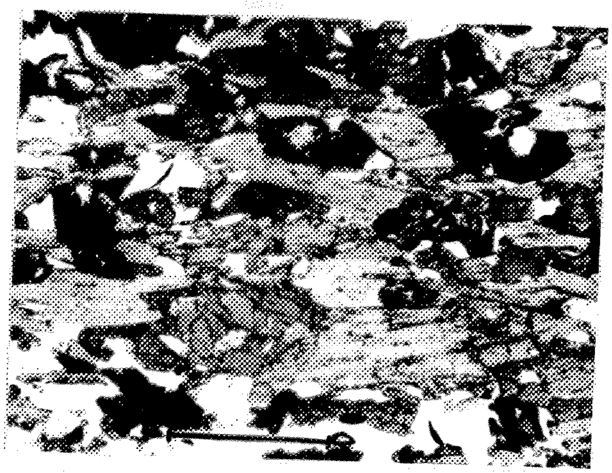


PLATE 11b.

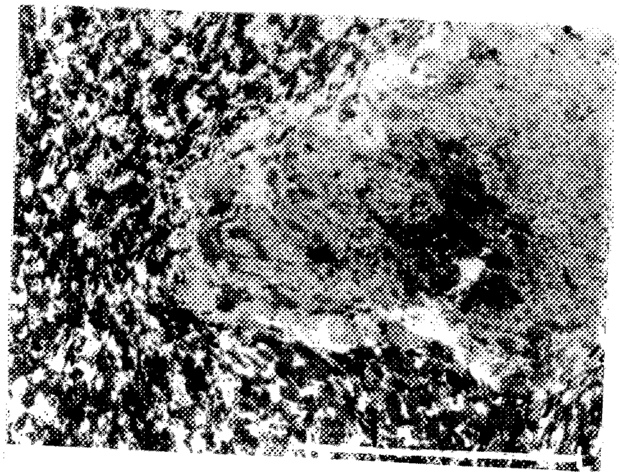


PLATE 11c.

PLATE 11d.

PLATE 11e.

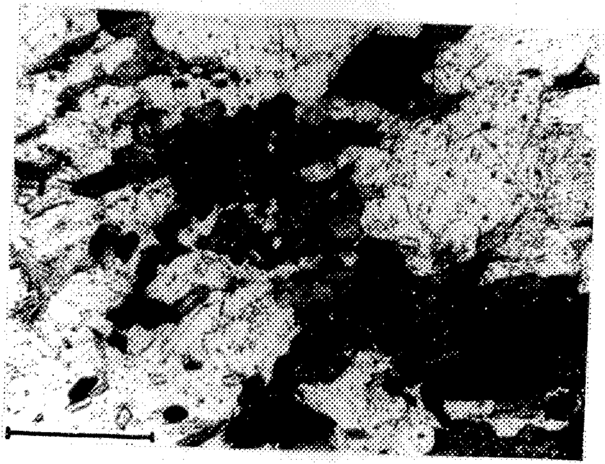


PLATE 11f (i).

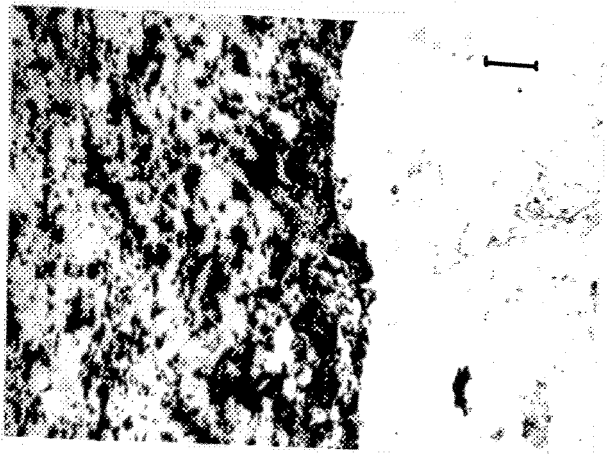
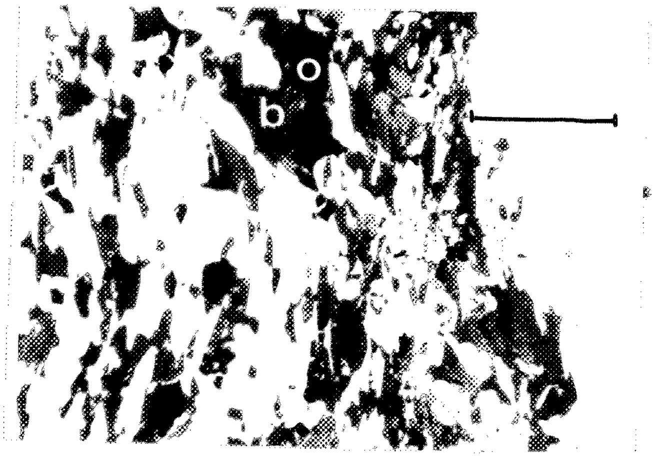


PLATE 11f (ii).



lesser plagioclase (~20%). Mafic minerals total about 5%, consisting of biotite and relict hornblende, altering to carbonate and opaques.

3-Rocks of Age Group III

Rocks postdating migmatization IIb and deformation IIc (Table 1) are poorly represented within the study area. Rocks represented on Fig. 2 as "granite III" consist of unfoliated, medium grained, pink biotite leucogranites and buff biotite leucotrondhjemites, which may be related to polyphase mobilizate III pegmatite injection. As such, these "granitic" rocks may not be correlated with syenitic granites and augengneisses outcropping to the west, near Chicoutimi (Fig. 1), as described by Dimroth et al (1980).

Figure 22 shows a relatively large mass of granite III intruding concordant amphibolite. The granite III here is even-grained (2-4 mm), containing about 60% potash feldspar (microcline), ~25% quartz, ~12% plagioclase, and 3% randomly distributed biotite flakes. Plagioclase-quartz rich (trondjemitic) mobilizate III pegmatite dykes follow the contact between the granite and host concordant amphibolite (Fig. 22), demonstrating that the granite antedates this particular phase of pegmatite injection.

Another variety of granite III outcrops at OS-14. The rock, as in the previous case, is even-grained (2-4 mm), but has a buff green fresh surface, and contains about 75% plagioclase, ~20% quartz, ~3% magnetite, and about 1% biotite, and only trace amounts of potash feldspar.

Consequently, these "granite III" rocks are compositionally identical to the range of granitic-trondhjemitic pegmatite dykes found within the study area, differing only in grain size and texture. A detailed account of the petrography, morphology, and mode of occurrence of mobilizate III pegmatites will be presented in section IV. It will be noted here, however, that pegmatite compositions vary between granitic (potash feldspar-quartz rich) to trondhjemitic (plagioclase-quartz rich) end members. The pegmatites are always leucocratic, containing <5% mafic minerals, chiefly biotite and/or hornblende, in varying stages of alteration. Locally, the pegmatites also may contain up to about 30% magnetite (ex. Plate 14). The compositional similarity between the pegmatites and those rocks mapped as "granite III" indicate that these units are genetically linked, textural differences possibly resulting from higher vapour pressures and volatile concentrations present in the case of the pegmatites.

FIGURE 22.

Pink, even grained biotite-bearing "granite III" intruding concordant amphibolite. The granite III antedates injection of thin trondhjemitic mobilizate III veins. Note the thin, discordant offshoot of an amphibolite IIa (amphibole-phyric) dyke in left-centre of the figure.

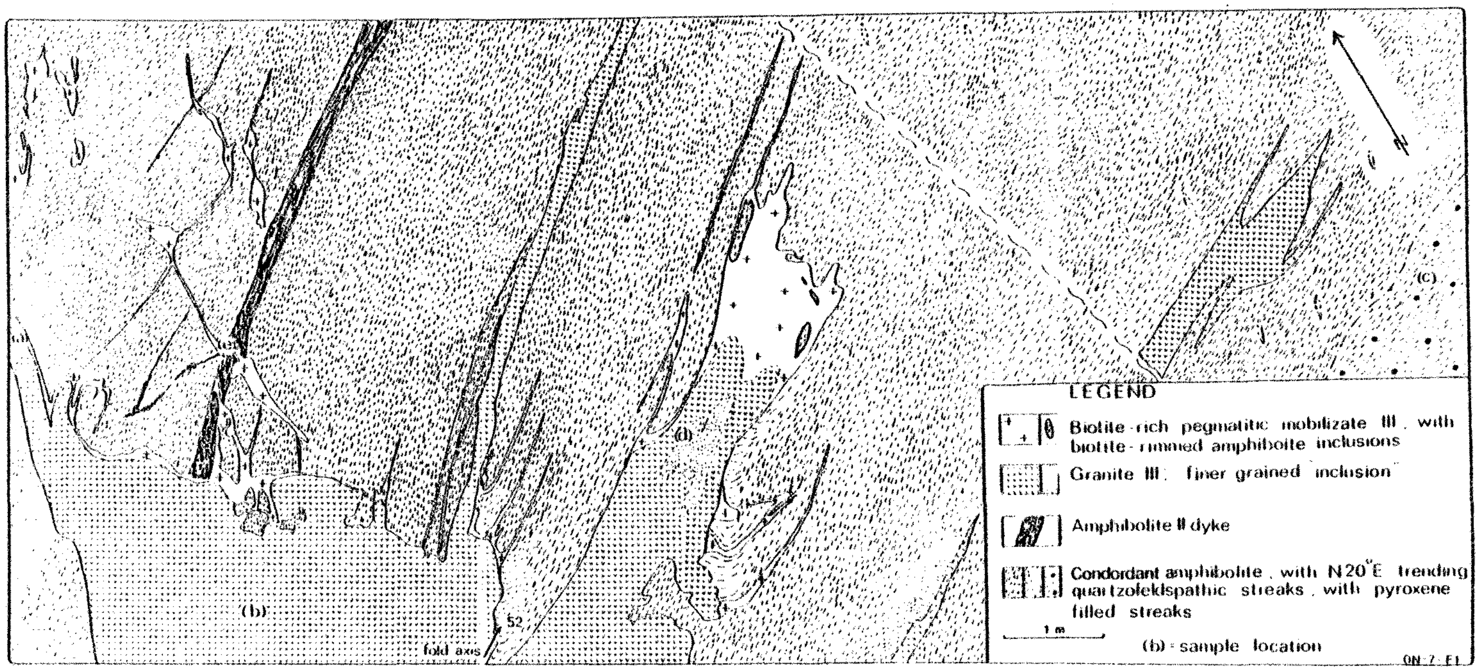

(b)
(c)
(d)
52
fold axis
LEGEND
Biotite-rich pegmatitic mobilizate III, with biotite-rimmed amphibolite inclusions
Granite III: finer grained "inclusion"
Amphibolite II dyke
Condordant amphibolite, with N20°E trending quartzofeldspathic streaks, with pyroxene filled streaks
1 m
(b) = sample location
ON-7-F1

FIGURE 22.

III. MIGMATITES

A. NOMENCLATURE

When Sederholm first defined migmatites as follows:

> "For the gneisses here in question, characteristic of which are two elements of different genetic value, one a schistose sediment or foliated eruptive, the other, either formed by the resolution of material like the first or by injection from without, the author proposes the name of migmatites: the position of this rock being intermediate between eruptive rocks proper, and crystalline schists of sedimentary or of eruptive origin" (Sederholm, 1907, p. 110)

he provided the geological community at the outset with a definition fraught with genetic implications. Sederholm himself preferred a mechanism operating by "injection from without", although his "ichors" were not true magmas, being rather "things showing gradations between an aqueous solution and a very diluted magma, eventually also a magma containing much water in a gaseous state" (Sederholm, 1907, p. 89), thus including metasomatic fluids as well as igneous melts.

In an effort to remove many of the genetic implications inherent in the contemporary terminology, Scheumann (1936) introduced a "non-genetic" nomenclature. Even this attempt was compromised to a certain degree: Scheumann´s term "metatect", still in common use to describe newly formed leucocratic material in migmatites, is derived from the Greek "tektos"-melt, thereby siding Scheumann with Sederholm.

K.R. Mehnert (1968) has provided a systematic nomenclature widely used in describing the morphology and mechanism of migmatites and migmatization processes. Migmatites are megascopically composite rocks, "consisting of two or more petrographically different parts, one is the country rock in a more or less metamorphic stage, the other is of pegmatitic, aplitic, granitic, or generally plutonic appearance" (Mehnert, 1968, p. 355). Following Mehnert's (1968) classification, a migmatite will generally consist of a paleosome (country rock) and a neosome (newly formed, often mobile, rock portion). The neosome may consist of a leucocratic quartzofeldspathic portion (leucosome) which is frequently bordered by a mafic melanosome, also variously referred to in the literature as a mafic selvage (selvedge), or an immobile restite.

Parts of gneissic rocks with leucocratic portions will here be referred to as leucocratic "segregations", as a general term. More specific terms will be used where appropriate (ex. veins, pods, streaks, flecks). Leucocratic segregations will be considered to be "mobilizates", a "petrogenetically neutral term" (Mehnert, 1968, p. 356), rather than "metatects", which implies a process of metatexis, that is, "partial, differential, or selective anatexis of the low-melting components of a rock" (Mehnert, 1968, p. 355). This is done in keeping with the goal of avoiding genetic implications in describing the mesoscopic and microscopic features of the leucocratic segregations seen in the migmatitic gneisses in the study area. Genetic considerations will be presented as a Discussion (Section V), conclusions coupling mesoscopic and microscopic observations and data, comprising the bulk of the text of the present work.

B. POSSIBLE ORIGINS OF MIGMATITES

1-Historical Background

Despite the fact that migmatites have been the subject of considerable geological investigation for over one hundred years, the origin of this widespread lithology remains controversial. This reflects the fact that different geologically-plausible mechanisms

FIGURE 23.

Morphology of the neosome components of a migmatitic gneiss.

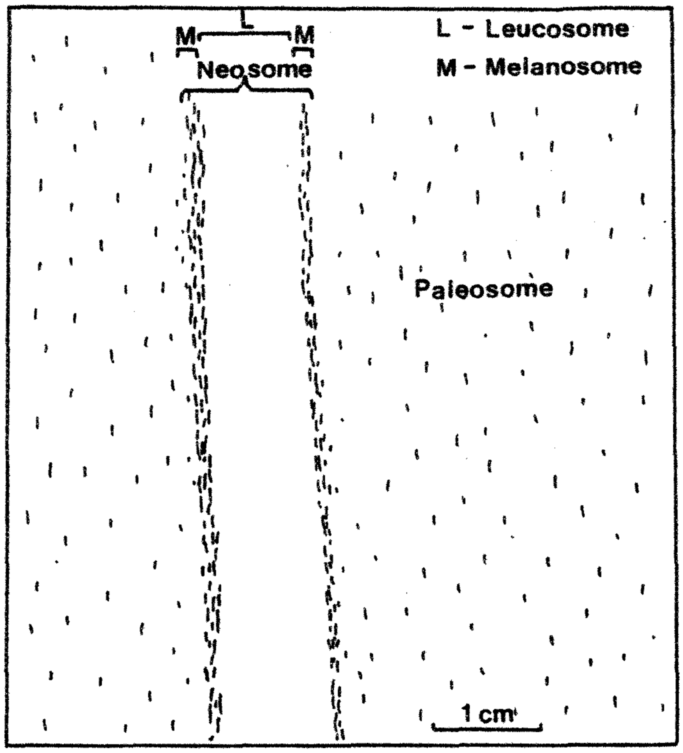


FIGURE 23.

of migmatization may produce morphologically and compositionally similar types of migmatites. As such, identical phenomena observed in migmatitic terranes have been interpreted by different geologists as being the products of markedly different migmatization processes.

The controversy concerning the origin of migmatites was well established early in this century, following systematic and detailed studies by J.J. Sederholm and P.J. Holmquist in Fennoscandia. Sederholm, who coined much of the terminology still used in describing migmatites, maintained that the leucocratic veins representing the "igneous" portion of migmatites were emplaced from deep, external sources as a melt (Sederholm, 1967 reprint). Holmquist, on the other hand, believed that the host rocks (paleosomes) were the source of the leucosomes, the vein material segregating either by the process of lateral secretion or by in situ partial melting. With regard to the latter case, Holmquist imagined deep crustal zones of sufficiently high pressure and temperature to initiate "a real fusion of the most fusible rock masses" (Holmquist, 1920, p. 210). The process of lateral secretion is now referred to as metamorphic segregation or differentiation, and present-day controversy involving possible processes of migmatization focuses on the merits of metamorphic differentiation versus anatexis as the most likely migmatization mechanisms.

Thus, two early schools of thought were established; one wherein igneous injection from an external source emplaced molten felsic material in the migmatitic terrane, the other supporting a more-or-less closed system, where vein material segregates by metamorphic differentiation or by in situ partial melting.

The relationship between some granitic massifs and the formation of migmatites became apparent during Barrow's (1893) studies in Scotland. Here, gradational changes of pelitic country rocks from slates, phyllites and schists through to granitic gneisses approaching a central granitic massif were interpreted as being the result of the thermometamorphism of the country rock of the granitic intrusion, the migmatitic nature of the gneisses resulting from the introduction of residual fluids from the granite in late stages of crystallization. As such, the important of field relationships of migmatites with stratigraphically equivalent country rocks was established, as later emphasized by Read (1957).

Read (1957), observing uninterrupted stratigraphic units passing directly into granitic rocks without an intermediate magmatic stage, interpreted these relations as being the products of metasomatic fluids emanating from the granite. Only sediments approximating the composition of a granite were so-transformed; limestones, quartzites, amphibolites, and other lithologies compositionally dissimilar to granites resisted granitization. These notions represent a fourth possible mechanism of migmatization: external metasomatism, which falls alongside Sederhölm´s igneous injection hypothesis as involving an open system

Experimental work in the last few decades has quantified possible conditions of crustal anatexis, as envisioned by Holmquist (1920). Tuttle and Bowen (1958) experimentally established that melts of granitic composition may be generated by regional metamorphic grade PT conditions in the presence of water, by the process of anatexis. The resulting granitic melt has a distinctive "minimum melt composition' falling near the cotectic of the synthetic system albite-orthoclase-quartz-(water) (Tuttle and Bowen, 1958). This, along with Winkler´s and Winkler and von Platen´s (c.f. Winkler, 1974) work on natural geosynclinal sediments (clays, greywackes), and other partial melting experiments on gneisses by Steuhl (1962), Mehnert et al (1973) and Busch et al (1974), indicate that partial fusion is initiated at temperatures between 600 and 750 C, at P-H20 from 2 to 10 kb. These conditions correspond, for instance, with crustal depths in the order of 20 km (lithostatic pressure approximately 5 kb) given a typical geothermal gradient of 30 C/km, (Mehnert, 1968), the depth varying with geothermal gradient accordingly. Experimental studies have shown that Tuttle and Bowen´s (1958) synthetic system is incomplete; natural systems contain plagioclase as an important constituent. Consequently, the quaternary system anorthite - albite - orthoclase - quartz - (water) more closely approximates natural rocks.

2-Mechanisms of Migmatization

Confronted with the problem of interpreting the genesis of a migmatite terrane, the researcher must seek reliable criteria or observations indicative of the fundamental physical-chemical conditions operative during the migmatization process(es). Is the migmatite a product of in-situ differentiation and/or has any material been introduced or removed from the system? That is, are we dealing with an open or a closed system? Have the "magmatic" -appearing portions (leucosomes) of the migmatite ever been fluid? Resolution of these basic problems will identify the fundamental migmatization process(es), according to those summarized in Table 3. It must be emphasised at the outset that unique, unequivocal definition of the process(es) responsible for the migmatization of a given area may not be possible; different mechanisms may develop similar phenomena.

Before discussing possible criteria for distinguishing between the migmatization process outlined in Table 3, it is advisable to briefly review some of the parameters and conditions controlling each process.

Igneous injection has rarely been described as the dominant or sole mechanism operative in a migmatitic terrane, insofar as igneous intrusions rarely impart a wholesale migmatitic aspect to their host rocks. A few examples of this , however, are described in the literature, for example, certain plutons in the Donegal district of northwestern Eire (Pitcher and Berger, 1972). The only conditions necessary for igneous activity to occur are, firstly, a source of magma, which may be of any composition, and secondly a mechanism of emplacement. It is the nature of the second condition that

TABLE 3: Mechanisms of migmatization.

			Material introduced from outside system?	
		PROCESS	Yes: Open System	No: Closed System
Melt Phase Present?	Yes:	Igneous	Igneous injection	Anatexis
	No:	Hydrothermal	External metasomatism	Metamorphic differentiation

(after White, 1966; Misch, 1968; and Yardley, 1978)

Note: Given the scale dependence of the concept of an open vs closed system, we consider a closed system to involve migration of migatitic fluids etc. within an outcrop scale, thus allowing for migrant anatectic mobilizates, formed within the outcrop rock assemblage. On the other hand, an open system will involve the introduction/migration of migmatitic fluids, etc. on a larger-than-outcrop scale.

determines whether igneous injection will yield rocks of migmatitic character. Magmas which permeate and brecciate country rocks during intrusion would contain abundant xenoliths, yielding a rock assemblage with an agmatitic aspect.

External metasomatism is a special case of hydrothermal activity, wherein "chemical potentials"(and hence fluid composition) are controlled externally relative to an initially homogeneous layer, and removal and/or precipitation of material occurs, resulting in a change in the bulk composition of the layer" (Yardley, 1978, p. 943). Ionic transport under anhydrous conditions is so limited in extent that migmatization in the absence of fluids is considered to be insignificant. As such, metasomatism invariably involves on transport through pore fluids in rocks. Transport of ions may occur via diffusion through a static pore fluid (diffusion metasomatism) or by the bulk flow of pore fluids (infiltration metasomatism). Regardless of the mechanism of ion transport, the important factor defining "external" metasomatism as a process of migmatization is the introduction of certain ions, and probable concomitant removal of other ions, through or by the pore fluid into a certain layer, demonstrably changing that layer´s bulk composition-in effect, migmatizing it. The migmatizing effect results from the fact that the mobile ions present in the pore fluid (eg. K, Na, Ca, Si, Al) tend to be those which segregate into veins, forming leucocratic layers. Where diffusion metasomatism on a small scale occurs, these leucocratic layers will have margins depleted in vein minerals (Yardley, 1975), although proponents of a partial melting mechanism ascribe an anatectic process to this feature. Diffusion metasomatism operative within compositionally heterogeneous rock sequences may, as such, be considered to represent an open system, on a layer to layer scale (eg infiltration of ions from one layer to another), but a more or less closed system within the context of the layered unit as a whole. From this standpoint, the migmatization process trends toward homogenization of the layered sequence. Where ions are transported into the system from an external source, the layered sequence will show bulk chemical compositional changes on all scales. In this case, as in the former case, leucocratic veins may develop, forming a migmatitic aspect, following fracture systems or foliations (eg. schistosity) in the unit. Hydraulic fracturing by the hydrothermal solutions may induce segregation of leucocratic veining (Yardley, 1975).

Anatexis refers to the partial melting (fusion) of rock material. The degree of partial melting may, depending upon PTX conditions and upon the material being fused, vary widely. Metatexites are rocks formed by incipient degrees of partial melting (metatexis), the partial melt fraction tending to segregate into thin veins and other morphologies, giving the rock the banded appearance so typical of migmatites. Diatexites are formed from rocks having undergone an advanced degree of melting (diatexis). The resulting rock has a diffuse appearance (ex. schlieric or nebulitic texture; Mehnert, 1968), wherein originally molten and unmolten portions may no longer be distinguished (Busch et al, 1974; Winkler, 1979).

Anatexis commences along the contacts between mineral aggregates. Leucocratic minerals tend to have lower melting points than ferromagnesians, consequently melting commences at triple points of quartz-plagioclase-potash feldspar, along quartz-plagioclase and quartz-potash feldspar boundaries, and along contacts between identical minerals (Molen and Paterson, 1979). In experimental melting of natural rock samples, quenching of samples exposed to PTX conditions initiating anatexis demonstrates that the partial melt forms consistantly thin films (15-20 microns thick) along the contacts described above (Mehnert et al, 1973). In the absence of water, initiation of partial melting requires prohibitively high temperatures, unlikely to be represented in the deep crust of Earth. Although aqueous pore fluids are present in substantial quantities in subducting geosynclinal sediments, these fluids are largely absent in deep seated continental gneisses. However, partial melting may nevertheless be triggered by dehydration reactions involving hydrous ferromagnesian minerals

(Brown and Fyfe, 1970, 1972). Partial melting may yield rocks of migmatitic character since the melt component tends to migrate into low pressure (dilational) zones present in the deformational/anatectic environment. The geometry of these dilation zones controls the morphology of the leucosome, also controlled by the degree of partial melting. Progressively advanced stages of partial melting systematically alter the composition of the melt phase, approaching the composition of the rock being melted.

3-Possible Criteria for Distinguishing Migmatization Mechanisms

Concise definition of three properties may be sufficient to completely describe a migmatite; morphological, mineralogical, and chemical properties.

Morphological properties focus on the mesoscopic field aspects of the various components of a migmatite. Since it is the origin of the leucocratic segregations (neosome) of the migmatite that is most problematical, aspects of leucosome field occurrences must be fully documented, in relation to a melanosome (where present), the paleosome, and to other leucocratic segregations, and to structural features in the migmatite. In the initial perusal of a migmatitic terrane, the "paleosome" should be considered to be merely the host rock of the leucocratic segregations, since, at the outset, it is not known if the migmatitiztion process operated under open or closed conditions. However, the presence of a melanosome bordering leucosomes proves beyond doubt that the system was in large part closed.

A fundamental property of leucocratic mobilizates is their preferential localization in structural dilation zones. Although planar leucosome veins concordant to paleosome foliation may not show signs of having had any fundamental control on their localization, apart from host rock foliation, petrographically similar material in the same outcrop may be segregated into obvious dilation zones. Some of these structural traps (summarized in Fig.

23) include interboudin infillings, localization in dilational fold hinges and flexural zones, the infilling of brecciated layers, and of joints, and the segregation of neosome material in down-gradient pressure shadows in the terminal regions of inclusions in the paleosome. In the latter case, the neosome may surround or partly surround the inclusion if bodily rotation has occurred during leucosome genesis (Ramberg, 1956). Another typical leucosome occurrence -an enigmatic one to the uninitiated-is as veins seen cross-cutting dykes in the paleosome. This is the so-called "Sederholm effect" (Sederholm, 1967, p. 325), which emphasizes the mobile nature of leucosomes in migmatites. Given these relations, chronological aspects of migmatization may also be defined.

Although these and other field occurrences of neosome material have been documented in different migmatite terranes of all ages throughout the world, their interpretation has varied considerably. Differences of opinion may stem from different interpretation as to the effect the different rheological properties on neosome and paleosome material will have on the localization of the neosome, and the formation of structures therein. This interpretation is linked directly to the physical state of the neosome during its development and segregation. For example, Ramberg (1956) eschews the possibility that leucocratic veins studied in west Greenland migmatites were ever in a fluid (ex. molten) state, citing structural evidence that certain features such as vein pinch and swell occur only along conformable competent layers in response to tensional dragging due to plastic flowage in the adjacent incompetent host rocks. Pinching in the vein develops locally because the competent vein will not yield homogeneously along its entire length by recrystallization flowage (Ramberg, 1956). Since pinch and swell will only occur along veins with less competent host rocks, the vein material could not have been fluid at the time of formation of this structure. Following a similar arguement, Escher (1966) concludes that pinch and swell structures in leucosomes in upper amphibolite grade gneisses in the Nanortalik area, south Greenland, formed by pushing adjacent gneissic host rocks aside plastically. These structures, interpreted as forming while the leucosome grew in the solid state, the continuity of paleosome layering on either side of pegmatoid veins, compositional similarity of paleosome and vein material, the non-dislocation of paleosome "inclusions" in leucosomes, feldspar porphyroblastic growth in the paleosome adjacent to leucosomes, and the amphibolite facies mineral assemblages (eg. <600 C) of leucosomes lead Escher (1966) to suggest a migmatization process of migration and/or in situ secretion of quartzofeldspathic material in slip planes and joints. This material grew by replacement and by pushing aside the host and earlier formed veins. Swelling in boudinaged veins indicates that locally more volume has been added than replaced. Migration of material into the system is indicated leucsome volumes exceeding that expected to have been generated from paleosomes. Granulite facies rocks in the area have been "degranitized", consequently these rocks provided Si, K, Na, Al, and Ca for the migmatization of the amphibolite facies rocks. Consequently, leucosome-paleosome relations and comparable mineral assemblages indicative of subanatectic PT conditions suggest migmatization by external metasomatism and metamorphic differentiation. Similarly, Ramberg (1956) argues for solid state growth of leucocratic material in interboudin zones. In Ramberg's study area, interboudin interstices are never partly filled by a void, and these interstices would invariably be filled not only by leucocratic material, but also by the adjacent incompetent gneiss, host to the competent layer being boudinaged, if the dilational site had ever been "empty". Despite Ramberg's (1966) and Escher's (1966) eloquent arguments, one might also imagine that pinch and swell structures in some veins were formed after consolidation of molten leucocratic material, and that interboudin dilation zones are never, or are rarely, "empty" rather being downgradient, low pressure zones, into which fluids, including melts and metasomatic fluids, migrate, later consolidating to form leucocratic, interboudin material. Furthermore, dehydration reactions occurring in upper amphibolite grade conditions may initiate anatexis (Brown and Fyfe, 1970).

Yardley (1978, Table 2) recognizes different morphological varieties of leucosomes in migmatites of different origins. Since the four principal proposed mechanisms of migmatization differ according to the presence of a closed versus an open system, and according to an igneous versus a hydrothermal origin for leucosomes, the mechanism of migmatization will have distinctive physico-chemical properties, which ultimately control the morphology, including volumes, of resulting mobilizates. For igneous mechanisms, rotation of paleosome inclusions in the leucosome is possible. In injected igneous veins rotation of these inclusions likely, depending upon the mechanism (eg passive vs forceful) of emplacement. On the other hand, rotation of inclusions in anatectic leucosomes is likely only where sufficiently large volumes of melt have been generated to extensively agmatize (Mehnert, 1968) the paleosome. This follows from the fact that intruded veins need only be molten as they are individually intruded, whereas anatexis will occur almost simultaneously in a given area in rocks of similar composition and water content. Thus, all leucosomes so-generated are molten at the same time, thereby mechanically weakening the host rock, encouraging agmatization. Before such a conclusion may be reached, however, contrary evidence should be sought: cross-cutting veins of similar petrography and morphology likely formed during the same anatectic (?) episode, but nevertheless demonstrate that not all leucosomes were simultaneously fluid.

Non-igneous leucocratic segregations would not be expected to contain rotated paleosome inclusions. During hydrothermal processes, only small amounts of migmatizing fluids need be present at any given time (Yardley, 1978), therefore extensive and closely spaced veining may occur without mechanically weakening the paleosome. However, as noted above, the volume of melt generated by anatexis varies widely. Furthermore, not all anatectic veins generated by the same period of partial melting need have been simultaneously fluid, as evidenced by cross-cutting leucocratic veins (Fig. 17). Thus, these criteria may be reliable only in specific cases, and where supported by other observations.

From the foregoing, it is clear that mesoscopic field occurrences of neosome material are related to structural features in the paleosome. The development of leucosome morphologies may thus be related to particular deformational episodes; whether particular morphologies develop prior to, during, or following a deformation is an open question, whose solution is founded in the researcher's interpretation not only of deformational features in and about the leucosome itself, but also according to his interpretation of the physical state (eg growth in the solid state, or precipitation from or consolidation of a fluid) of the leucosome at its time of development. This is perhaps best obtained from detailed examination of the mineralogy, textures, and compositions of leucosomes, and the relations of these to adjacent melanosomes and paleosome material, where present.

Mineralogical properties afford several criteria indicative of the physical state of the system at the time of neosome formation. Except for the case of trace elements, chemical criteria may be considered alongside mineralogical parameters. Reliable estimates of the bulk composition (major oxides) of leucosomes may be had by modal analysis , as well as by standard analytical techniques (Ashworth, 1976). Similarly, optical techniques may replace chemical analysis in determining individual solid solution mineral compositions, most importantly, that of plagioclase, and, to a lesser degree, the albite content of orthoclase.

Leucocratic segregations that are the products of anatexis should yield mineralogical and chemical characteristics in accordance with those predicted by experimental melting of natural and synthetic systems. Perhaps the most important of these is the quaternary system albite-anorthite-quartz-orthoclase-(water). Ideally, anatectic quartzofeldspathic segregations will have a compositiom falling near this system's cotectic, representing the granitic "minimum melting composition" (Winkler, 1979). Owing to the strong fractionation of the albite component of paleosome plagioclase into initial partial melts during anatexis, granitic leucosomes would be expected to have plagioclases in the order of 10 to 40% more albitic than that in the adjacent melanosome (Yardley, 1978). Tobschall (1971) reports anatectic migmatites from Beaume-Tales, Frances, having leucosome plagioclases of composition An 9-14, compared with more calcic (An 30-40) melanosome plagioclase. As such, the presence of relatively sodic leucosome plagioclase is a strong indication of an anatectic origin. Conversely, similar leucosome/melanosome plagioclase compositions indicate either a non-anatectic origin, or the subsolidus reequilibration of the leucosome with the adjacent melanosome (Yardley, 1978). Where leucosome/melanosome plagioclase compositions are similar, or are ambiguous, other criteria should be consulted when considering possible migmatization mechanisms. For example, Misch (1968) reports slight but consistent albite -enrichment in leucosome plagioclases in the Skagit Gneiss, Washington. However, he concludes that the migmatization process was one of metamorphic differentiation, with bulk compositional changes also indicating external metasomatism. Plagioclase compositions in the leucocratic Skagit gneiss show statistically close relationships to the schists and amphibolites from which they were derived; the gneiss plagioclases vary widely in composition, in accordance with the compositions of the plagioclase in their parent rock. A non-anatectic origin is also supported by the absence of basification of schist and amphibolite remnants, as would be expected due to the subtraction of leucocratic minerals, and the leucotrondhjemitic to quartz dioritic composition of the migmatitic gneisses, which are impoverished with respect to K20 compared with parent rocks. Within the Skagit gneiss, some features may be entirely attributed to either metamorphic differentiation or metasomatic replacement, but in most cases both processes are indicated, with metasomatism being largely responsible for regional migmatization.

The significance of leucosome K20 content, chiefly represented by potash feldspar, is made apparent by experimental melting studies, in which it has been shown that anatectic leucosomes will

X

contain significant quantities of potash feldspar even when derived from paleosomes relatively impoverished with respect to potassium. For example, if biotite is the sole potassium-bearing paleosome mineral, potash feldspar will nevertheless be generated during incipient melting due to the breakdown of biotite in the developing melanosome, leaving, as a residue, garnet or cordierite (Kilinc, 1972, Yardley, 1978). Leucosome potash feldspar will also form at the expense of potash feldspar in the developing melanosome, depleting the latter to near exhaustion (Ashworth, 1979; White, 1966). As such, quartz-plagioclase veins would not be expected to form from the partial melting of K-mineral bearing paleosomes (Yardley, 1975; Amit and Eyal, 1976).

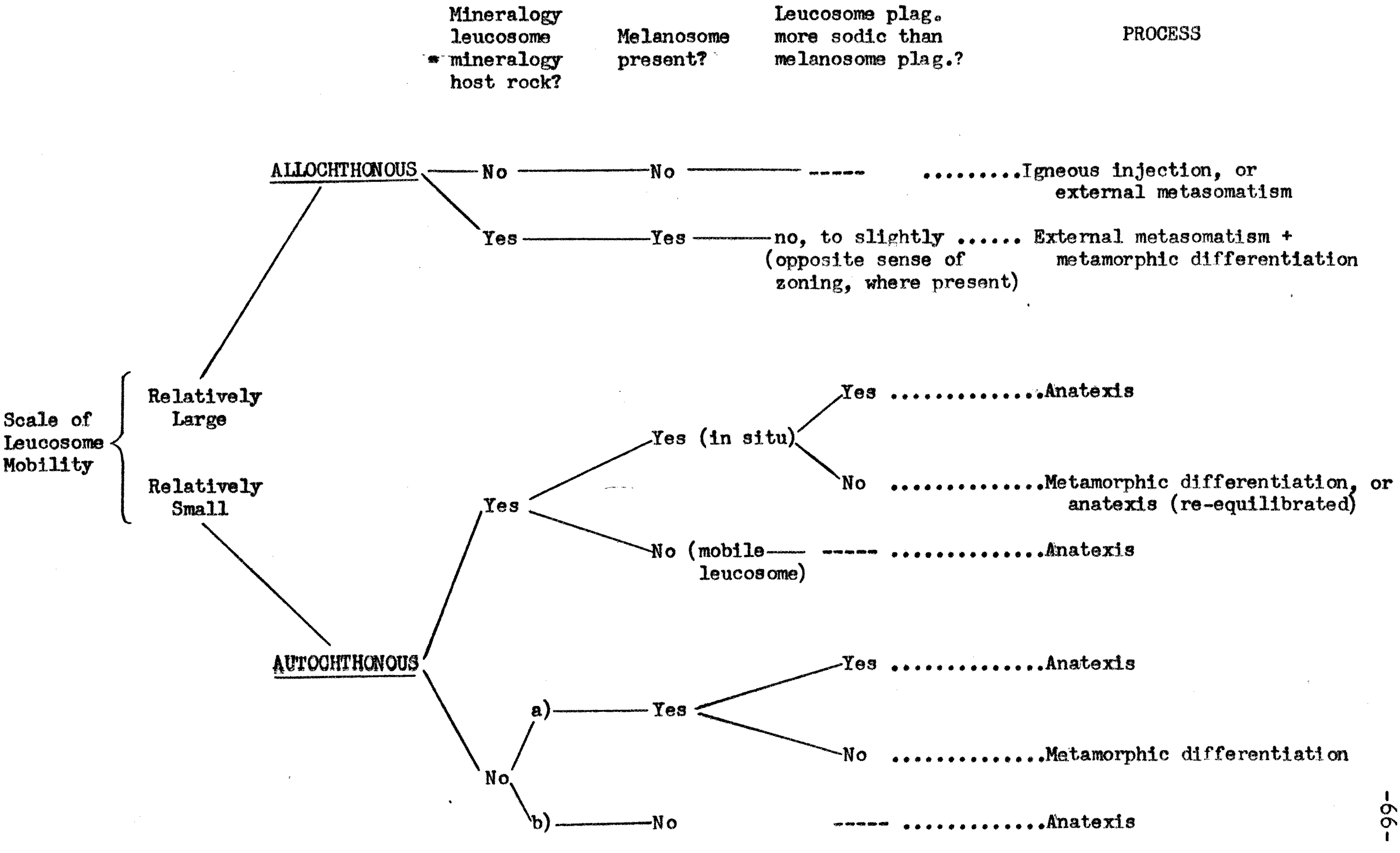
From this the importance of leucosome-melanosome relations is made apparent. While it is clear that the leucosome develops at the expense of melanosome material, whether this segregation of paleosome components occurs in the solid state, or in a partly fluid (molten) state is uncertain. Proponents of an anatectic mechanism consider the melanosome to represent refractory material (restite) which accumulates to form mafic seams bordering the segregating vein of mobile leucocratic melt. Supporters of hydrothermal processes believe that this segregation occurs in the solid state, possibly being initiated along primary compositional planes (bedding) or along planes of weakness, especially in ductile paleosome (Yardley, 1978). Metamorphic or metasomatic pore fluids provide the medium of transport, via ionic diffusion through a static fluid, or through the bulk flow of fluid. Hughes (1970) suggested that mafic selvages form along interfaces between rock with a silicate pore fluid formed during incipient partial melting, and rock with a hydrothermal pore fluid. The ubiquitous presence of melanosome seams bordering leucocratic veins in migmatites of different compositions, and of different metamorphic grades, indicates that these may form by different processes, consequently, in the absence of further information, especially a comparison of melanosome/leucosome plagioclase composition, the compositional complementary nature of quartzofeldspathic veins and their marginal mafic selvages does not, in itself, favour either an anatectic or hydrothermal mechanism. Neither does the absence of a melanosome necessarily favour an igneous injection origin. Rather, the absence of melanosomes, or melanosomes insufficiently thick to account for leucosome volume, indicates the mobility of anatectic melts, or, equally plausible, a combination of metamorphic differentiation (creating the selvage), with concomitant introduction of leucocratic material via external metasomatism. Large volumes of leucosomes also indicates an unspecified source in the paleosome, thus not all leucosome material is generated in the melanosome.

From the foregoing arguments, we are led to the inexorable conclusion that neither morphological nor mineralogical criteria furnish ironclad methods for distinguishing migmatization processes. A particular process may be preferred, not so much for its own merits, but insofar as another process, or processes, may be excluded from the realm of possiblity, based on the evidence at hand. Although summarizing the typical features of different genetic types of migmatites is of some use in classifying migmatization mechanisms (c.f. Yardley, 1978, Table 2), determination of the genetic process(es) responsible for the migmatization in a given area is best accomplished by a process of exclusion. This may be undertaken by considering which features may determine if a) the migmatization process was isochemical; b) if the leucosome material crystallized from a melt. The process may be systematically employed by noting the presence/ absence of these features. The method is presented in flow-chart format in Table 4. Note that distinction of an open versus a closed environment of migmatization is usually a goal of research, not a starting point. However, the scale dependance of the concept provides a certain leeway in interpretation. Obvious evidence supporting a closed system (eg. melanosome-leucocome relations) permits classification of leucocratic segregations in the field, pointing toward an allochthonous or autochthonous origin. Evidence for metasomatism may be clear cut, as in the case of quartz-rich veins in quartz-poor paleosomes, or nebulous, in which case bulk chemical analyses may be required.

By comparing the result obtained from Table 4 with PT conditions indicated by mineral assemblages, the adequacy of the method may be tested. For example, leucosomes interpreted as being the products of anatexis should be restricted to upper amphibolite or granulite metamorphic facies asemblages.

TABLE 4.

Petrographic indicators of migmatization processes, in flow-chart format. The various paleosome-neosome relations seen in the Old Gneiss Complex are fully described by the features/mechanisms indicated here. By comparing the result obtained from Table 4 with PT conditions indicated by mineral assemblages, the adequacy of this method may be independently tested. For example, leucosomes interpreted as being the products of anatexis should be restricted to upper amphibolite or granulite metamorphic facies assemblages.



note: a) new minerals (ex. K-feldspar) formed during migmatization

b) mobile leucosome ("Sederholm Effect")

TABLE 4.

IV. MESOSCOPIC FEATURES AND PETROGRAPHY OF LEUCOCRATIC SEGREGATIONS IN THE STUDY AREA

A. AGE SUBDIVISIONS

A chronology of migmatization events has been established, based on cross-cutting leucocratic segregations. Coupled with structural controls of localization, different periods of migmatization may be placed within a structural framework, as described in section IIA and outlined in Table 1. Although rather rare, exposures of all generations of cross-cutting leucosomes within rocks of corresponding chronology, excluding dykes, have been documented. Careful definition of the mesoscopic petrography and mode of occurrence of each generation of leucosome, whose age relative to that of other leucosomes is indicated by discordant contacts, permits extrapolation from this specific case to the general case, where no intrusive relationships are seen. Consequently, individual leucosomes may be related to a specific period of migmatization. Undoubtedly, some leucosomes will now and then be misidentified, however, the criteria by which different generations of leucosomes may be recognized and identified are both numerous and rigorous. In sampling and choosing material for thin section, only those leucosomes whose identification was certain were selected.

A list of generalized criteria for distinguishing the products of different periods of migmatization is presented in Table 5. Three types of criteria may be defined:

1) Petrographic: leucosome mineralogy and textures are directly related to paleosome composition. Primary fabrics are overprinted by tectonic granulation, particularly in older generations of leucosomes and in small scale segregations (eg. thin veins).

2) Morphological: presence/absence of morphological subdivisions as defined by Mehnert (1968). This reflects the migmatization process, and is controlled in part by the structural control of leucosome accumulation (ie. mode of occurrence).

3) Mode of Occurrence: structural controls of leucosome localization. Leucosomes invariably accumulate in dilational zones (Fig. 23), that is, low pressure traps or "sinks". The size and shape of the segregation reflects the dimentions of the dilational zone as it developed through time. In situ leucocratic segregations almost invariably are controlled by the dominant schistosity in their source paleosome; discordant veins are rare, and provide the cross-cutting relationships necessary in establishing a relative chronology.

Very locally, intersecting products of migmatization episodes I, II (complex), and III may be observed within the same outcrop (Fig. 24). More commonly, however, two generations of leucosomes are seen to cross-cut. Plates 13a,b show thin, granulated mobilizate I veins cross-cut by ptygmatically folded mobilizate I veins infiltrated and cross-cut by medium grained diffuse mobilizate IIa material, in paragneiss.

Polyphase migmatization II is subdivided into three principal phases: mobilizate IIa material accumulated in dilational openings of S2a schistosity in rocks of age groups I and II, while mobilizate IIb follows strain-slip cleavage surfaces (S2c) axial planar to F2c refolding of F2b-folds (which fold both the S2a-schistosity and mobilizate IIa segregations; Fig. 3). As such, mobilisate IIb material consistently cross-cuts mobilizate IIa veins. However, recrystallization of mafic minerals in the paleosome of mobilizates commonly passively overprints both the paleosome and mobilizate I, IIa veins therein, adjacent to leucocratic mobilizate IIb veins. Coarse grained pods of mobilizate IIc cross cut foliations S2a, S2c, and

TABLE 5: Mesoscopic criteria for distinguishing different generations of mobilizates (not necessarily applicable to dyke rocks)

Mobilizate III

Petrography:
Coarse grained (0.5 to 15 cm) granitic to trondhjemitic leucocratic pegmatites and granitoids. Composition unrelated to host rock. Generally non-graphic and unzoned. Deformed only by S3-shearing, therefore usually are not granulated. Biotite and hornblende are the mafic minerals; orthopyroxene is not seen, and tourmaline was found in only one location (ON-3). Not uncommonly contains significant magnetite.

Morphology:
Demonstrates no strict morphological features. Pegmatite masses are generally unzoned, and melanosomes are completely absent. Tend to recrystallize host rocks allong narrow contact margins.

Mode of Occurrence:
Generally irrespective of structural elements within host rocks (ie. usually cross-cuts S2a). However, at OS-3,-4 mobilizate III is preferentially localized along some S2c slip surfaces (Fig. 23, 24). Forms centimetre to decametre scale dykes, pods, and irregular masses. Not uncommonly have dislodged, recrystallized fragments of host hock. Pegmatites are of several generations, even dykes of similar compositions are seen to cross-cut.

Mobilizate IIc

Petrography:
Coarse grained (0.5 to 5 cm) granitic pegmatoids identified only in granite I paleosomes. Unlike mobilizate IIa, mobilizate IIc leucosomes are generally unzoned (ie. quartz is not segregated in cores of veins). Postdates deformations IIb and IIc, therefore, like mobilizate III, these leucosomes generally are not granulated.

Morphology:
Well defined leucosome-melanosome relations. Melanosomes may be absent where mobilizate IIc forms discordant pods, however, concordant offshoots may have thick (5 or 6 mm) melanosomes grading diffusely into the granite I paleosome. Mobilizate IIc vein offshoots not uncommonly show pinch and swell, or are coarsely lobate.

Mode of Occurrence:
Typical occurrence is as lobate, metre-scale discordant pods with thick (5 to 20 cm) concordant offshoots, paralleling S2a in the granite I paleosome. "Inclusions" (rafts) of granite I in mobilizate IIc masses show no sign of rotation, neither are they recrystallized by the leucosome.

Mobilizate IIb

Petrography:
Mineralogy varies with host rock composition. Granitic (microcline-quartz-plagioclase) leucosomes are found in granitic gneisses; trondhjemitic (plagioclase-quartz; plagioclase composition not implied) leucosomes are found in concordant amphibolite. Not uncommonly, mobilizate IIb contains streaky mafic clots, chiefly consisting of recystallized poikilitic (quartz inclusions) hornblende porphyroblasts, oriented parallel to the vein. S2c is represented in mobilizate IIb by tectonically aligned quartz plates.

(continued)

(Table 5, cont´d)

Morphology:
Lacks a marginal melanosome, indicating mobility on a metre-scale (at the most). Mineralogy always consists of the same minerals as found within host rock (paleosome). These leucosomes may range in thickness from well defined 1 cm thick veins, to more diffuse leucocratic bands, rich in mafic clots. Mafic clots may occur within the band itself, or may diffusely overprint adjacent paleosome/ mobilizate IIa material over a distance of tens of centimetres. Restricted to S2c strain slip shear surfaces, mobilizate IIb veins usually are closely (<50 cm) spaced.

Mode of Occurrence:
Mobilizate IIb veins are restricted to S2c strain slip cleavage surfaces, axial planar to F2c folds, locally seen to refold F2b folds, as outlined by mobilizate IIa veins. Locally, mobilizate IIb material offshoots from the S2c surface, forming veins of identical petrography, here concordant to S2a in the paleosome. Wider bands of mobilizate IIb commonly isolate in situ "inclusions" of paleosome (+ mobilizate IIa) whose shape is controlled by arcuate (F2b-folded) S2a surfaces, truncated on two sides by S2c. The mobilizate is best represented in granite I paleosomes.

Mobilizate IIa

Petrography:
Mineralogy of mobilizate IIa varies with host rock composition. Granitic leucosomes are found in granitic gneisses; trondhjemitic leucosomes are restricted to concordant amphibolite. Leucosomes occasionally contain well formed mafic minerals, or ragged clots of mafic minerals, whose mineralogy always matches that of the melanosome, which is most often present, bordering mobilizate IIa segregations. In paragneisses, leucosomes may contain microcline, quartz, (plagioclase) as well as garnet, cordierite and retrograde biotite and sillimanite (both intergrown with quartz). Melanosomes consist of biotite and sillimanite.

Morphology:
Generally consists of well defined leucosomes-melanosomes. Mineralogy of these always matches that of the paleosome, indicating an in situ origin, with minimal mobilizate migration. Melanosomes may be thin (1 mm) and well defined, or thicker (to 5 mm) diffusely grading into the paleosome. Melanosomes may impinge upon one another where leucosomes are closely spaced ("double restite"). In granite I, mobilizate IIa veins typically have quartz rich central cores.

Mode of occurrence:
Controlled by flexural opening of S2a-schistosity in the paleosome, and by dilation zones related to F2a folding (fold hinges, interboudin infillings, infillings of brecciated dykes, etc.). Mobilizate IIa material frequently is migratory, accumulating in breccia interstices and intersecting dyke amphibolites. In these cases, no melanosome is present, and the leucosome typically recrystallizes the host in which it has accumulated, provided that the host has a markedly different composition compared to the paleosome source of the leucosome (ie amphibolite dykes in granitic gneiss). Mobilizate IIa veins not uncommonly intersect, indicating that mobilizate IIa generation and crystallization occurred over a period of time, so not all leucosomes were concomitantly fluid. Mobilizate IIa veins are folded by F2b, refolded by F2c, and cross-cut by mobilizate IIb veins.

Mobilizate I

Petrography:
Leucosome mineralogy varies with host rock composition. As such, mobilizate I veins are of a similar composition as mobilizate IIa veins

(continued)

within the same paleosome, however, the latter are always coarser grained, since mobilizate I veins are highly granulated (grain size <0.5 mm). These veins usually are pale grey in all rock types.

Morphology:

Leucosomes are thin (2 to 5 mm), and show only scant relicts of melanosomes (usually biotite, hornblende, pyroxene (rare). In pelitic paragneiss, melanosomes typically contain prograde biotite and sillimanite. Grain size of mobilizate I matches that of the paleosome, both components having suffered granulation due to deformation I and subsequent folding episodes, while mobilizate IIa is coarser grained, by up to a factor of 20 over and above the paleosome.

Mode of Occurrence:

As flattened isoclinal folds (F2a). Vein surface represents S1; the axial plane of F2a parallels S2a. These veins are cross-cut by mobilizate IIa, and younger, leucosomes.

mobilizates IIa and IIb (Fig. 28). Different aspects of these relationships are presented in Section IVB(2,3) (Plate 32a-d, and Figures 8 and 27.)

However, this subdivision of migmatization into two phases is an oversimplification. The continuity of layering in zones containing in excess of 40 or 50 volume % mobilizate II material, and the local intersection of this material (Fig. 17, inset) indicate that not all of the mobilizate IIa material within a given exposure was fluid at the same time. Indeed, were all of this pegmatoid simultaneously fluid, one might expect it to have coalesced and migrated out of the system, as indicated by Ramberg (1956), instead of consistently being bordered by melanosome seams, indicating migration of a small (m-scale at most) scale. Furthermore, agmatitic structures are rarely seen in the study area. Aside from the morphologies of mobilizate II material described above, on a practical basis only three (mobilizates IIa,b,c) categories of migmatization II leucosomes may consistently be distinguished.

Although mobilizate III pegmatites typically form metre-scale masses, here and there thin pegmatite dykes, granitic to trondhjemitic in composition, and not uncommonly rich in magnetite, cross-cut migmatization I and II segregations. Thin veins or dykes of mobilizate III may resemble coarse grained mobilizate IIc leucosomes, however, the former are never rimmed by melanosome seams, and are rarely granulated, except where containing an internal S3-schistosity (Figs. 9, 26), and are unfolded (Table 5). Figure 26 shows a granitic mobilizate III dyke cross-cutting concordant , coarse grained mobilizate IIa segregations in granite IIb, while Plate 14 shows a greenish-coloured trondhjemitic , magnetite rich mobilizate III vein cross-cutting pink granitic mobilizate II material filling interstices between a boudinaged amphibolite II dyke, in granite I.

FIGURE 24.

Mobilizate cross-cutting relationships, in granite I. Inset shows F1 folded fine grained grey mobilizate I veins cut by a medium grained ptygmatically folded mobilizate IIa vein (reproduced in Plate 13a). This material is itself cut by a slightly granulated coarse grained potash feldspar-quartz rich mobilizate III dyke, whose attitude is apparently controlled by S2c strain slip cleavage surfaces seen elsewhere in the outcrop. These are, however, F2b folds; no mobilizate IIb is seen in the outcrop area represented by the figure.

FIGURE 25.

a) Sketch from photograph of hand sample of paragneiss from St. Fulgence. Hand sample provided by P. Lacoste.

b) Explanation: F1 folded fine grained, pale grey mobilizate I veins have S2a (somewhat contorted) as axial plane. The mobilizate I material is cross-cut and infiltrated by medium grained pink (microcline rich) mobilizate II.

FIGURE 26.

Thin dyke of pegmatitic mobilizate III cutting large concordant pods of mobilizate II in granite IIb. The mobilizate II is medium grained, and contains 1 cm uralitized pyroxene metacrysts (c.f. Plates 28b, 29). The mobilizate III dyke can be followed along strike for some 10 m, and contains an internal S3 shear fabric, translation has bent the strong S2a schistosity in the granite IIb host, indicating the sense of movement. The mobilizate III contains quite fresh black hornblende crystals, along with considerable potash feldspar and quartz.

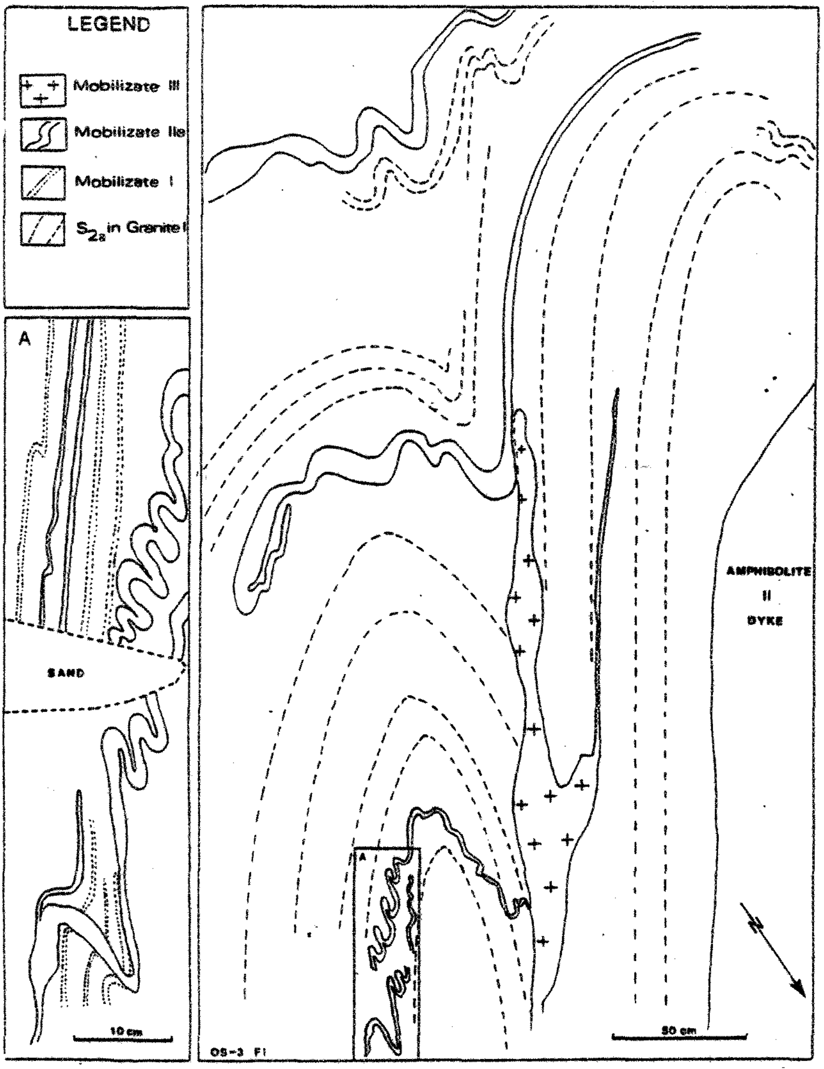


FIGURE 24.

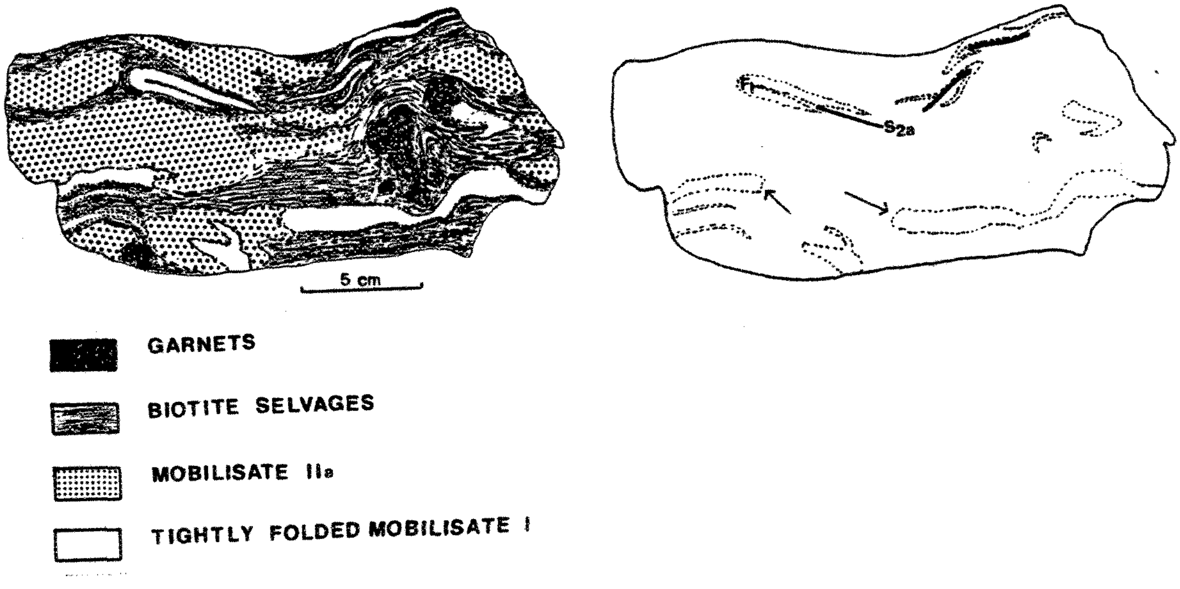


FIGURE 25.

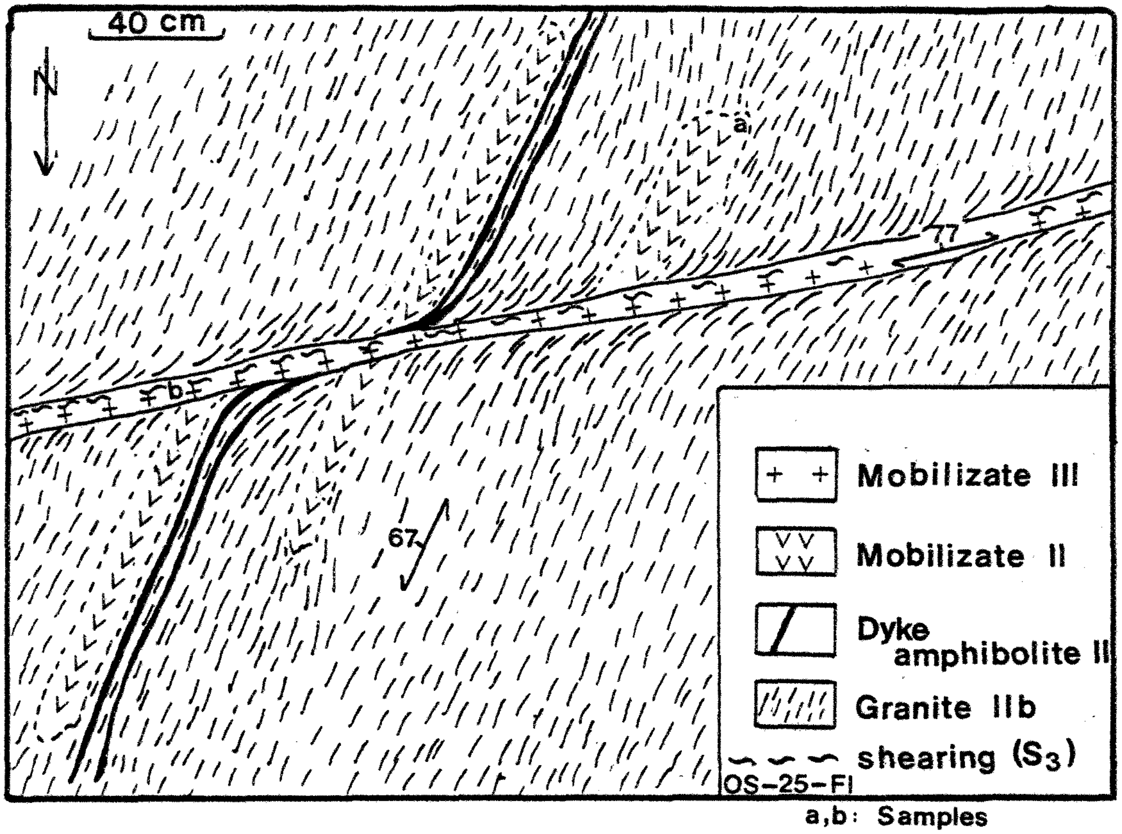

40 cm
N
a
b
77
67
Mobilizate III
Mobilizate II
Dyke amphibolite II
Granite IIb
shearing (S_3)
OS-25-FI
a,b: Samples

FIGURE 26.

Figure 27. Summary of occurrences of different generations of mobilizates in para- and orthogneisses of the Old Gneiss Complex.

(Scale of sketches is variable: width of mobilizate II segregations may be used as an indicator of scale, insofar as these mobilizates typically range from 1 to 10 cm, up to about 1 m in the case of example B)

A-1: mobilizate II material filling dilation zones between dyke amphibolite II boudins. The dyke is shown as being concordant to the S2a schistosity in the host gneiss, indicating that both dyke pinch and swelling, and mobilizate II generation, are related to deformation IIa. This observation represents the only evidence that mobilizate II generation commenced during F2a; most mobilizate IIa material segregates in dilational flexures of S2a, developed during F2b folding.

A-2: pinch and swell in a mobilizate IIa vein.

A-3: mobilizate IIa vein cross-cutting S2a and isoclinally folded mobilizate I veins

A-4: mobilizate II material filling interstices between dyke amphibolite breccia fragments, presumably formed during deformation IIa (c.f. Fig. 17) Source of the mobilizate is the gneissic host to the dyke. As such, the mobilizate is usually granitic, and recrystallizes margins of amphibolite fragments, as do vein-like mobilizate penetrations following the dyke's S2a schistosity, as indicated in example A-1.

A-5: Mobilizate IIa filling dilational leaves: flexural openings of S2a developed during deformation IIb.

A-6: pods of mobilizate II material, following S2a in the paleosome.

A-7: mobilizate IIb following S2c strain slip cleavage surfaces, cutting mobilizate IIa veins outlining S2a in the paleosome.

B: mobilizate IIc in dilational zones of S2b folding, Note that layering (S2a) and folds (F2b) of the gneiss are continuous between the rafts, indicating that these have not been displaced.

C-1: mobilizate II material accumulating in F2b flexural zones, typical of granites I and II.

C-2: thin dyke of mobilizate III cutting an S2a-concordant mobilizate IIa segregation, demonstrating age relationships.

D: although mobilizate III usually cross-cuts gneiss foliations (ex. C-2, above), this material locally is controlled by S2c surfaces, thereby paralleling mobilizate IIb segregations, as at OS-3, -4 (Fig. 2). In this case, the pegmatite veins are emplaced 1 to 2 m apart.

E: mobilizate II accumulating in dilation zones associated with displaced fold hinges. The gneiss is lineated in the hinges.

F-1: melanosome forming border of mobilizate IIa vein, where direction of mobilization was perpendicular to the length of the vein.

F-2: melanosome streaks forming between/within mobilizate IIa veins in which direction of mobilization was parallel to the length of the vein.

G: "spider morphology", typical of mobilizate II material in banded concordant amphibolite. The mobilizate II cuts mobilizate

Figure 27 (cont`d)

I veins, which show F1-isoclinal folding. The mobilizate II spider morphology is characteristic of the concordant amphibolite, since this type of paleosome, due to cm-scale interbanding, is strongly pinch and swelled (F2a). Both mobilizate I and II material is trondhjemitic (plagioclase composition not implied; amphibolite plagioclase is labradorite).

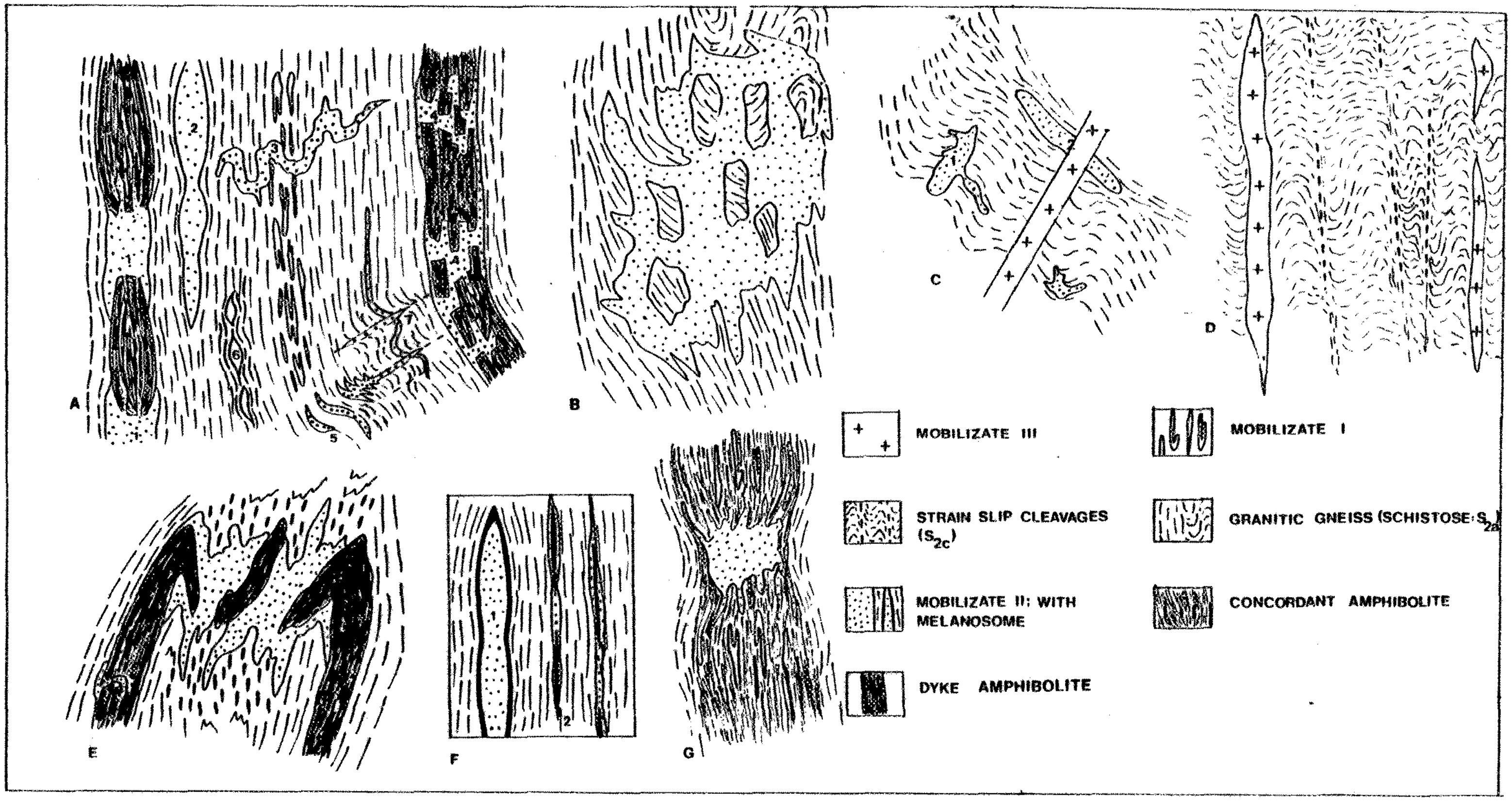

A
B
C
D
E
F
G
1
2
3
4
5
6
7
MOBILIZATE III
MOBILIZATE I
STRAIN SLIP CLEAVAGES (S_{2c})
GRANITIC GNEISS (SCHISTOSE S_{2a})
MOBILIZATE II: WITH MELANOSOME
CONCORDANT AMPHIBOLITE
DYKE AMPHIBOLITE

FIGURE 27.

PLATE 13. Cross-cutting mobilizate relations in granite I.

a) F2b folded medium grained mobilizate IIa vein cuts granulated, F1 folded mobilizate I veins. c.f. Fig. 24, inset. Location: OS-3. Scale in cms.

b) Hand sample ON-2-6. Ptygmatically folded, medium grained, rose coloured mobilizate IIa vein cuts thin, fine grained, light grey coloured planar mobilizate I veins (upper right).

PLATE 14.

a)Mobilizate III cutting mobilizate II in granite I. For explanation, see b):

b) Trondhjemitic mobilizate III dyke cross-cutting mobilizate II infiltrating interboudin dilation zone. Source of the mobilizate II is the granite I host to the boudinaged dyke amphibolite IIb. Note the recrystallizing effect of the migrant mobilizate: amphibole clots abound. The thickness of the mobilizate III dyke at left of figure is exaggerated due to outcrop surface relief.

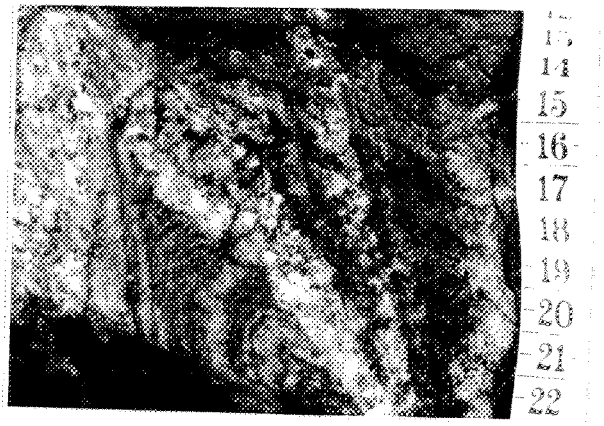


PLATE 13a.

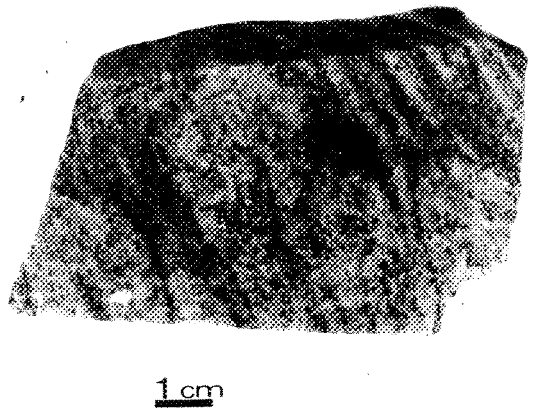
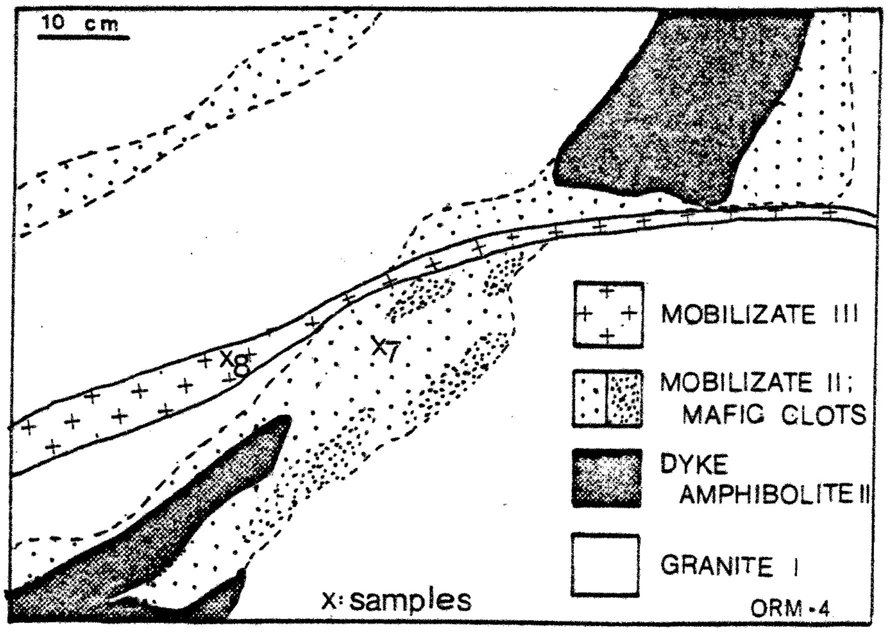


PLATE 13b.

a) PLATE 14.



b) Explanation.

B. PETROGRAPHY OF THE MOBILIZATES

Mesoscopic features of all generations of mobilizates have been described in general terms; cross-cutting relationships have been described in section IVA, and criteria for distinguishing the different generations of mobilizates are summarized in Table 5. Petrographic features of each generation of mobilizate will now be described for each type of paleosome.

1-Mobilizate I

Mobilizate I occurs uniquely as thin (<1 cm) veins, tightly folded by deformation I, in all rocks of age group I. As a result of this, and subsequent, deformation, the grain size of these veins closely matches that of the adjacent paleosome. Only vestiges of melanosome seams are seen bordering mobilizate I veins; these selvages rarely attain 1 mm in thickness. As a result, comparison of plagioclase compositions in the leucosome and melanosome is not possible, insofar as plagioclases lying within the sparse melanosome cannot be clearly distinguished from those in the adjacent paleosome. Nevertheless, it is seen that there may be a marked increase in the proportion of mafic minerals in the relict melanosome, compared to the paleosome; mafic mineralogy is identical in both cases. As a result of granulation or recrystallization, melanosome material is marginally finer grained than either the leucosome or paleosome.

The composition of mobilizate I veins varies with the paleosome. Mobilizates in granite I are granodioritic (Table 6-1); those in concordant amphibolite are trondhjemitic (Table 6-3). Mobilizate I veins in paragneiss contain significant quantities of microcline, in the virtual absence of plagioclase (Table 6-2). Furthermore, mobilizate I veins in paragneiss contain neither garnet nor cordierite, although mobilizate II leucosomes within the same hand sample commonly contain one or both of these minerals. Homogeneous paleosomes do not occur within the paragneiss sequence: the compositional heterogeneity of the unit results from the polyphase mobilization of what was initially a thinly bedded heterogeneous sedimentary sequence. As such, the paragneiss is a banded gneiss, often containing in excess of 60 volume % leucosomes (mobilizates I and II). Possible paleosome material may nevertheless be locally recognized as homogeneous, discontinuous layers separating leucosomes, in which mafic minerals are more or less evenly distributed. These same mafic minerals, in particular biotite and sillimanite, segregate, forming melanosomes bordering the in situ leucosomes. The paleosome material rarely contains significant proportions of plagioclase; like the leucosomes, the paleosome contains microcline and quartz as important leucocratic minerals.

i. Mobilizate I in Granite I.

Characteristics of mobilizate I-granite I mineralogy are outlined in Table 6-1. This same material is portrayed in hand sample ON-2-6 (Plate 13b), and in thin section as Plate 15a. This material is texturally identical to the host granite I paleosome, and may be described as granoblastic polygonal. The vein material is quartz rich, with quartz occurring as lobate to elongated grains up to 4.8 mm long (exceptional). Potash feldspar occurs as xenomorphic grains (0.2 to 1 mm) irregularly distributed along the vein, as grid-twinned microcline, less commonly with patchy exsolved plagioclase. As a result of the uneven distribution of K-feldspar, parts of the vein consist of quartz-plagioclase. Plagioclase, locally perthitic, occurs as equigranular, xenomorphic to subidiomorphic grains, forming mosaics with quartz and with quartz-K-feldspar. Sample ON-2-6 is unusual insofar as the granite I contains clinopyroxene and biotite instead of hornblende-biotite as mafic minerals. Along with opaques and sphene, clinopyroxene and biotite segregate along parts of the vein, representing an enrichment factor over and above the paleosome of 0 to ~2 (Table 6-1). Mafics occur in sparse quantities in the leucosome.

ii. Mobilizate I in Paragneiss.

Characteristics of mobilizate I-paragneiss mineralogy are outlined in Table 6-2. The typical field aspect of this material is shown in Plate 16a; the photomicrographs in Plates 15b,c show material similar to this, sampled from the same outcrop. Paragneiss thin sections with mobilizate I veins also contain mobilizate II leucosomes (Plate 16a; photomicrograph Plate 15bii), seen to cross- cut the first. Although mobilizate I veins are rather rare in granite I, they are well represented in paragneiss. Leucosome veins generated by migmatization I and II tend to be closely spaced in the paragneiss, consequently melanosomes of adjacent veins commonly juxtapose, enhancing the leucocratic-melanocratic layered aspect of the rock. At the same time, veritable paleosome material is poorly represented: migmatization-related heterogeneities abound between well developed leucocratic veins, rendering a comparison of leucosome - paleosome relations difficult. However, leucosomes always match the mineralogy of the adjacent gneiss, in particular, paragneiss mobilizate I veins, like the host gneiss, are microcline-quartz assemblages, in which plagioclase is a minor (<10%) component. Unlike mobilizate I in granite I, mineral species are often inequigranular (Plate 15b). All leucocratic phases, including plagioclase, are xenomorphic, quartz not uncommonly being polygonal. Therefore, the texture of these veins may be described as xenomorphic-heteroblastic (Plate 15b) to polygonal granoblastic . Typical grain size ranges for vein minerals.match those in the adjacent gneiss. Leucosomes generated during migmatization II are always considerably coarser grained than both mobilizate I and the gneiss.

Mobilizate I veins in paragneiss are quartz-microcline rich. Quartz forms polygonal to serrated (Plate 15c) mosaics with microcline. Individual quartz grains are polygonal to lobate-serrated in shape, and are not oriented. Individual veins may contain in excess of 50 volume % quartz; xenomorphic, grid-twinned microcline makes up the bulk of the remainder of the leucosome, excluding small amounts of plagioclase and included mafic minerals, chiefly randomly oriented biotite, and thin curtains of sillimanite. Excluding these, the quartz-K-feldspar ratio may vary between 7:3 and 4:6 in different veins. Neither garnet nor cordierite has been observed in paragneiss mobilizate I veins.

iii. Mobilizate I in Concordant Amphibolite.

Characteristics of mobilizate I-concordant amphibolite mineralogy are outlined in Table 6-3. The typical field aspect of this material is shown in Plate 16b; the photomicrograph in Plate 15d shows vein material similar to this, sampled in the same outcrop. Migmatization I and II leucosomes in concordant amphibolite consistently are trondhjemitic (note: plagioclase is labradorite) in composition. Melanosomes are not seen, neither are paleosome interfaces juxtaposing the leucosomes recrystallized. Mobilizate I here may be described as polygonal granoblastic. Quartz forms polygonal to lobate, equigranular grains, forming mosaics with xenomorphic to hypidiomorphic plagioclase. Grain size is similar in both the leucosome and paleosome. Plagioclase-quartz ratios are fairly consistent, ranging from about 65:35 to 50:50.

Typical textures of granulite-grade gneisses are outlined in Table 7a. Table 7b compares paleosome textures with those textures seen in the different generations of mobilizates. Modal analysis data for paleosomes and mobilizates are listed in Appendix 1; modal compositions of the leucocratic fractions of mobilizates are presented graphically as Figure 37, in the Discussion (section V).

PLATE 15. Photomicrographs of mobilizate I in various paleosomes.

a.(i) Mobilizate I in clinopyroxene-bearing granite I. With the exception of the large quartz patch at the top of the photograph, the mobilizate is roughly equigranular, having a granulometry similar to the paleosome. The paleosome has a higher microcline:plagioclase ratio than the mobilizate, unlike a ptygmatically folded mobilizate IIa vein in the same sample (c.f. Plate 13b). Thin section ON-2-6. X-nicols. Bar: 2 mm.

a.(ii) As above, but in plane polarized light. Note the weak enrichment of mafic minerals (clinopyroxene, opaques, sphene, biotite) in the relict melanosome. Typical paleosome mafic content is seen at left in photograph: at most, the melanosome has a two- to threefold mafic enrichment over this.

b.(i) Mobilizate I in paragneiss. The leucosome is rich in quartz (q) and microcline: only a few grains of plagioclase (p) are seen. At left, a sillimanite (s) rich melanosome borders the mobilizate. The melanosome also contains quartz plates paralleling the vein. Thin section ON-2-4b. X-nicols. Bar:1 mm.

b.(ii) Same vein as illustrated above, being intersected by coarser grained mobilizate IIa, having a higher microcline:quartz ratio (c.f. Fig. 36). Bar: 1 mm.

c. Mobilizate I in paragneiss. The leucosome is compositionally and granulometrically similar to b(i), however, this vein has lobate and serrated microcline-quartz mosaics, rather than polygonal mosaic contacts. Thin section ON-2-4a. X-nicols. Bar: 1 mm.

d. Mobilizate I in concordant amphibolite. The leucosome is trondhjemitic, with lobate quartz, and twinned , hypidiomorphic plagioclase. At centre of photograph is a thin, fine grained biotite-quartz-plagioclase band separating two mobilizate I veins, possibly representing the melanosome. Thin section OS-1-5. X-nicols. Bar: 1 mm.

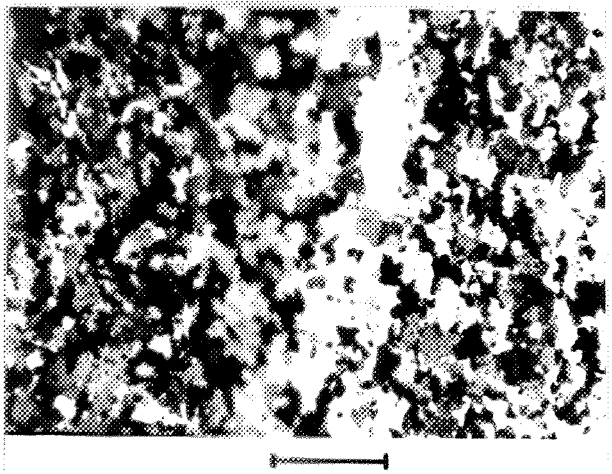


PLATE 15a (i)

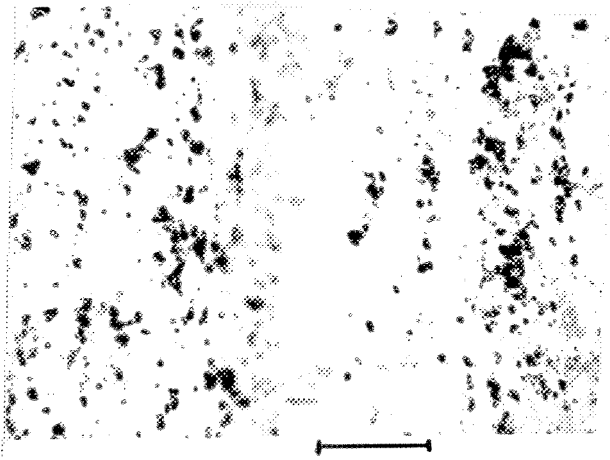


PLATE 15a (ii)

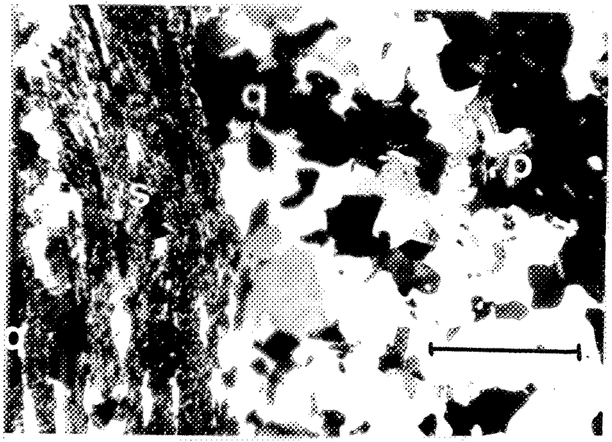


PLATE 15b (i)

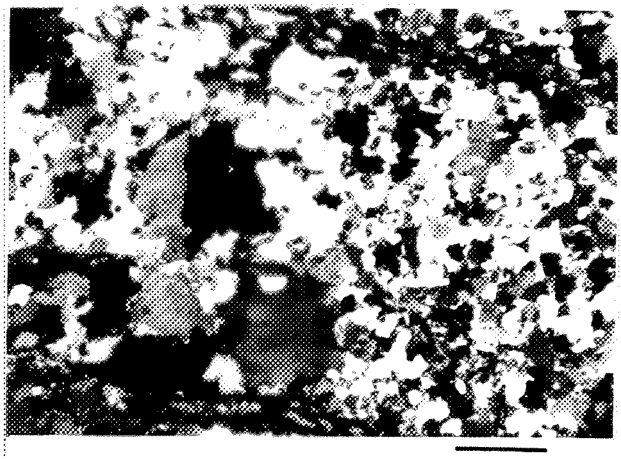


PLATE 15b (ii)

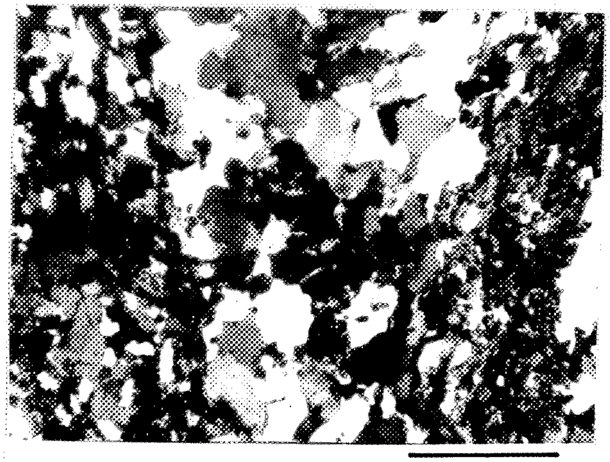


PLATE 15c.

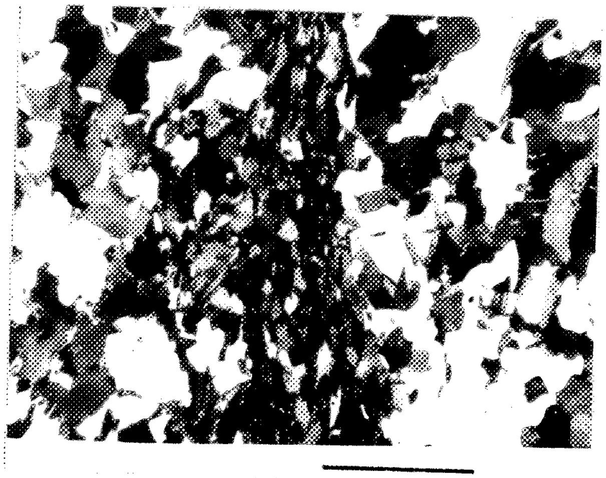


PLATE 15d.

PLATE 16.

a. F1 flattened folds shown by thin, granulated mobilizate I veins in paragneiss. Note ill-defined, medium grained patch of mobilizate II intersecting mobilizate I veins. Below the scale (base of photo) is a 2 cm thick, well defined mobilizate IIa vein with 1 mm thick biotite melanosomes. Note the host gneiss (paleosome) is heterogeneous, consisting of thinly banded gneiss, in this case, the thin leucosomes/melanosomes are products of migmatization I. Location: ON-2.

b. Relatively thick (1 cm), folded and coalescing ribbons of mobilizate I (below hammer) in concordant amphibolite. Above hammer handle is medium grained mobilizate IIa, easily distinguished from the fine grained mobilizate I. Both mobilizates are, however, compositionally similar, consisting of plagioclase (labradorite)-quartz. Location: OS-1.

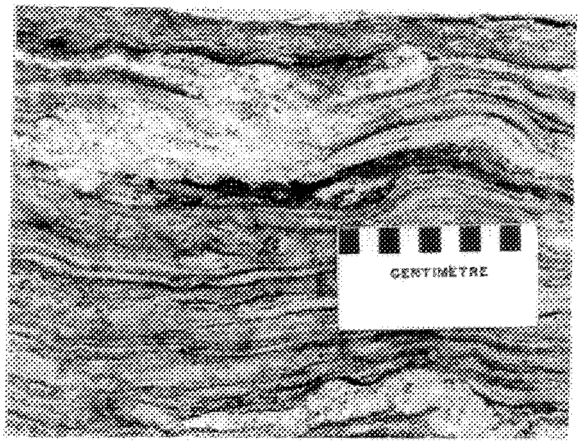


PLATE 16a.

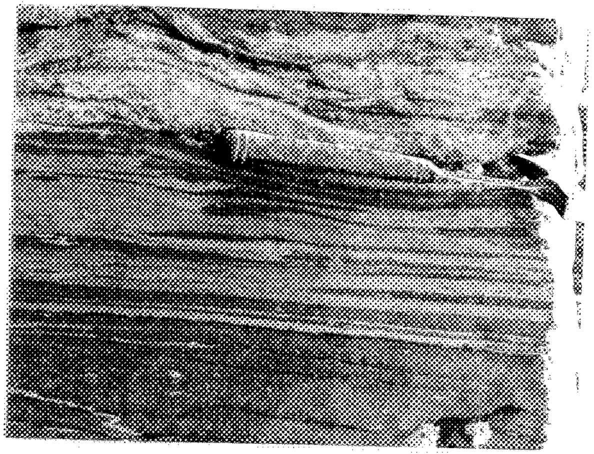


PLATE 16b.

TABLE 6-1: Mineralogical characteristics of mobilizate I-paleosome.

GRANITE I: (thin section ON-2-6)

Note: The fabric of granite I and contained mobilizate I is dominated by tectonic recrystallization effects. Consequently, mobilizate I vein textures are the products of deformation; these equigranular textures are not primary (see Tables 7a, 7b)

	Leucosome	Melanosome	Paleosome
Thickness (mm):	1 to 3	0 to 1.2	-
Typical grain size:	0.6 mm	0.35	0.5
% mafics:	1	5 to 10	6
K-Feldspar			
Typical grain size:	0.5 mm	0.3	0.4
Grid twin:	common	present	common
Antiperthite:	present (patch)	present (patch, flame)	present (patch)
Mode of occurrence:	equigranular xenomorphic grains	granular mosaics with qz-plag.	equigranular mosaics with qz-plag.
Plagioclase			
Typical grain size:	0.5 mm	0.4	0.5
Zoning:	none	none	none
Alteration:	slight	slight to moderate	slight
Myrmekite:	common	common	common
Mode of occurrence:	equigranular mosaics with qz-microcline in all components		
Quartz:			
Typical grain size:	0.9 (max. 4.8)	0.4	0.5
Orientation:	larger grains may parallel vein	small qz plates parallel vein	none seen
Extinction:	larger grains in all components show undulose extinction		
Mode of occurrence:	lobate to elongated polygons	equigranular-lobate polygons	
Mafic Minerals			
Clinopyroxene			
%; grain size:	trace; 0.3 mm	1; 0.3	1; 0.3
Mode of occurrence:	ragged to idiomorphic crystals, locally partly mantled by (retrograde) green hornblende, subsequently altered. Hornblende is a common mafic accessory in granite I, hence the virtual absence of this in the sample suggests that the breakdown of amphibole gave rise to the pyroxene.		
Biotite			
%:	trace	2	1
Mode of occurrence:	0.2 to 0.5 mm flakes paralleling S2a		

Also occurring in the different components are trace amounts of fine grained (0.2 epidote, opaques, sphene, apatite.

TABLE 6-2: Mineralogical characteristics of mobilizate I-paleosome.

PELITIC PARAGNEISS: (thin sections ON-2-4a,b)

Note: no homogeneous paleosome exists in pelitic paragneiss. However, leucosomes are bordered by mafic-enriched selvages (melanosomes), easily distinguished from the adjacent paleosome gneiss.

	Leucosome	Melanosome	Paleosome
Thickness (mm):	1 to 12	0.5 to 1.5	-
Typical grain size:	0.5 mm	0.1	0.4
% mafics:	2	>50	15 to 25
K-Feldspar			
Typical grain size:	0.4 mm	K-spar not seen	0.4
Grid twin:	common	-	common
(Anti)perthite:	not seen	not seen	not seen
Mode of occurrence:	xenomorphic, heteroblastic grains	-	xenomorphic, heteroblastic grains
Marginal symplectic intergrowths:	common (micrographophyric)		common (same)
Quartz			
Typical grain size:	0.7 (max. 2.4)	0.2	0.5
Orientation:	none	tabulate plates parallel vein	none
Extinction:	in all components, even to slightly undulose		
Mode of occurrence:	granoblastic mosaics with quartz	(see above)	granoblastic mosaics with quartz

Plagioclase: the paragneiss contains only trace %'s of plagioclase

	Leucosome	Melanosome	Paleosome
Mafic Minerals			
Sillimanite			
%; grain size:	0-2; <0.1 mm	0-80; <0.1	0-25; <0.1
Mode of occurrence:	streaky bundles within leucosome	streaky bundles and v.f.g. aggregates	v.f.g. aggregates

Note: the sillimanbite within mobilizate I and adjacent melanosome is prograde (muscovite + quartz ---> K-spar + sillimanite + V)

	Leucosome	Melanosome	Paleosome
Biotite			
%; grain size:	1; 0.2 mm	5-50; 0.2	<5-15; 0.2 (max. 1.2)
Mode of occurrence:	randomly oriented flakes, bordering qz, microcline	oriented flakes paralleling vein	randomly to oriented flake
Garnet			
%; grain size:	not seen	not seen	trace; <1 to 1.5 mm
Mode of occurrence:	garnet porphyroblastic growth/crystallization occurred during migmatization II. Garnets are not seen in mobilizate I veins even though garnets may occur within the paleosome and mobilizate veins within the same hand sample.		

TABLE 6-3: Mineralogical characteristics of mobilizate I-paleosome.

CONCORDANT AMPHIBOLITE (thin sections ON-5-2, OS-1-5, OS-7-2)

Note: Melanosomes have not been identified for any generation of mobilizates in concordant amphibolite, probably as a result of the high colour index of the paleosome; fine grained, leucocratic paleosomes (ex. granite I) preferentially develop distinct melanosomes, since a relatively small degree of mafic enrichment is readily noticed.

	Leucosome	Paleosome
Thickness (mm):	2 to 8	-
Typical grain size:	0.4 mm	0.4
% mafics:	1 to 3	25 to 45
Plagioclase		
Typical grain size:	0.4 (max. 1.0)	0.4
Zoning:	not seen	rare, but seen in ON-7-2
Alteration:	absent	absent
Myrmekite:	absent	absent
Mode of occurrence:	hypidiomorphic grains	hypidiomorphic to idiomorphic grains
Quartz		
Typical grain size:	o.4 mm	0.3 mm
Orientation:	none	none
Extinction:	weakly undulose	weakly undulose
Mode of occurrence:	polygonal to lobate mosaics with plag.	intersitial to plag. and mafics. Polygons.
K-Feldspar:	absent in all components of concordant amphibolite.	
Mafic Minerals		
Hornblende		
%; grain size:	<1-2; 0.2 mm	10-40; 0.4
Mode of occurrence:	granoblastic hypidiomorphic grains in both components	
Biotite		
%; grain size:	0-1; 0.1 mm	1-40; 0.1 to 0.8
Clinopyroxene:	seen locally in mobilizate II (ON-7-F1c) and in the amphibolite paleosome (OSF-1)	

2-Mobilizate IIa

Leucosomes generated in rocks of age groups I and II are subdivided on the basis of field occurrences into three chronologic categories. Mobilizate IIa consistently is seen to be segregated along flexural dilation zones related to F2b folding of the predominant S2a schistosity. Mobilizate IIb veins cross-cut mobilizate IIa and S2a, following S2c slip cleavage surfaces axial planar to F2c refolding of F2b folds (Figs. 3, 28). Mobilizate IIc occurs as partly discordant, coarse grained pods, cutting mobilizates IIa,b and intersecting foliations S2a and S2c. Mobilizate IIa assumes many morphological varieties. Well developed melanosomes are usually present, except in cross-cutting veins, and where the mobilizate infiltrates rock layers (ex. brecciated or boudinaged dykes) of different lithology than its source paleosome (Figs. 30, 31, Plates 20a,b). Leucosomes segregated in interboudin interstices developed during deformation IIa (c.f. Figs. 17, 18 and Plates 20a,b) probably represent the initial stages of migmatization II mobilization (Table 1).

i. Mobilizate IIa in Granite I

From a morphological point of view, mobilizate IIa material is best developed in granite I. As a paleosome, granite I is very homogeneous, both from a compositional and textural stand. As a result, coupled with the consistently fine-grained nature of granite I, neosomes are clearly and unambiguously developed. Mobilizate IIa most commonly segregates as 0.5 to 10 cm thick veins in granite I, concordant to the S2a biotite-hornblende foliation (Plate 17a). Not uncommonly, these veins show pinch and swell structure (Plate 17b), or are ptygmatically folded (Fig. 24). Melanosomes are well developed, usually 1 to 3 mm thick. Where veins are closely spaced, adjacent maleanosome may impinge upon one another, forming a "double restite" effect (Plate 17c). Cross cutting veins are rather rare; these usually lack a marginal melanosome, reflecting the mobility, and hence discordance, of the vein material (Plate 17d).

Mobilizate IIa most commonly ocurs as concordant veins, with well developed marginal melanosomes. Given a concordant vein morphology, it is not always possible to relate the segregation to a particular structural dilation zone, since mobilization in large part occurred during F2b folding, which continued to fold the leucosome veins after flexuring the S2a schistosity in which the mobilizate accumulated (c.f. Fig. 3). Concordant veins bounded by melanosomes indicate a direction of mobilization perpendicular to the length of the vein. Where mobilization parallels this schistosity, streaky neosomes develop, with melanosome material forming the core of a leucocratic streak (Plates 19a,b). Mobility on a larger scale typically results in cross-cutting relationships. This leads to the second effect of leucosome mobility: migrating mobilizates tend to recrystallize rock layers of different lithology than their source paleosomes. A typical example of this is the presence of 1 cm hornblende porphyroblasts occurring in and along granitic mobilizates infiltrating amphibolite dykes in granitic host rock (Plates 14, 20a,b).

Characteristics of mobilizate IIa-melanosome mineralogy in granite I paleosome are outlined in Table 6-1. However, since these segregations are exceptionally well represented in granite I, it is worthwhile to delve further into the petrography of these components.

Of particular interest is the presence of well developed mafic selvages separating the coarse grained mobilizate IIa from the homogeneous , fine grained granite I paleosome. Usually, the mobilizate juxtaposes a well defined melanosome always of the same, or slightly finer, granulometry as the paleosome. A special case, however, is illustrated in Fig. 29, a sketch of a thin section of sample ON-1-1 (c.f. Plate 17a). Here, the neosome shows distinct zoning, reflecting relative mobility of the mobile components constituting the leucosome. Modal analysis (Appendix 1) permitted quantification of the each zone (Fig. 29) From this, it is seen that potash feldspar and plagioclase have migrated from the mafic melanosome "Ma" zone inwards, toward the leucosome. As such, the mafic selvage "Ma" is a quartz-hornblende-(plagioclase, biotite, opaque) rich assemblage, exemplifying the typical melanosome in granite I. Moving toward the leucosome, zone "Mb" is seen to be of similar granulometry as "Ma", containing, however, considerably less mafic minerals and quartz, and more plagioclase and potash feldspar, the latter being irregularly distributed. Certain portions of this zone are plagioclase-quartz assemblages, while other parts consist mostly of potash feldspar-quartz. Since this zone is fine grained, and contains minerals (plagioclase, mafics) which are poorly represented in the coarse grained leucosome, zone "Mb" is considered to be part of the melanosome (in view of its leucocratic nature, more appropriately a "restite"). The leucosome is essentially a microcline-quartz assemblage, which form mosaics with lobate contacts. Plagioclase forms fine grained, hypidiomorphic grains interstitial to the coarse grained microcline-quartz mosaics. The leucosome itself is zoned: quartz is segregated in the core of the mobilizate, forming a central, discontinuous vein.

The vein illustrated in Fig. 29 is typical of mobilizate IIa in granite I. In the general case, these veins do not show distinct zoning as seen in the present example, however, the leucosome-mafic selvage relations are consistent. With the exception of quartz, melanosomes are depleted in the leucosome vein minerals. Taken as a whole, the neosome mineralogy matches that of the paleosome, although, textural and granulometric parameters are dissimilar in the different components. No markedly desilicified zones were noted. However, given the quartz-rich ($\leq$33%) nature of granite I, and the maximum neosome quartz enrichment of about 40% over and above this figure, it is not surprising that a precise source of neosome quartz is difficult to locate. Melanosomes are well developed in granite I simply because of the fine grained, homogeneous and leucocratic (mafics totalling 5 to 6%) nature of the paleosome, and a five-fold enrichment of these same mafic minerals in melanosome seams. Conversely, one might expect that melanosomes would be relatively difficult to recognize in melanocratic paleosomes, for example, amphibolites.

ia-Mobilizate IIc: A Comparison with Mobilizate IIa in Granite I.

Metre-scale, lobate masses of coarse grained mobilizate locally cross-cut the foliation in the host paleosome. These pegmatoids typically have concordant offshoots bounded by well developed melanosomes (Plate 17c), indicating migration of a limited extent. Locally, these irregular masses are seen to cross-cut and fill noses of tight F2b folds (Fig. 28). "Inclusions" of folded host gneiss within the mobilizate show no evidence of dislocation and rotation. Since these masses of pegmatoid cross-cut mobilizates IIa and IIb, and are always of granitic compositon in granite I paleosomes, consistently with marginal melanosomes, these coarse grained mobilizates are considered to be products of migmatization II, and are labelled mobilizate IIc.

Determinations were made on melanosome and mobilizate IIc plagioclases from a typical sample of granite I (OS-1-2b; Plates 17c, 18). Since this sample has a 5 mm thick melanosome, distinction of plagioclases lying within the paleosome from those in the melanosome presented no difficulties. Melanosome plagioclases showing 010 albite twins consistently have maximum symmetrical extinction angles of 8 to 9 (also seen in sample ON-1-1). Since these plagioclases are seen to have refractive indices exceeding those in adjacent quartz grains (Becke line test), a composition of An 28 is indicated from the Michel-Levy chart. Paleosome plagioclases, by the same method, are slightly more sodic (An 25). A 1 cm plagioclase crystal separated from the mobilizate IIa vein in this sample is seen to have refractive indices α 1.536, β 1.542, γ 1.544, as determined by oil immersion. These indices correspond with a plagioclase composition of An 15, markedly more sodic than plagioclase within the adjacent melanosome, from which the leucosome, in large part, was segregated.

Although mobilizate IIc postdates mobilizate IIa veins, the morphological and compositional similarity between these neosomes indicates a common origin. The mobilizate IIa veins sampled have thinner (< 1 mm) melanosomes than sample OS-1-2b, therefore are less amenable to melanosome plagioclase determination, since, under the microscope, it cannot be clearly distinguished where the paleosome ends and the melanosome begins.

Since mobilizate IIa leucosomes are best developed in granite I, it is worthwhile to summarize some of their features. Mobilizate IIa segregations typically are localized in flexural openings of S2a-schistosity. Consequently, vein type morphologies predominate; since deformation IIb developed no axial plane schistosity, mobilizates tend to occur near F2b-fold hinges, and are never seen to be axial planar to these folds. Mobilizate IIa segregations typically are coarse grained (5 mm), although tectonic granulation and recrystallization may diminish primary granulometry considerably. Melanosomes are invariably present. These consist of the same mafic minerals as seen in the paleosome, and may be (mesoscopically) thin (1 mm) and sharply defined, or thicker (5 mm), grading diffusely into the paleosome. Coarse mafic clots are not uncommon in coarse grained mobilizates (Plates 17a,c). These clots consist of melanosome minerals, in various stages of alteration: hornblendes commonly are chloritized along cleavages. Cross-cutting relationships indicate that not all petrographically-similar migmatization II leucosomes were simultaneous. Thus, mobilizate IIc leucosomes, may be distinguished from non-granulated mobilizate II veins (eg. coarse grained) by their typical mode of occurrence, accumulating as metre-scale pods cross-cutting paleosome schistosities and earlier-formed leucosomes. The fluid nature of mobilizate II leucosomes is demonstrated by discordant offshoots from melanosome-seamed concordant veins (Plate 17e), and by mobilizate infillings seen in brecciated rock layers, of different lithology than the mobilizate´s source paleosome. On the basis of samples ON-1-1 and OS-2-1b, chosen for their well developed, thick melanosomes, migmatization II leucosomes contain plagioclases considerably more sodic than plagioclases in the adjacent melanosome.

PLATE 17. Aspects of mobilizate II veins in granite I.

a. Sample ON-1-1. Mobilizate IIa concordant to the hornblende-biotite S2a foliation in the granite I paleosome. The well developed 1 mm thick melanosome consists of hornblende-biotite. The leucosome is rich in microcline, with quartz concentrated along the vein centre. Note mafic clot (chloritized hornblende) in leucosome.

b. Pinch and swell in a mobilizate IIa vein, similar to ON-1-1. Location: OS-3.

c. Sample OS-1-2b. Diffuse, 5 mm thick, bordering pinch and swelled mobilizate IIc veins. Close proximity between the veins causes the diffuse melanosomes to juxtapose, forming a "double restite". Sample taken from concordant vein offshoots from a largely discordant mobilizate pod, illustrated as Plate 18.

d. Sample OS-16-1. Cross-cutting mobilizate IIa veinlet, culminating in a 2 cm pod. The absence of a melanosome here reflects the mobility of the leucosome material: it has migrated from its granite I source, at most a few tens of centimetres distant.

e. Concordant mobilizate IIa veins with well developed melanosomes. The vein to the right of the amphibolite IIb dyke has a discordant offshoot: this leucocratic material traverses the dyke, indicating that concordant as well as discordant mobilizate IIa segregations are mobile-and fluid-to a greater (cm to m) or lesser (mm) degree.

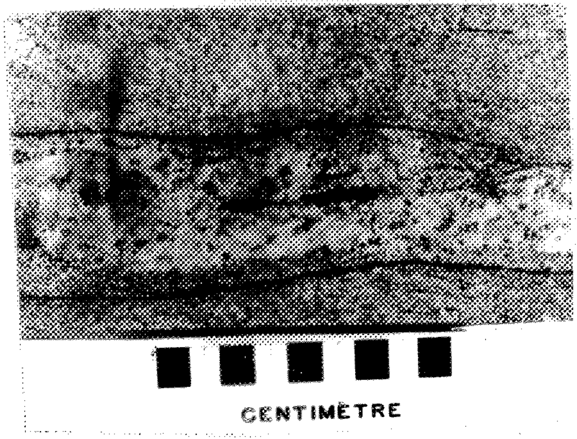


PLATE 17a.

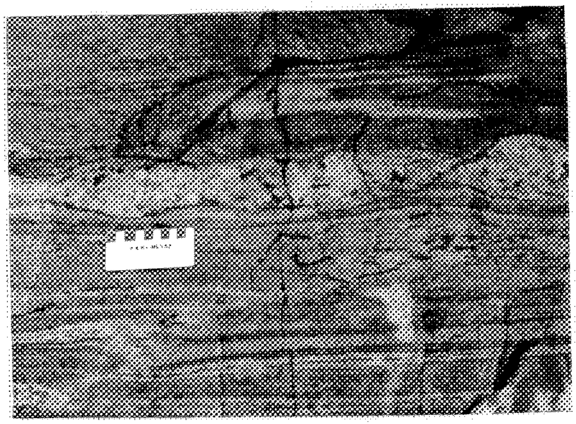


PLATE 17b.

PLATE 17c.

PLATE 17d.

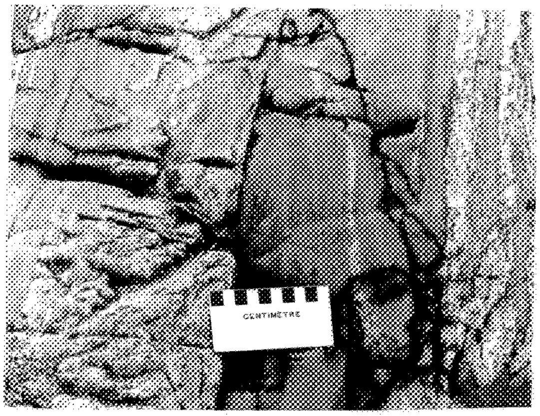


PLATE 17e.

PLATE 18.

Metre-wide irregular pod of coarse grained (microcline crystals attain 3 cm) mobilizate IIc, in granite I. With respect to the biotite foliation in the granite I (S2a), the bulk of the mass is discordant; here melanosome material is thin and discontinuous. However, concordant cm-scale offshoots have thick (5 mm) melanosomes: the sample illustrated as Plate 17c was taken from one of these offshoots. Location: OS-2.

FIGURE 28. (following page)

Discordant to subconcordant lobate masses of coarse grained (2 cm) mobilizate IIc in granite I. The leucosomes cross-cut both F2b folds (upper right, no axial plane cleavages) and mobilizate IIb-filled S2c shear surfaces (bottom of map). Inset shows the relation of S2c and mobilizate IIb localization to incipient F2c refolding of isoclinally F2b folded amphibolite IIb dykes

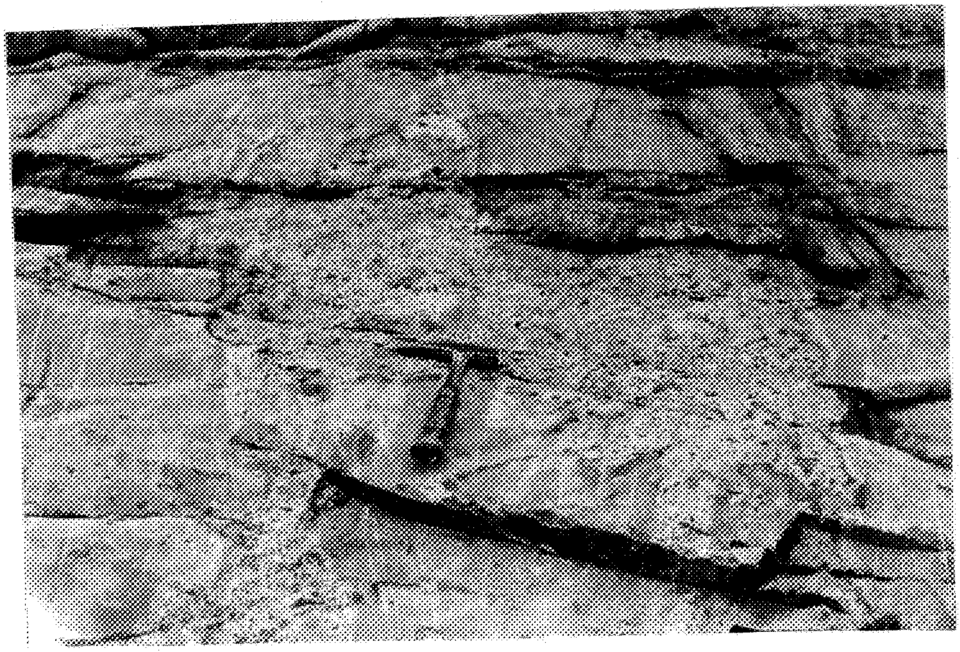


PLATE 18.

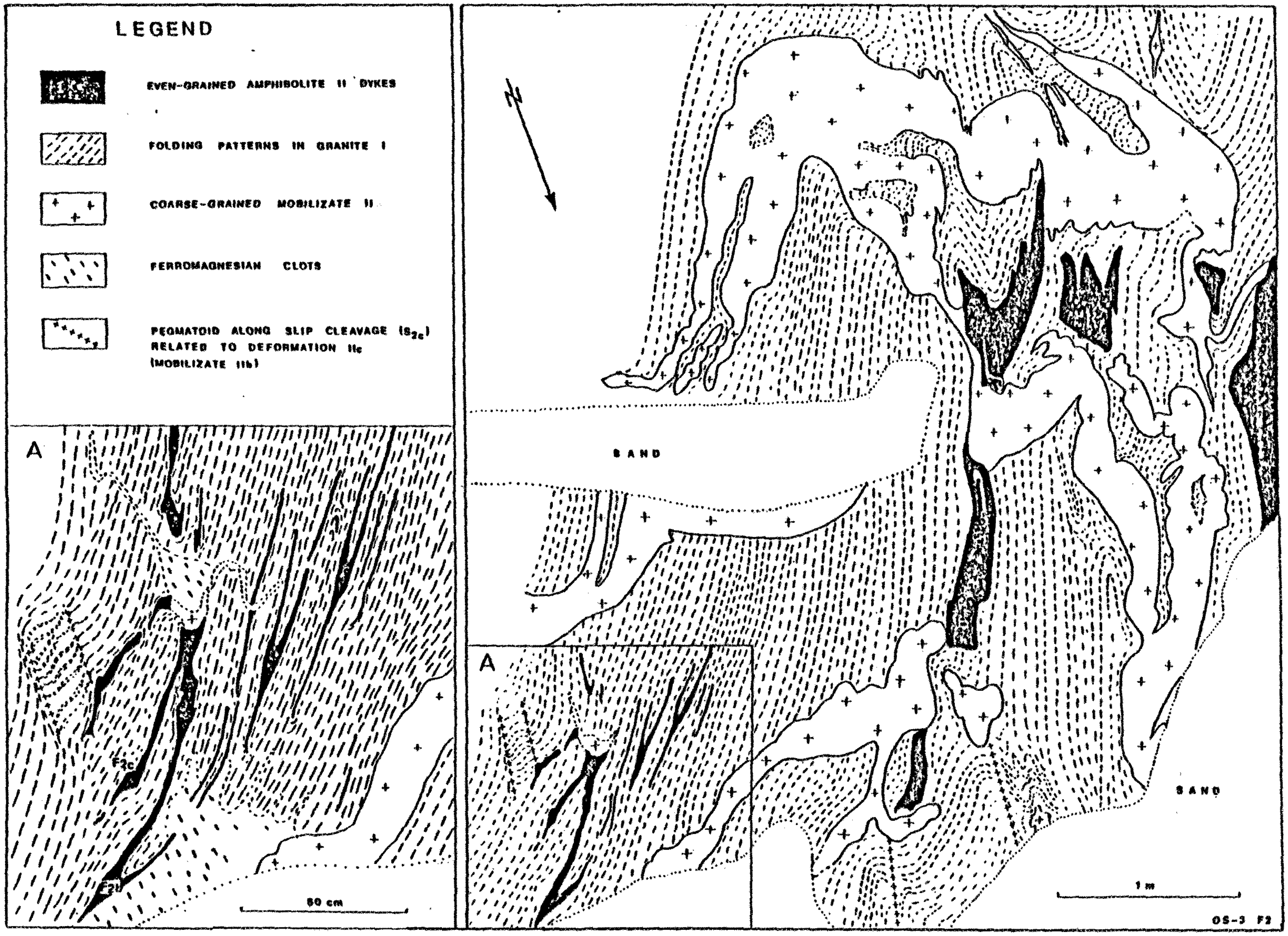

LEGEND
EVEN-GRAINED AMPHIBOLITE II DYKES
FOLDING PATTERNS IN GRANITE I
COARSE-GRAINED MOBILIZATE II
FERROMAGNESIAN CLOTS
PEGMATOID ALONG SLIP CLEAVAGE (S_{2c}) RELATED TO DEFORMATION IIc (MOBILIZATE IIb)
A
F2c
F2b
50 cm
N
SAND
SAND
A
1 m
OS-3 F2

FIGURE 28

PLATE 19.

a. Field aspect of melanosome-cored mobilizate IIa streaks in granite I, at ON-1. Leucosome mobilization largely paralleled the streak (and S2a). Tape in centimetres.

b. Hand sample ON-1-1b. Cross section of mobilizate IIa streaks shown in Plate 19a. Scale: cm.

PLATE 20.

a. Coarse grained mobilizate IIa filling interstices between boudinaged dyke amphibolite IIb. The mobilizate is granitic, and contains 1 cm hornblende clots due to reaction with the amphibolite. The amphibolite is concordant to the S2a foliation in the granite I host, the paleosome source of the mobilizate. Note the concordant mobilizate IIa vein in the granite (above dyke) with marginal melanosome. Location: OS-26.

b. Mobilizate IIa, granitic in composition, infiltrating the butt of an isolated dyke amphibolite IIb boudin, in granite I. The boudin, as such, has the same mechanical properties as an inclusion: under confining stress, the mobilizate generated in the granite I accumulates in the low pressure terminal region of the boudin, infiltrating the boudin's cleavage (S2a), and recrystallizing amphiboles. Same outcrop as Plate 20a.

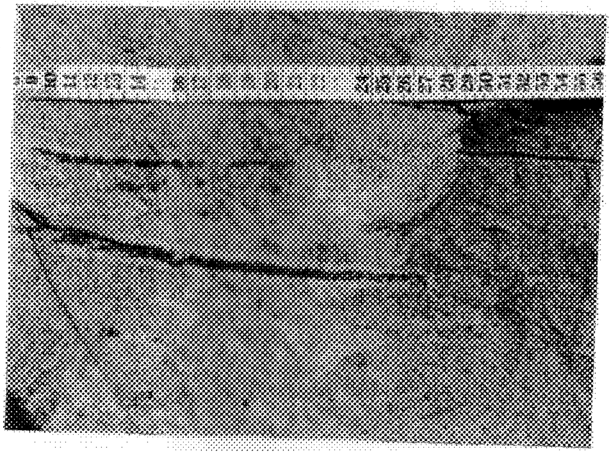


PLATE 19a.

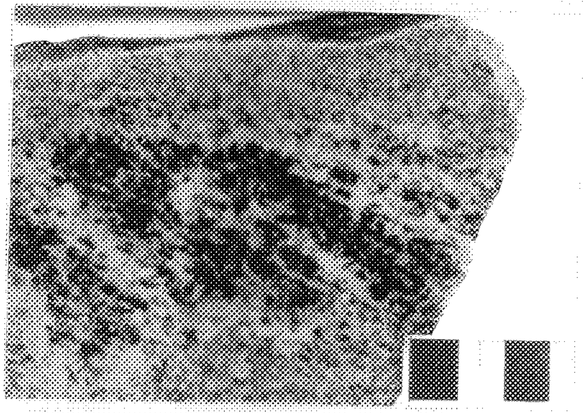


PLATE 19b.

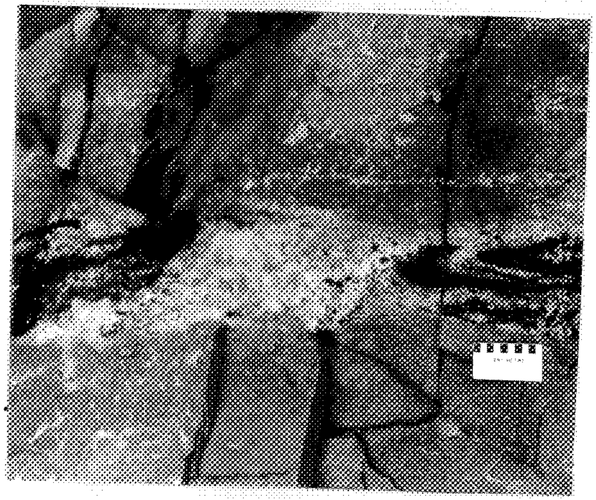


PLATE 20a.

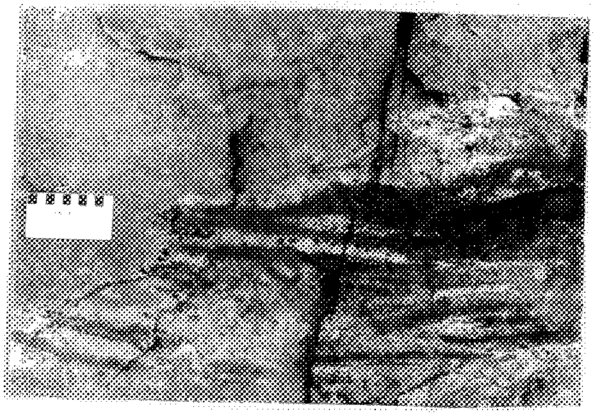


PLATE 20b.

FIGURE 29.

Sketch of part of thin section ON-1-1 (c.f. Plate 17a): mobilizate IIa in granite I. The coarse grained leucosome contains a central quartz (white)-rich vein. Quartz forms lobate mosaics with microcline (stippled). The melanosome is subdivided into a plagioclase-microcline-quartz-mafic bearing zone (Mb), equally fine grained as the adjacent melanocratic seam (Ma), consisting of recrystallized quartz plates and hornblende (minor biotite, opaques) with lesser plagioclase and microcline. Plagioclase represented by hatching; mafics are black. Zone Mb is usually absent: plagioclase tends to form sporadically occurring megacrysts instead of segregating in a marginal zone (Mb). The plagioclase distribution of the Mb zone is extremely variable, as indicated by the dashed line in the quantitative profile. The exceptional degree of zoning in this example reflects relative mobilities (quartz>microcline>plagioclase; mafics are essentially immobile) of the mineral components of the neosome. Zone Mb is included as part of the melanosome despite its leucocratic nature because of its granulometry, enrichment in plagioclase (depleted in this case in the leucosome) and higher mafic content. Compositional data based on point counts listed in Appendix 1. Note that problems in distinguishing between different neosome components on a microscopic scale tend to compromise the accuracy of these data.

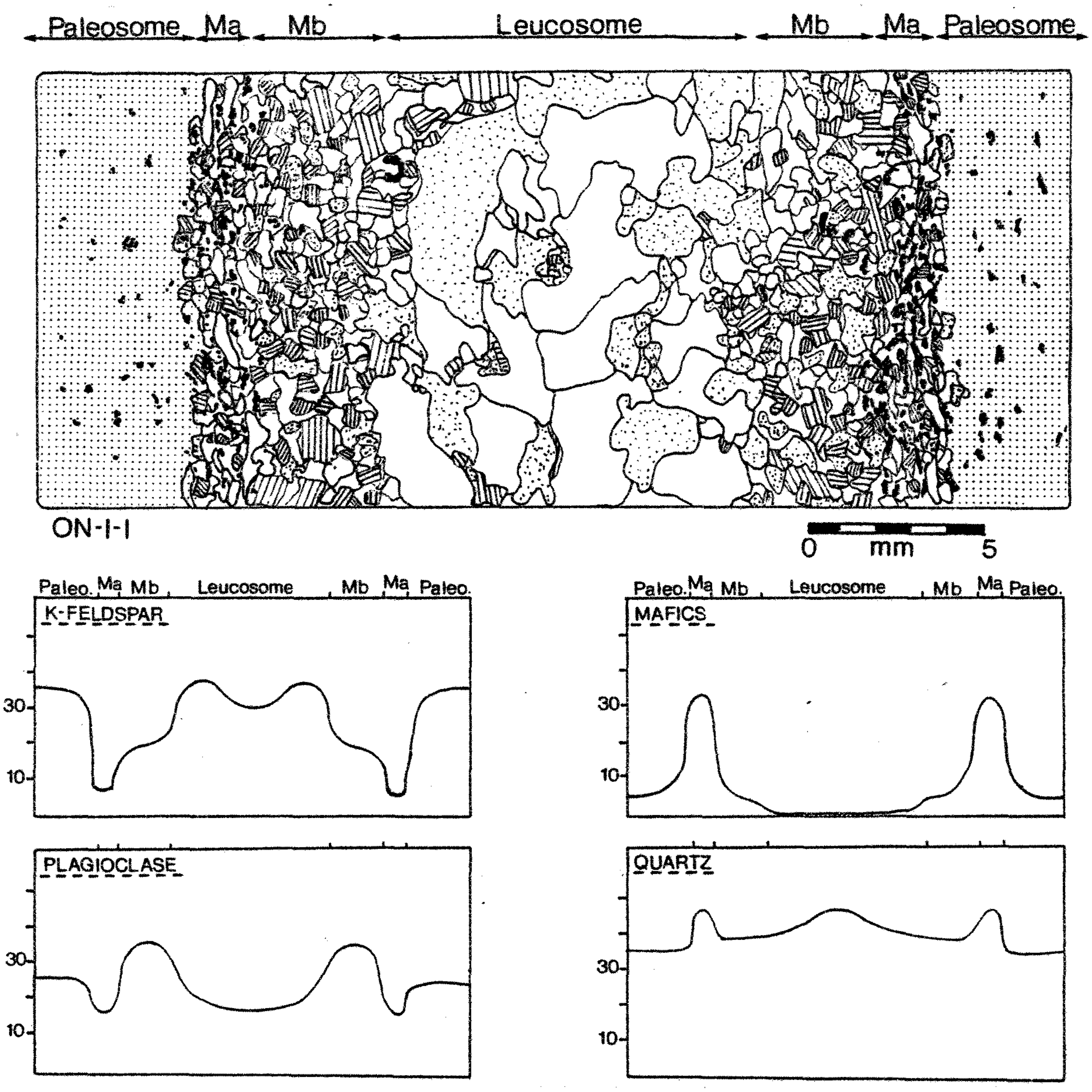

Paleosome
Ma
Mb
Leucosome
Mb
Ma
Paleosome
ON-1-1
0
mm
5
Paleo.
Ma
Mb
Leucosome
Mb
Ma
Paleo.
K-FELDSPAR
30
10
MAFICS
30
10
PLAGIOCLASE
30
10
QUARTZ
30
10

FIGURE 29.

PLATE 21.

"Granitic" composition of mobilizate IIa in granite I. The leucosome consists of grid-twinned microcline, interstitial quartz (white, even grey, black) and small amounts of plagioclase (twinned, at left in photo). Stained thin section ON-4-1. X-nicols. Bar: 2 mm.

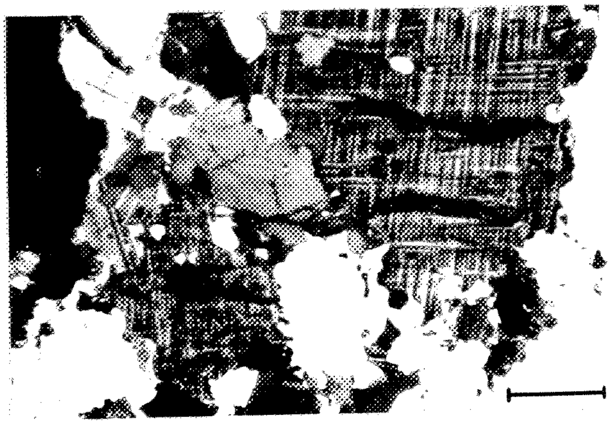


PLATE 21.

ii. Mobilizate IIa in Paragneiss.

Mobilizate IIa in paragneiss typically occurs as 1 to 5 cm thick, melanosome bordered leucocratic veins (Plate 16a). Diffuse mobilizate patches not uncommonly truncate tightly folded mobilizate I veins (Plate 16a), however, metre-scale discordant lobate-shaped segregations (mobilizate IIc), as seen in granite I, were not observed in the paragneiss sequence. The large volumes of closely spaced leucocratic veins in the banded paragneiss make distinction of different vein structures difficult. However, where individual veins are more widely spaced, these features may be observed. Plate 22a shows pinch and swell structure in an isolated leucosome in paragneiss. Similar veins in the same outcrop contain small amounts of garnet and cordierite. Boudinaging of primary compositional layering (bedding), where distinguishable, acts as a local control of mobilizate localization. Plate 22b shows pink , microcline rich mobilizate IIa material diffusely infiltrating the pinched dilational zone of a 10 cm thick boudinaged quartzite interbed in biotite paragneiss.

As in the case of mobilizate I, leucosome-paleosome relations are difficult to establish for mobilizate IIa veins in the paragneiss. Despite the absence of homogeneous paleosome, the complementary mineralogy seen in leucosomes and the adjacent gneiss demonstrates an in situ origin for mobilizate IIa. Similarly, melanosome minerals, chiefly sillimanite and biotite, locally with garnet, also occur in the adjacent gneiss, identifying the latter as the paleosome source of the mobilizate.

As seen in Table 7-2, both the paleosome and mobilizate segregations are rich in microcline and quartz; plagioclase is a minor component. Compared to mobilizate I veins even within the same hand sample, mobilizate IIa veins in paragneiss are always coarser grained (ex. 2.5 mm vs 0.5 mm), and tend to contain a higher

TABLE 7a: Principal textures of granulite-grade gneisses (after Barraud, 1977)

1. <u>Primary</u>

   a. Granoblastic
   b. Inequigranular

   no deformation or recrystallization effects. May be seen in undeformed anatectic mobilizates

2. <u>Secondary</u>

   (overprinting of primary textures 1a,b. Resulting texture is a function of the degree and mechanism of deformation and recrystallization)

   A. Gneissic cataclastites

   a. mortar texture: < 10 % of grains/grain volumes are recrystallized (recrystallized portion consititutes "mesostasis" usually consisting of 0.1 mm grains). Mesostatis surrounds porphyroclasts.

   b. augen texture: 1 to 50 % recrystallization. Mesostasis isolates lens-shaped porphyroclasts

   c. flaser texture: 50 to 75 % recrystallization. Quartz forms plates partly enveloping lens-shaped porphyroclasts.

   d. blastomylonite texture: (platy granoblastic) Recrystallization masks previous mylonitic texture. Quartz plates in an equigranular mesostasis wrap about lenticular porphyroclasts.

   B. Secondary granoblastic textures

   a. heterogranular textures: 10 to 80 % porphyroclasts; 90 to 20 % mesostasis.

   b. equigranular textures: < 10 % porphyroclasts; > 90 % mesostasis. Mesostasis forms mosaics having straight to lobate grain contacts.

   C. Blastotectonic textures: intermediate betwen A. and B. (above). Quartz forms elongated masses, but does not attain a degree of stretching to define plates or augen wrappings. May be:

   a) heterogranular
   b) equigranular

Note: Barraud's definition of the term "granoblastic" is at odds with its' common definition, that is, an equigranular metamorphic texture, representing a high degree of tectonic recrystallization.

TABLE 7b: Paleosome and in-situ mobilizate textures, Old Gneiss Complex

	Mobilizate I	Mobilizate IIa	Mobilizate IIb	Paleosome
Dyke amphibolites:				
IIc	---	1a	---	2Bb str.
IIb	---	2Bb serr.	---	2Bb str.
IIa	---	NE	---	2Ba str./serr.
uncorrelated (pre-IIb) granitic dykes	---	NE	---	2Ba str./serr.
Granite IIb	---	1a	NE	1a, locally 2Aa, 2Ab
Granite IIa and charnockitic gneiss	---	1a	---	1a
Granite I	2Cb lob.	2Aa, 2Bb lob to 2Cb lob.	2Ca,b lob.-str.	2Bb lob-str.
Pelitic Paragneiss:	2Bb lob.	2Ba lob.	NE	2Bb lob.-str.
Concordant amphibolite	2Bb lob.	2Ba lob.-str.	NE	2Bb str.

SYMBOLS: --- not present
NE not examined

Grain contacts: str. (straight)
serr. (serrate)
lob. (lobate)

PLATE 22.

a. Pinch and well structure in discontinuous mobilizate IIa vein, in the St. Fulgence paragneiss sequence (Location: ON-3). Note tne well developed biotite melanosome. This paleosome is the most homogeneous seen in paragneiss within the study area. Even so, thin (< 5 mm) migmatization-related layering can be seen. Elsewhere in the outcrop, cordierite and garnet occur in similar mobilizate IIa veins.

b. Sample OS-11-8. A 10 cm quartzite bed shows pinch and swell structure. Potash feldspar rich mobilizate IIa infiltrates the dilation zone in the quartzite bed, the leucosome originating in the biotite-garnet paragneiss host of the quartzite interbed.

PLATE 23.

a. Thin section ON-2-4a. Mobilizate II in sillimanite-biotite paragneiss. The mobilizate is rich in grid-twinned microcline and bead-perthitic potash feldspar, not uncommonly retaining relicts of grid twins. Edges of potash feldspars show mortar texture. At lower right of photo, note the presence of thin films of twinned albite mantling the perthite where contacting interstitial plagioclase (in photo: black, with thin white twins). Bar: 1 mm.

b. Thin section ON-2-4b. Mobilizate II in sillimanite-biotite-garnet paragneiss. Quartz (q) is lobate, and interstitial to microcline (m). Bar: 1 mm.

note: mobilizate IIa is invariably coarser grained than mobilizate I veins occurring within the same rock. Compare the granulometry of the above photomicrographs with Plates 15b,c showing mobilizate I vein material from the same samples illustrated above.

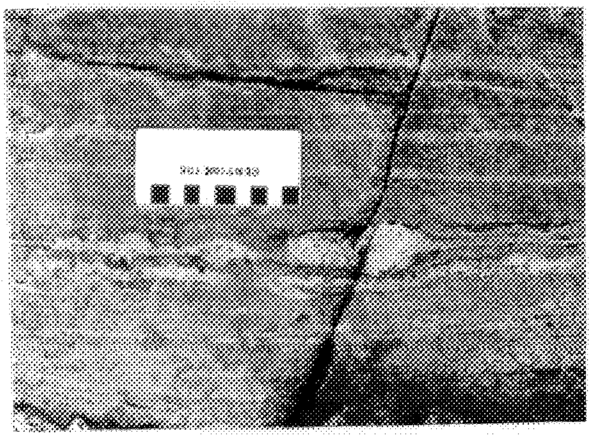


PLATE 22a.

PLATE 22b.

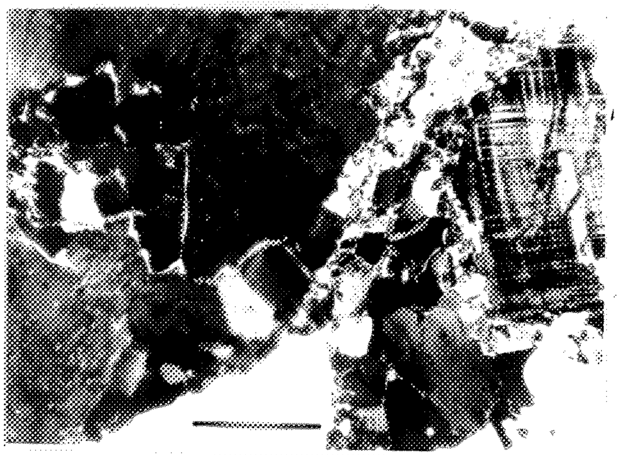


PLATE 23a.

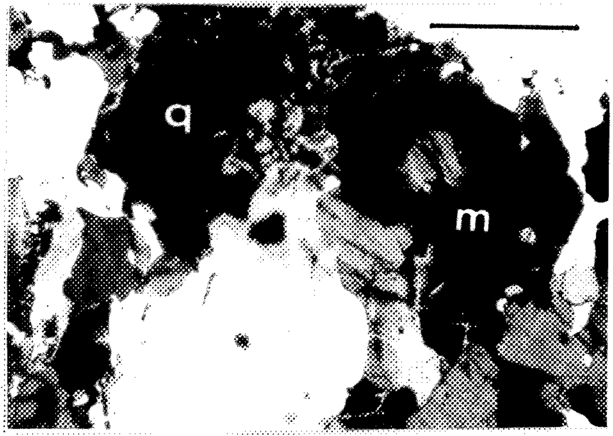


PLATE 23b.

microcline:quartz ratio. In this material, all mineral species are xenomorphic, except for small quantities of hypidiomorphic plagioclase. Mortar texture may be well developed, and microcline may be mantled by thin (0.05 mm) twinned albite films, where contacting interstitial plagioclase (Plate 23a). Microcline also may exsolve plagioclase (untwinned), forming bead and string perthite (Plate 33a). Where not granulated or recrystallized, quartz occurs as lobate to serrate patches interstitial to microcline (Plate 23b). Quartz rarely defines an oriented fabric in these veins.

iii-Mobilizate IIa in Concordant Amphibolite

Occurrences and mineralogy of mobilizate IIa in concordant amphibolite differ markedly from that in either granite I or paragneiss. Although mobilizate IIa commonly segregates as veins in concordant amphibolite, its most typical occurrence is as interboudin accumulations. This results from the banded, heterogeneous nature of the unit: individual bands ranging from 1 to >30 cm characteristically show pinch and swell along their length. Mobilizate IIa segregates in the interboudin dilational zone, sometimes partly wrapping about either boudin, and following S2a in the boudinaged layer, giving a "spider-like" morphology (Plate 24a). Figure 31 traces the development of this structure, all stages of which are seen in outcrop.

In one location (ON-7), the concordant amphibolite is flecked with 1 to 10 cm long quartzofeldspathic streaks, many containing mafic cores up to 4 cm across (Fig. 22, Plate 24b). Although this flecky amphibolite, occurring as a concordant band some 4 m wide, borders in part considerable volumes of granite III within the concordant amphibolite (Fig. 22), these leucocratic streaks predate the granite. This is indicated by the fact that the bulk of concordant amphibolite bordering the granite III is devoid of mafic cored leucosomes, along with the fact that the granite III cross-cuts the S2a schistosity that is in part defined by these streaks. The granite itself is unfoliated. Note also that irregular networks of pegmatitic mobilizate III postdate the granite III, hence the streaks are not a product of this pegmatitic stage of migmatization III. Considering the medium grain size and the absence of F1 folding, these streaks are inferred to be products of migmatization II.

As in the case of mobilizate I, products of migmatization II are always trondhjemitic in concordant amphibolite. Petrographic features of mobilizate IIa are outlined in Table 8-3. Compared with mobilizate I veins in the same outcrop or sample (ex. ON-5-2), mobilizate IIa is somewhat coarser grained (~1.5 mm vs 0.5 mm), and may have a higher quartz:plagioclase ratio (Appendix 1).

Despite the large volumes of mobilizate IIa that may occur in concordant amphibolite (Plate 24c), melanosomes are not seen. Neither is there any change in paleosome mafic mineralogy approaching leucosomes, as is the case where trondhjemitic (Plate 36) to granitic (Fig. 35) mobilizate III pegmatites intrude concordant amphibolite. In the latter cases, the amphibolite has been metasomatized; pegmatites are enveloped by biotite rich seams.

Variations in paleosome mafic mineralogy bordering mobilizate IIa segregations in different concordant amphibolite outcrops reflect the same variations in hornlende:biotite ratios seen throughout the amphibolite sequence, in the absence of leucosomes. With the exception of allochthonous pegmatoids (ex. migrant granitic mobilizate II, or mobilizate III pegmatites), leucosomes in concordant amphibolite do not influence either the mineralogy or the percentage of mafic minerals in the adjacent paleosome.

Unlike mobilizate IIa in granite I, leucosomes in concordant amphibolite do not commonly bear mafic megacrysts, altered and recrystallized equivalents of the same mafic minerals as in the melanosome and paleosome (ex. Plates 17a,b,c,). The flecky gneiss illustrated in Plate 24a is noteworthy insofar as the mafic cores of the leucocratic streaks consist of clinopyroxene-a mineral not seen in the adjacent amphibolite. The gneiss consists of typical concordant amphibolite, foliated and granoblastic textured, with about 40 to 45% subidiomorphic green hornblende, 50% plagioclase, 4% biotite, 2% opaques, and trace percentages of quartz and apatite. The quartzofeldspathic streaks consist of plagioclase and quartz. Unlike the very fresh plagioclase in the gneiss, the leucosome plagioclase shows incipient saussuritization. The quartz and feldspar in the leucosome is much coarser grained than that in the gneiss: here crystals up to 14 mm across are seen. The small (1%) amounts of biotite and hornblende occurring in the leucosome as 0.5 mm scattered grains show no apparent signs of recrystallization. Trace percentages of opaques and apatite are also seen.

The mafic core of the leucosome consists of a central 1 to 3 cm aggregate of clinopyroxene crystals up to 6 mm across, in part mantled by a sieve-like intergrowth of green hornblende, pseudomorphic after the clinopyroxene, and quartz. This mantle is up to 3.5 mm wide; the hornblende mimics the pyroxene cleavage, and contains variable amounts (15 to 60%) of fine grained (0.05 to 0.5mm) irregularly shaped quartz grains (Plate 25). Triple point junctions are not uncommon where several quartz grains juxtapose. In places, the pseudomorphic hornblende passes directly into the gneiss matrix hornblende, showing amphibole cleavage, the gradation being optically continuous. The central clinopyroxene core contains cleavage controlled actinolite (uralite), fibrous and pleochroic from greenish yellow to yellowish brown. The actinolite is variably altered to yellowish green chlorite, having anamalous blue birefringence. A small amount of quartz occurs in the clinopyroxene aggregate. The clinopyroxene

PLATE 24. Aspects of mobilizate IIa in concordant amphibolite.

a. "Spider"-morphology mobilizate IIa, filling dilation zone of a boudinaged 15 cm thick melanocratic layer in concordant amphibolite. This is an intermediate stage of development of the morphology; in more advanced stages (Fig. 30), the mobilizate wraps about the boudins, and infiltrates the schistosity in each. Location: ON-5. Quarter-dollar gives scale.

b. Flecky gneiss: concordant amphibolite with mobilizate IIa streaks, paralleling S2a. Mafic cores consist of clinopyroxene marginally replaced by pseudomorphic green hornblende with quartz intergrowths (c.f. Plate 25). Leucocratic bulk of each fleck is, as in all mobilizate I and IIa,b material, trondhjemitic (plagioclase composition not implied) in concordant amphibolite. Location: ON-7 (c.f. also Fig. 22). Quarter-dollar gives scale.

c. Large volumes of vein-mobilizate IIa in concordant amphibolite. Pen follows an S2c strain slip surface, filled by mobilizate IIb. Note the medium grain size (2 to 3 mm) of the leucosome; mobilizate I is always finer grained (0.5 mm). Location : OS-10.

PLATE 25.

Mafic core of mobilizate II from "flecky"concordant amphibolite (c.f. Plate 24b). The leucosome portion of the leucosome is a plagioclase -quartz assemblage. The mafic core consists of clinopyroxene (cpx), partly chloritized and uralitized along cleavages. The marginal portions of the clinopyroxene are pseudomorphically replaced by hornblende (hbl) with quartz (white) intergrowths. The pseudomorphic hornblende may pass into paleosome hornblende (hbl, dark grey) with complete optical continuity. Thin section ON-7-F1c. X-nicols. Refer to Fig. 22 for sample location.

PLATE 24a.

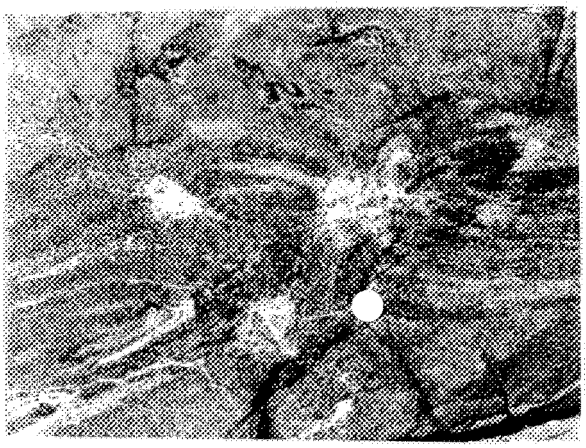


PLATE 24b.

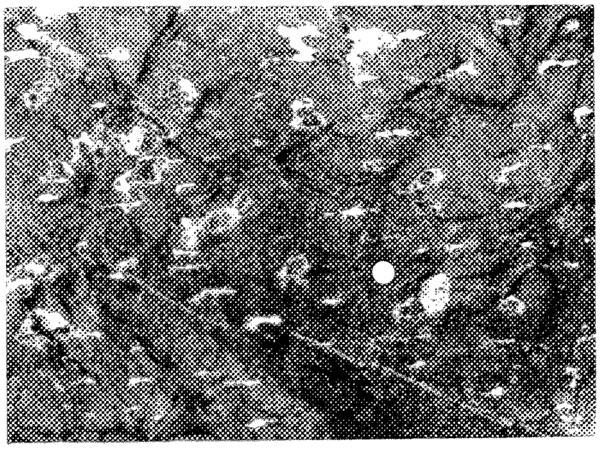


PLATE 24c.

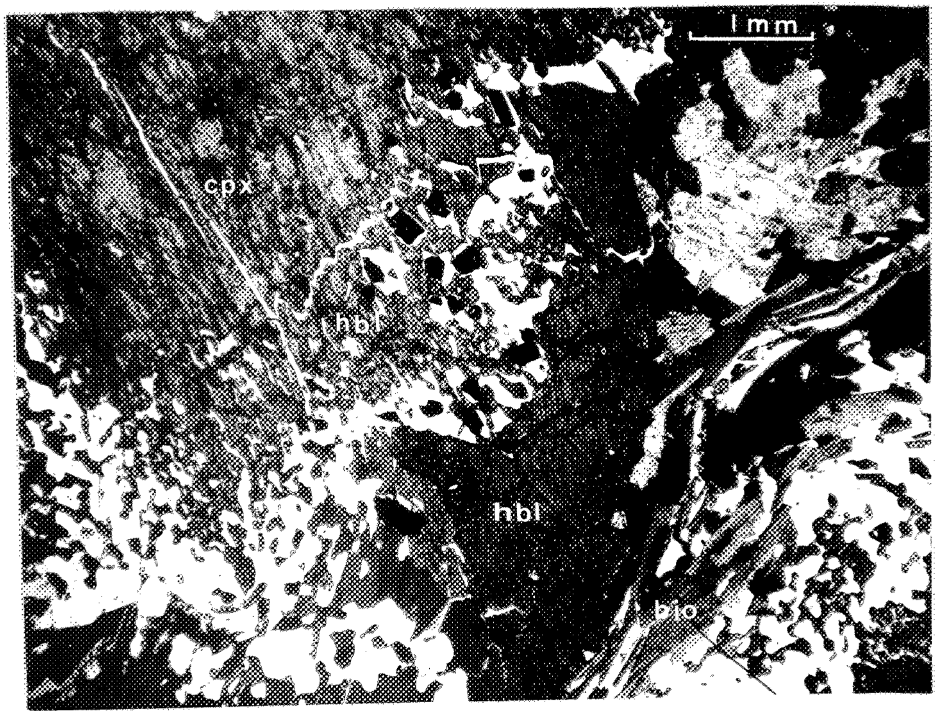


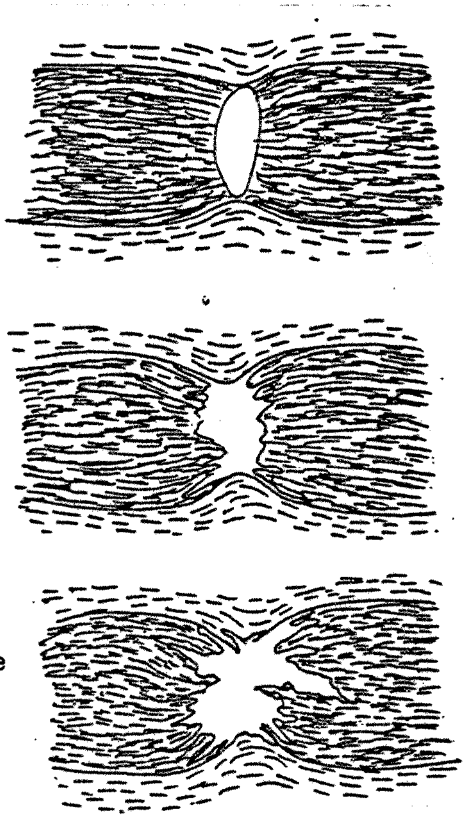
PLATE 25.

FIGURE 30.

Stages of development of "spider" morphology, typical of mobilizate IIa, as found in interboudin dilation zones in concordant amphibolite. All stages of development are seen in the amphibolite. Mobilizate IIa veins may, eventually, partly wrap about both boudins on either side of the dilation zone. Sketch after Wegmann, 1963, Fig. 13). Compare with Plate 24a.

PLATE 26.

Photomicrograph of mobilizate IIa "spider morphology" from banded concordant amphibolite. In the sample (OS-5-2) studied, this material has a higher quartz:plagioclase ratio than mobilizate I veins, cross-cut in the sample by mobilizate II. The mobilizate II is also coarser grained than the mobilizate I leucosomes (compare with Plate 15c). Modal compositions for the sample are represented on Fig. 37. Plagioclase is twinned, quartz is white, even grey, back (extinct). At right of photo are hornblendes, unaffected by the mobilizate. Bar: 1 mm.



Stages of development of "spider" morphology, typical of mobilizate IIa, as found in inter-boudin dilation zones, in concordant amphibolite (heterogenous)

All stages of development are seen in the amphibolite. Mobilizate IIa veins may, eventually, partly wrap about both boudins on either side of the dilation zone.

FIGURE 30.

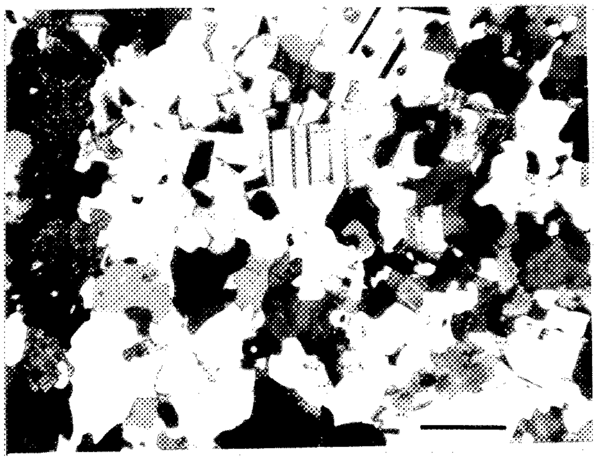


PLATE 26.

probably formed under the same conditions and at the same time as the rest of the leucosome, with subsequent marginal inversion of the pyroxene to form pseudomorphic hornblende with bleb-like quartz intergrowths.

iv-Mobilizate IIa in Granite II

Mobilizate IIa in streaky textured granite IIa and charnockitic gneiss forms diffuse, ill-defined subconcordant veins and patches. Individual veins may range from 1 to 15 cm in thickness, and may be followed along their length for a few metres. Compositionally, leucosomes are very similar to the paleosome (point count results, Appendix 1). Both are granitic, containing abundant grid- twinned microcline and quartz, with lesser, variable (8 to 18%) amounts of plagioclase. Texturally, mobilizate IIa and granite IIa are also very similar, so much so that, disregarding the small quantities (<12%) of mafics in the paleosome, the components are indistinguishable (Table 7b). No melanosome selvages have been recognized bordering mobilizate IIa veins in granite IIa, charnockitic gneiss, or granite IIb augengneiss. Nevertheless, on the outcrop, mobilizate IIa segregations may be recognized by their leucocratic nature, and the lack of an internal fabric, as seen in the paleosome. Locally, leucosomes may contain unoriented, well formed metacrysts of the same mafic minerals as seen occurring in the paleosome (Plate 271a).

Characteristics of mobilizate IIa in streaky granite IIa are outlined in Table 8-4. Plate 27b is a photomicrograph illustrating leucocratic mobilizate IIa sampled a few metres from the hornblende metracryst bearing segregation shown as Plate 27a.

As in the case of segregations in granite IIa and charnockitic gneiss, mobilizate IIa in granite IIb lacks recognizable melanosome margins. There is no doubt, however, that the granite IIb in which these segregations are found is indeed the paleosome source of the leucosomes. Small (cm-scale) leucocratic segregations isolated in flexural hinges of F2b-folds (Plate 28a) within metre-scale outcrops of granite IIb are undeniably isolated in three dimensions, consequently they likely segregated in situ. The granite IIb and contained leucosomes share common mineralogy, in varying proportions (Appendix 1): quartz, microcline and plagioclase occur in subequal quantities. In both components, these minerals average in excess of 1 mm (Table 8-5). Granite IIb retains relict primary granoblastic textures (Table 7b), showing variable degrees of granulation and recrystallization, manifested in thin section as mortar texture, in hand sample as rapakivi-textured augen mosaics. The mobilizate shows no granulation in the thin sections examined, therefore the texture may be described as primary granoblastic (Table 7b). In one outcrop, the mobilizate occurs as concordant elongated pods up to 20 cm wide, 1.5 m long (Fig. 26). These pods contain ragged serpentinized amphibole metacrysts up to 3 cm in diameter (Plate 28b). Amphiboles in the paleosome occur as streaky aggregates partly mantling feldspathic augen; these are similarly altered, however, elsewhere in the outcrop fresh hornblendes are seen. Plate 29 illustrates the typical thin-section aspect of the mobilizate IIa material in the outcrop. Although the material examined does not demonstrate mortar texture, granulation in leucosomes may be expected where deformation IIc or III shear is prevalent.

PLATE 27.

a. Mobilizate IIa in granite IIa. Two morphologies are seen:
1) coarse grained pod of mobilizate with 15 mm black amphibole metacrysts.
2) discordant mobilizate vein, also contains amphiboles (5 mm). The streaky granite has hornblende as the main mafic mineral in this outcrop. Location: OS-20.

b. Photomicrograph of mobilizate IIa segregated from granite IIa paleosome. Same outcrop as Plate 27a. Note the granitic composition of the leucosome: abundant microcline is grid-twinned; quartz is white to even grey. One plagioclase grain was observed in the field of view represented by this photograph. Thin section OS-20-1. Bar: 2 mm. X-nicols.

PLATE 28. Mobilizate II in granite IIb.

a. Leucosome segregations accumulating in F2b flexural hinges. Location: OS-11.

b. Mobilizate II with 1 cm mafic clots, consisting of serpentinized amphibole. Note fanning of the S2a foliation about the segregation, indicating a dilative structural trap into which the mobilizate accumulated. Location: OS-25.

PLATE 29.

Ragged serpentinized hornblende megacrysts in granitic mobilizate IIa in granite IIb. Similar material is photographed from the same outcrop in Plate 28b, and sketched as Fig. 26. At photo centre, note fine quartz-amphibole myrmekitic intergrowth. Potash feldspar is grey, quartz is white. Thin section OS-25-Fla. Plane polarized light. Bar: 5 mm.

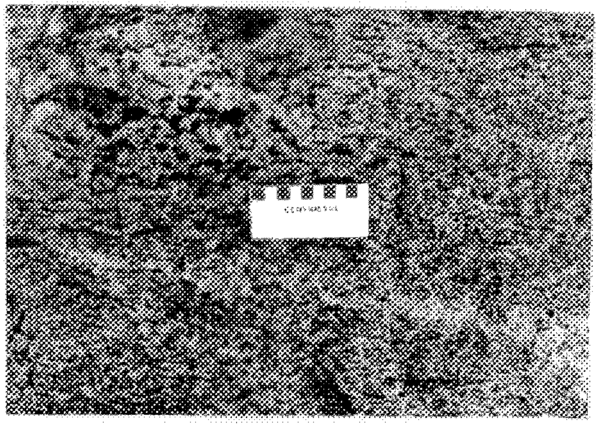


PLATE 27a.

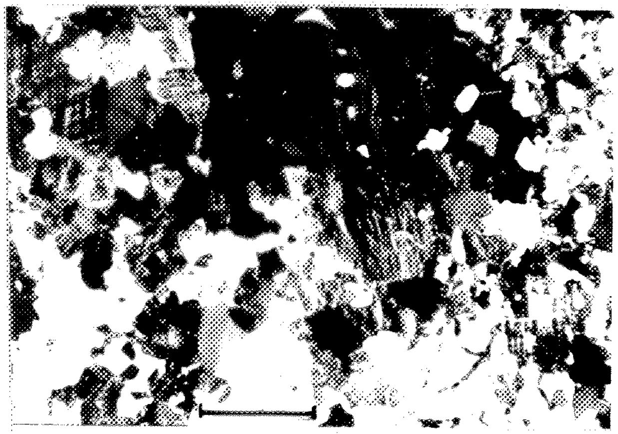


PLATE 27b.

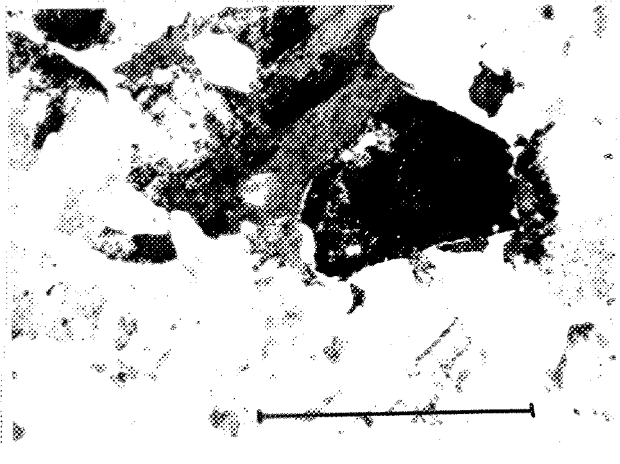


PLATE 29.

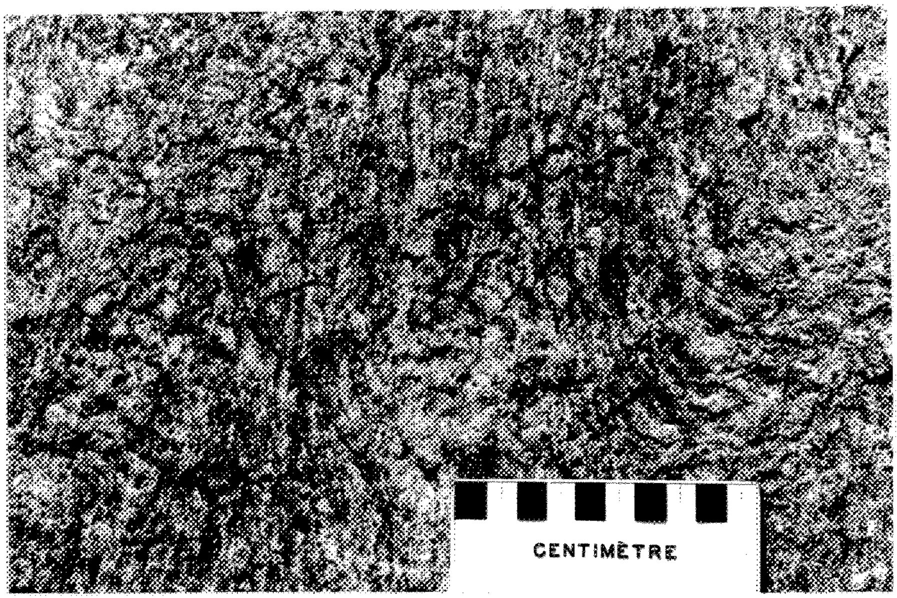


PLATE 28a.

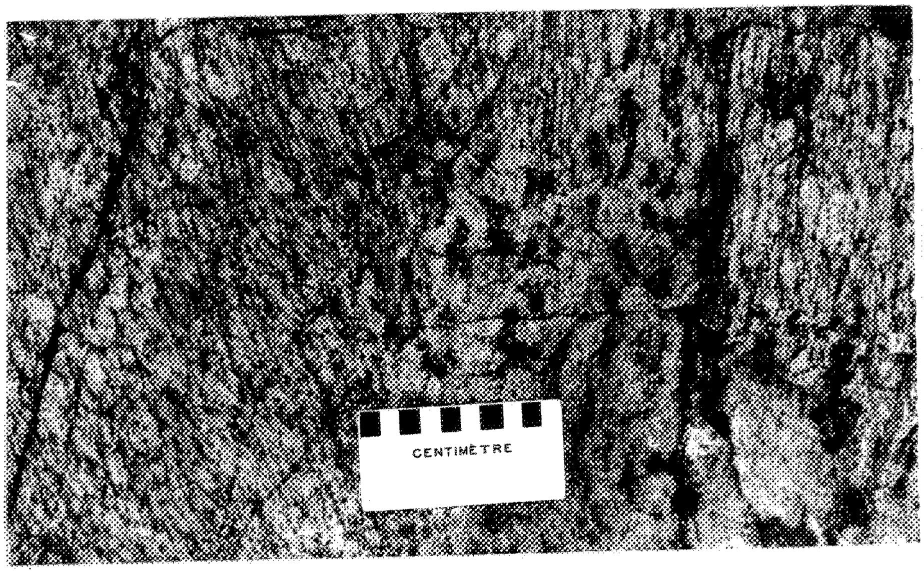


PLATE 28b.

TABLE 8-1: Mineralogical characteristics of mobilizate IIa-paleosome.

GRANITE I (thin sections ON-1-1, OS-1-2b(i,II0, ON-2-6, ON-1-2)

(note: OS-1-2b(i,ii) is mobilizate IIc, petrographically/compositionally similar to mobilizate IIa, in granite I)

	Leucosome	Melanosome	Paleosome
Thickness (mm):	10 to 30	0.8 to 4.0	-
Typical grain size:	2 mm (max. 14)	0.3	0.4
% mafics:	2	15 (5-30%)	6
K-Feldspar			
Typical grain size:	1-3 mm	0.3	0.4
Grid twin:	common	present	common
Perthite:	common (patch, bead, string, braid)	present	common (patch, string)
Mode of	inequigranular, xenomorphic grains	granoblastic mosaics with qz-plag.	
Plagioclase			
Typical grain size:	0.8 mm	0.3	0.3
Zoning:	absent	absent	absent
Myrmekite:	common	present	present
Alteration:	absent to moderate	absent to slight	slight
Mode of occurrence:	inequigranular, subidiomorphic grains	granoblastic mosaics with qz-plag-(mafics)	
Quartz			
Typical grain size:	<1-3 mm	0.3	0.4
Orientation:	absent	some plates parallel vein	absent
Extinction:	larger grains undulose	even to weakly undulose	even
Mode of occurrence:	irregular interstitial patches	irregular elongated grains/plates	polygons
Mafic Minerals			
Hornblende			
%; grain size:	0-2; 0.3-10 mm	0-15; 0.3	1-3; 0.3
Mode of occurrence:	isolated grains and aggregates	idiomorphic oriented grains	idiomorphic grains
Biotite			
%; grain size:	0-1; 0.3 mm	trace-5; 0.3	trace-3; 0.3
Mode of occurrence:	in all components: as oriented idiomorphic flakes		

Also seen: opaques, apatite, epidote, sphene, and, in ON-2-6, clinopyroxene in the absence of hornblende)

TABLE 8-2: Mineralogical characteristics of mobilizate IIa-paleosome.

PELITIC PARAGNEISS (thin sections ON-3-7, ON-6-1, ON-2-4a,b, ON-2-2,, ON-2-F1a, OBH-1, OS-13-1)

	Leucosome	Melanosome	Paleosome
Thickness (mm):	3 to 40	0.5 to 2.8	-
Typical grain size:	2 to 3 mm	< 0.8	0.4 to 0.6
% mafics:	1 to 10	5 to >40	10-25
K-Feldspar			
Typical grain size:	2.5 mm	0.4	0.4 to 0.8
Grid twin:	common	present	common
(Anti)perthite:	not seen	not seen	not seen
Mode of occurrence:	inequigranular xenomorphic	rare; forms xenomorphic grains	inequigranular xenomorphic
Quartz			
Typical grain size:	2 to 4 mm	0.5	0.6
Orientation:	may parallel schistosity	oriented plates paralleling vein	rarely oriented
Extinction:	in all components, only larger grains are undulose		
Mode of occurrence:	as xenomorphic lobate to elongated grains; inclusions in garnet	granulated polygons, and plates	polygonal to seriate xenomorphic grains

Plagioclase (significant quantities of plagioclase occur only in a few sections- ON-2-F1a, OS-13-1)

	Leucosome	Melanosome	Paleosome
Typical grain size:	2.0-2.5 mm	not seen	paleosome not identifiable in plag.-bearing sections
Zoning:	none		
Myrmekite:	common		
Alteration:	moderate		
Mode of occurrence:	hypidiomorphic to idioblastic, equant to tabular grains, with interstitial (and myrmekitic) quartz. With quartz and garnet in the absence of K-feldspar (ON-Block 5)		
Mafic Minerals			
Sillimanite			
%; grain size:	1; v.f.g.-0.4 mm	5 to >40; 0.4-2.0	1 to 15; v.f.g.
Mode of occurrence:	streaks, bundles	streaks, bundles	dissem's, bundles

note: both prograde (muscovite + qz ---> K-spar + sillimanite + V) and retrograde (cordierite + garnet + K-spar ---> biotite + sillimanite + quartz) sillimanite may occur in paragneiss (OBH-1). Retrograde sillimanite occurs as platy intergrowths with quartz; the same texture is seen with biotite and garnet. See Discussion (Section V).

	Leucosome	Melanosome	Paleosome
Biotite			
%; grain size:	0-2; 0.2-5.0 mm	2- >50; 0.4-2 mm	5-15; v.f.g. to 1.5
Mode of occurrence:	in all components:	oriented flakes; sometimes intergrown with quartz.	
Garnet			
%; grain size:	0-5; avg. 10 mm	(rare)	0-5; 5-30 mm
Mode of occurrence:	poikilitic porphyroblasts. May form paragnesis with cordierite, qz. Locally altered to chlorite	isolated grains	poik'c porphyroblasts

TABLE 8-3: Mineralogical characteristics of mobilizate II-paleosome.

CONCORDANT AMPHIBOLITE (thin sections ON-5-2, ON-7-F1c, OS-7-1)

Note: Melanosomes have not been identified for any generation of mobilizate in concordant amphibolite.

	Leucosome	Paleosome
Thickness (mm):	5 to 25	-
Typical grain size:	1.5 to 3 mm	0.4 to 0.8
% mafics:	1 to 20 (ON-7-F1c)	25 to 45
Plagioclase		
Typical grain size:	2 mm	0.4
Zoning:	none	none
Alteration:	absent	absent
Myrmekite:	absent	absent
Mode of occurrence:	subidiomorphic grains, forming mosaics with qz	
Quartz		
Typical grain size:	2 mm	0.3 (0-15 %)
Orientation:	Parallels host schistosity only in vein morphology	none
Extinction:	even to weakly undulose	
Mode of occurrence:	lobate grains, interstitial to plag. as inclusions in cpx/hbl (ON-7-F1c)	polygons interstitial to plag/mafics
K-Feldspar:	absent in all components of concordant amphibolite	
Mafic and Accessory Minerals		
Hornblende		
%; grain size:	0-5; 0.5 mm	10-40; 0.4
Mode of occurrence:	a) subidiomorphic grains	subidiomorphic grains
	b) replacing poikilitic cpx (ON-7-F1c)	
Biotite		
%; grain size:	0-1; 0.2 mm	1-40; 0.1-0.8
Mode of occurrence:	idiomorphic flakes, randomly to weakly oriented	idiomorphic flakes defining schistosity
Clinopyroxene:		
%; grain size:	0-10; 10 mm (max)	not seen
Mode of occurrence:	megacrysts; margins transformed to hbl + qz	

TABLE 8-4: Mineralogical characteristics of mobilizate II-paleosome.

GRANITE IIa (thin sections OS-20-1, OS-20/21)

Note: Melanosomes have not been identified in rocks of age group II.

	Leucosome	Paleosome
Thickness (cm):	1 to 20	-
Typical grain size:	2-3 mm	1-2 mm
% mafics:	traces	2-8
K-Feldspar		
Typical grain size:	1.5-2.5 mm	1
Grid twin:	common	common
Perthite:	present	rare
Mode of occurrence:	irregular grains/patches forming mosaics with qz-plag.	
Plagioclase		
Typical grain size:	0.8 mm	0.6
Zoning:	absent	absent
Alteration:	slight	slight
Myrmekite:	common	common
Mode of occurrence:	subidiomorphic grains	subidiomorphic grains
Quartz		
Typical grain size;	2-3 mm	1.5
Orientation:	weak, parallels vein and S2a	defines schistosity
Extinction:	even to weakly undulose in both components	
Mode of occurrence:	lobate and irregular to elongated interstitial grains/patches	lobate to elongated interstitial grains and patches
Mafic and Accessory Minerals		
Biotite		
%; grain size:	not seen	2-5; 0.2-1 mm
Mode of occurrence:		isolated flakes and streaky aggregates of flakes; rarely intergrown with quartz
Hornblende		
%; grain size:	not seen	2-5; 0.3 to 1.5 mm
Mode of occurrence:		subidiomprhic grains forming streaky aggregates + biotite
Garnet (seen only in OS-20/21)		
%; grain size:	not seen	1; 1.5 to 2 mm
Mode of occurrence:		isolated porphyroblasts. In one case, the garnet is mantled by fanning biotite with polygonal quartz (retrograde)

TABLE 8-5: Characteristics of mobilizate II-paleosome.

GRANITE IIb (thin sections OS-11-4, OS-25-F1a)

Note: Melanosomes have not been identified in rocks of age group II.

	Leucosome	Paleosome
Thickness (cm):	1 to 20	-
Typical grain size:	1.5-2.5	1 to 2
% mafics:	0 to 5	5 to 12
K-Feldspar		
Typical grain size:	1.5 mm	1.2
Grid twin:	common	common
Perthite:	not seen	present
Mode of occurrence:	irregular to subidiomorphic grains forming mosaics with qz-plag.	xenomorphic grains, forming mosaics with qz-plag.
Plagioclase		
Typical grain size:	1 mm	1 to 2
Zoning:	absent	absent
Alteration:	slight to moderate in both components	
Myrmekite:	common	common
Mode of occurrence:	irregular to subidiomorphic grains, forming mosaics with qz-K-spar.	
Quartz		
Typical grain size:	1.5 to 2 mm	1.5 to 2
Orientation:	no preferred orientation in either component	
Extinction:	evenly to weakly undulose in both components	
Mode of occurrence:	lobate to ameboid masses	granular to ameboid masses
Mafic Minerals		
Biotite		
%; grain size:	0-tr.; 0.4 mm	0-10; 0.8
Mode of occurrence:	isolated flakes	aggregates of flakes mantling augen structures
Hornblende		
%; grain size:	0-5; 0.5-30 mm	0-8; 0.5-1.5 mm
Mode of occurrence:	in both components, as chloritized metacrysts	

Note: also trace amounts of apatitie, muscovite, opaques

v-Mobilizate IIa in Dyke "Amphibolites"

The presence of mobilizate IIa leucosomes in dyke rocks is of special significance, insofar as some leucosomes are evidently autochthonous, while others demonstrably have been introduced from the dyke´s host rock (Plate 17e). Since dyke "amphibolites" of age group II incorporate a variety of lithologies, a similar range of autochthonous leucosomes is to be expected. Indeed, dyke leucosomes which, morphologically, appear to be isolated in three dimensions, typically are mineralogically related to the dyke. For example, uncorrelated evenly fine grained granitic dykes of age group II (Table I) frequently contain pink granitic leucosome streaks and veins (Fig. 21). Similarly, dioritic IIc dykes contain trondhjemitic coarse grained leucosomes (Plate 11f, Table 9-1), even though, in this case, the dyke´s host rock is granite I (Fig. 18) which generates granitic mobilizates exclusively. Therefore, the granite I host to the dyke cannot be the paleosome source of this leucosome-we must consider the dioritic dyke to be the paleosome. A wider range of possibilities is presented by true "amphibolite" dykes, namely, dyke amphibolites IIa,b. Here, both autochthonous and allochthonous leucosomes are commonly represented, even within the same individual dyke. Injected mobilizates are easily recognized where the host rock is granitic. In this case, pink microcline-quartz rich veins (Table 9-2) which criss cross the dyke (Plate 17e) may be traced to their source in the dyke´s host rock (Fig. 31). These granitic leucosomes commonly recrystallize the dyke amphibolite (Table 9-3) and may contain hornblende clots (Plates 14, 20a,b). The problematical leucosomes, however, are trondhjemitic in composition (plagioclase composition not implied), mineralogically similar , therefore, to mobilizates I and II in concordant amphibolite. However, a wide range of quartz-plagioclase-(microcline) assemblages may be represented within the same dyke, and even within the same hand sample (Table 9-4). It is noteworthy that, in this case, individual leucosomes occur as pinched lenses, which, although presently appearing to be isolated in three dimensions, probably formed vein networks prior to deformation. As such, microcline-bearing quartz rich leucosomes (Table 9-4) may be considered to have been introduced from a source outside of both the amphibolite dyke and the granite I host. The remaining trondhjemitic leucosomes which, within individual dykes or in different dykes of similar composition, show similar quartz:plagioclase contents, probably formed by a process or processes responsible for autochthonous trondhjemitic mobilizates in concordant amphibolite.

One such example is of particular interest. In this case, a clinopyroxene-bearing trondhjemitic leucosome is concordant within an even-grained amphibolite IIb dyke, in charnockitic gneiss host rock. Since the charnockitic gneiss always generates granitic leucosomes, the amphibolite may be safely described as the paleosome. The leucosome-paleosome material may be subdivided into four components (see also Table 9-5):

a) central, coarse grained clinopyroxene-bearing trondhjemitic mobilizate II (Plate 30a)

b) marginal, fine grained clinopyroxene - plagioclase - quartz - (biotite) zone, largely devoid of hornblende

c) clinopyroxene-bearing amphibolite

d) amphibolite, devoid of clinopyroxene (paleosome)

Features and thicknesses of these zones are described in Table 9-5. Although no melanosome material has been observed in any autochthonous dyke leucosomes, in this one example, zone b) may safely be considered to have been, in large part, the zone in which a), the leucosome, was generated, and from which the leucosome migrated. This is demonstrated by textural evidence (Plate 30b) indicating the breakdown of hornblende, yielding clinopyroxene.

PLATE 30.

a. At left, coarse grained trondhjemitic (plagioclase composition not implied) mobilizate II with clinopyroxene (grey, irregular cleavage): zone "a". At middle, fine grained clinopyroxene-plagioclase-quartz-(biotite, hornblende): zone "b" (c.f. Plate 30b). At right, clinopyroxene bearing dyke amphibolite: zone "c". Clinopyroxene continues through zone "c" for a distance of some 3 cm, gradually diminishing. The dyke amphibolite paleosome contains no clinopyroxene. Thin section OS-21-3 (i). Plane polarized light. Bar: 5 mm.

b. From zone "b", constituting the melanosome (restite) bordering clinopyroxene bearing trondhjemitic leucosome in dyke amphibolite IIb. Textural evidence for the reaction hornblende (h)----->clinopyroxene (c). Thin section OS-21-3 (i). Plane polarized light. Bar: 1 mm.

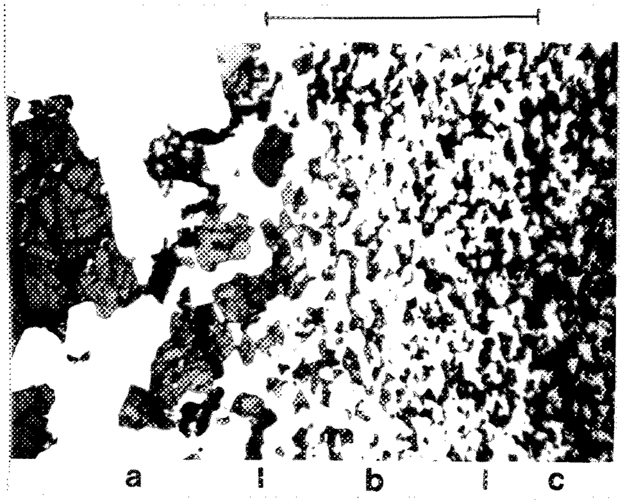


PLATE 30a.

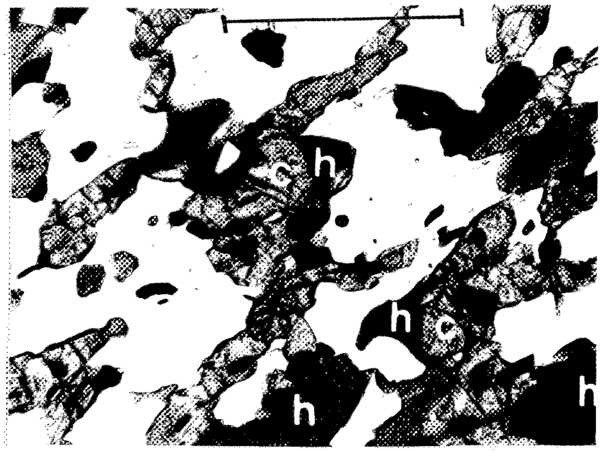


PLATE 30b.

Allochthonous mobilizate II leucosomes are not restricted to intersecting amphibolite II dykes. At two localities (ON-3, OS-13) granite I contacting garnet-sillimanite bearing biotite paragneiss has been brecciated, and infiltrated by garnetiferous mobilizate II generated in the paragneiss. Figure 31 shows a boudinaged and brecciated granite I sill in paragneiss. The interboudin dilation zone hosts pegmatitic allochthonous mobilizate III material, while garnetiferous mobilizate II infiltrates breccia fragment interstices. Small amounts of garnet occur in diffuse mobilizate patches in the marginal zones of some granite I fragments (Fig. 31, inset). The allochthonous mobilizate II (paleosome: paragneiss) contains garnet as the sole mafic mineral, while the granite I contains biotite. A comparison of mineralogical characteristics of the migrant mobilizate II, granite I host, and paragneiss paleosome is presented in Table 9-6.

3-Mobilizate IIb

With the exception of dyke amphibolites, mobilizate IIb leucosomes are locally seen following S2c slip cleavage surfaces in all rocks of age groups I and II. These surfaces and leucosomes are particularly well developed in granite I (Figs. 3, 7, 28, 33), but similar structures are also seen locally in concordant amphibolite (Plate 31, and granite IIb (Fig. 33). Since mobilizate IIb leucosomes, by definition, accumulate along planar slip surfaces, this material occurs only as veins, usually parallel to subparallel to one another within the same outcrop. Mobilizate IIb veins tend to be closely (10 to 50 cm) spaced, and usually are 1 to 5 cm thick, although more diffuse mobilizate-bearing slip zones up to 1.5 m wide are not uncommon. In the former case, veins are discontinuous along their length; individual veins about 10 to 30 cm long abruptly terminate where S2c -slip was insufficiently developed to permit leucosome localization (Fig.3). Along the same surface, the vein material may reappear where shearing is more fully developed (Fig. 3). Internal S2c is manifested as parallel quartz plates (Plate 33a).

FIGURE 31.

Migrant mobilizate II generated in granite I crisscrossing concordant and F2b folded amphibolite IIb dykes ("Sederholm effect"). Schistosity measurement indicates the leucocratic granite I biotite foliation (S2a) which, like the dykes, is folded by F2b which has no axial plane schistosity.

FIGURE 32.

Pegmatitic mobilizate III filling dilation zone between large boudins of brecciated granite I within the paragneiss sequence at St. Fulgence. The granite has been infiltrated by allochthonous garnetiferous mobilizate II, generated in the paragneiss host of the granite I sill. The mobilizate III recrystallizes the granitic material, especially the leucocratic mobilizate II; biotite colts advance up to 25 cm along veins of the latter. Some of the mobilizate II veins in the paragneiss have also been granitized by the pegmatite: these veins are exceptionally quartz-rich and contain potash feldspar megacrysts up to 5 cm across. Inset shows the distribution of garnetiferous mobilizate II and granite I breccia fragments. In the map, note the presence of partly recrystallized breccia fragments in the mobilizate III.

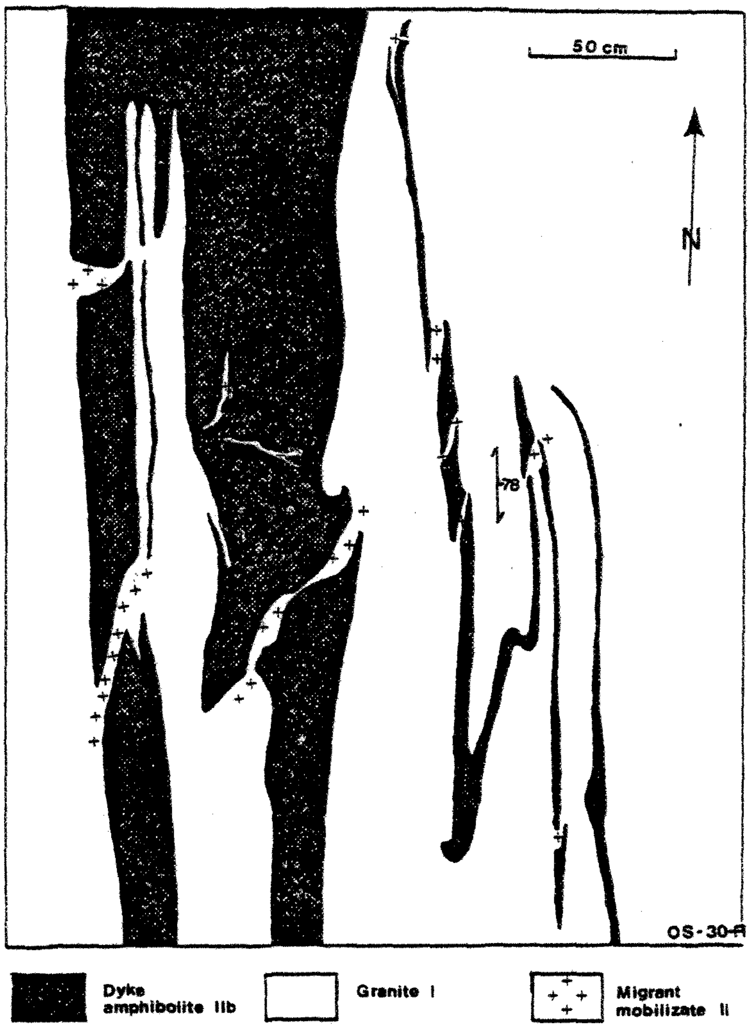


FIGURE 31.

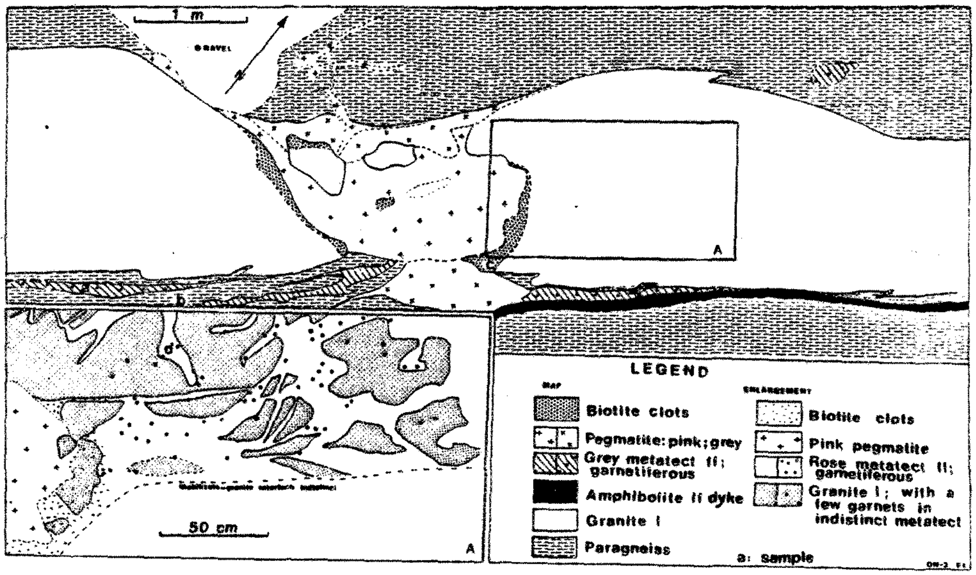


FIGURE 32.

PLATE 31.

Mobilizate IIb veins following closely spaced and parallel slip surfaces in concordant amphibolite. These veins truncate and offset a series of subparallel mobilizate IIa veins. Here, mobilizate IIb veins trend N55E. Location: ON-5.

FIGURE 33.

Mobilizate IIb following slip cleavage surfaces (S2c) in granites IIb and I. Note in both cases that the mobilizates have thin offshoots concordant to S2a foliation in the paleosome, thereby paralleling mobilizate IIa veins (not shown in figure). This leads to the isolation of patches of paleosome (eg. granite I), bounded on two sides by parallel S2c surfaces, and on the remaining two sides by curved (F2b-folded) S2a foliation. c.f. Plate 32c.

PLATE 32. Aspects of mobilizate IIb in granite I.

a. Thin mobilizate IIb veins, trending N20E, in granite I. Note at bottom of photo S2a-concordant mobilizate IIb (texturally identical to the main vein leucosome) intruding the paleosome. At top of photo, coarser grained mobilizate IIb material occurs as a diffuse patch subconcordant to the paleosome schistosity, and contains hornblende clots, absent in the vein. Location: OS-4.

b. Mobilizate IIb following S2c surfaces, in granite I. Note the offset of mobilizate IIa veins in the granite I (left). Right half of photo shows extensive hornblende clot overprinting of granite I and contained mobilizate IIa. Hornblende clots consistently parallel S2c surfaces, indicating that clot recrystallization is concomitant with deformation IIc. The overprint zone extends 2 to 3m into the paleosome. Location: OS-3.

c. Hornblende clot bearing mobilizate IIb occurring as a thick (50 cm) zone trending along S2c in granite I. Offshoots from this zone parallel S2a in the paleosome, partly isolating granite I rafts (above hammer). Note the mafic clot overprinting of the paleosome (right). Location: OS-3.

d. Sample OS-3-5. Mobilizate IIb with 8 mm hornblende clots. The host granite I paleosome is not overprinted by mafic clots in this example. Note that the leucosome fades out toward left of photo, as the degree of strain slip diminishes. At right, the mobilizate IIb diffusely infiltrates and recrystallizes the paleosome and mobilizate IIa veins, following S2a. Note melanosomes bordering the mobilizate IIa veins in the paleosome at photo centre. Even though S2c is weakly developed in this example, a considerable volume of mobilizate has accumulated.

PLATE 31.

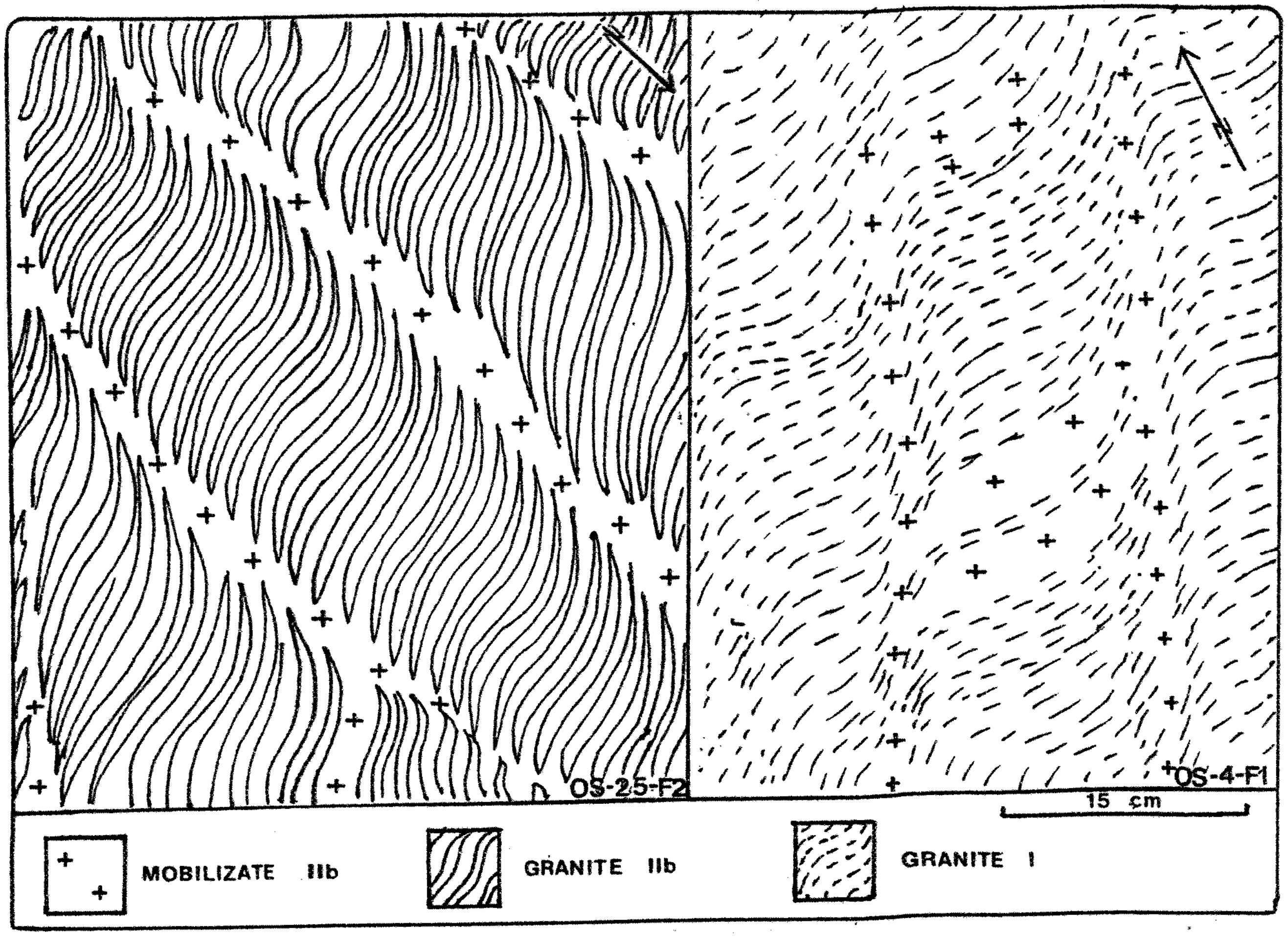


FIGURE 33.

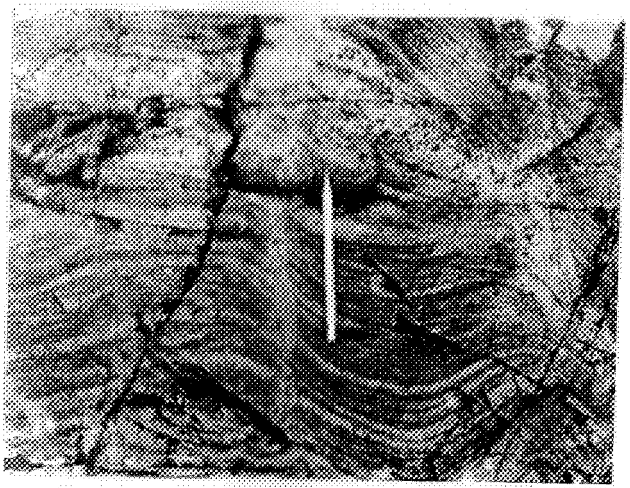


PLATE 32a.

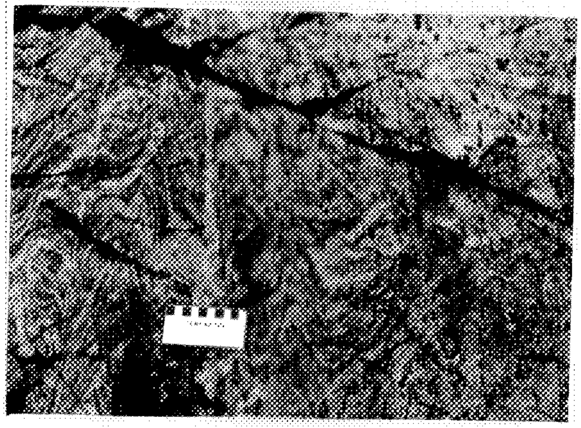


PLATE 32b.

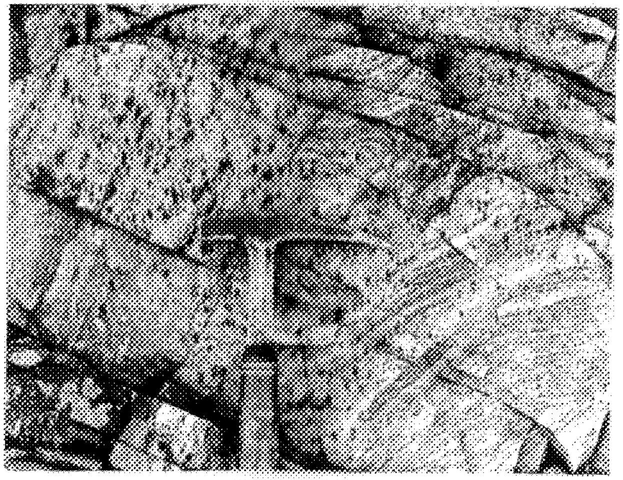


PLATE 32c.

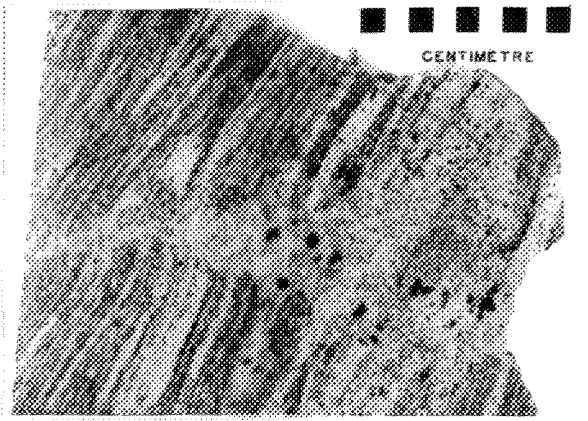


PLATE 32d.

Regardless of the host paleosome, mobilizate IIb veins are never bordered by melanosomes. Thin, isolated veins usually contain no mafic minerals whatsoever (Plate 31, 32a). However, thicker veins, often closely spaced, forming semi-continuous mobilizate rich zones, contain elongated mafic clots which parallel S2c (Plate 32b). These mafic clots consist of the same mafic minerals as occur within the paleosome, for example, hornblende clots occur in hornblende-bearing granite I (Plates 32b,c). These mafic clots may overprint the paleosome and mobilizate I and IIa veins (Plates 32b,c). Mobilizate IIb veins commonly trend away from the parallel series of S2c surfaces, forming 1 cm thick offshoots paralleling S2a (and mobilizate IIa) in the paleosome. Several of these offshoots may occur, joining closely spaced S2c surfaces, thereby isolating patches of the paleosome (Fig. 33, Plate 32c). Although mafic clots often overprint the adjacent paleosome (Plate 33b), mobilizate IIa segregations may also contain 1 cm amphiboles, similar mafic clots not being seen in the adjacent gneiss (Plate 32d).

Table 10 summarizes the petrography of mobilizate IIb and its adjacent mafic overprint zone, in granite I. The compositional similarity of these zones is reflected in modal analysis data, summarized in Appendix 1.

4-Mobilizate IIc

Coarse-grained discordant pods of leucosomes with S2a-concordant offshoots bounded by well defined melansomes are seen locally in granite I. Since these pegmatoids cross-cut mobilizate IIb, schistosity S2c, and all earlier mobilizates and schistosities, these leucosomes are termed mobilizates IIc. They have only been identified in granite I paleosomes, particularly at outcrops OS-1 to OS-4. These granitic leucosomes were initially identified as mobilizate III pegmatites, owing to their coarse (to 3 cm) grain size and large volumes, relative to thin, albeit well defined, melanosomes. However, the presence of marginal melanosomes, and apparent isolation in three dimensions (Fig. 28) indicate that these pegmatoids are in situ. Furthermore, as discussed in section IVB-2, melanosome-leucosome plagioclase compositions indicate an anatectic origin for these leucosomes. As a result of the petrographic similarity of mobilizate IIc to mobilizate IIa, and its unique (?) occurrence in granite I paleosomes, the petrography of mobilizate IIc is described in section IVB-2.

In addition to the segregation of leucocratic veins, migmatization II locally initiated feldspar blastesis in amphibolite dykes in granite IIb (Plate 34). Since microcline porphyroblasts in both granite IIb and the dyke are mantled by plagioclase (rapakivi texture), it is clear that the augen-texture typifying granite IIb in part developed during migmatization II.

PLATE 33.

a. Internal S2c shearing in mobilizate IIb in granite I is manifested as parallel quartz plates (q). Thin section OS-3-block (i). Bar: 1 mm. X-nicols.

b. Ragged, poikilitic hornblende aggregate from mafic overprint zone bordering a mobilizate IIb vein, in hornblende-bearing granite I. Note the similarity of these amphibole clots with those occurring in recrystallized granite I adjacent to granitic mobilizate III (Plate 38b). Thin section OS-3-2. Bar: 2 mm. Plane polarized light.

PLATE 34.

Feldspar blastesis "homogenizing" an amphibolite dyke in granite IIb. Both the microcline porphyroblasts in the dyke and the augen structures in the granite locally show rapikivi texture. Location: ORM-1. Scale: feldspars in the dyke are 1 to 2 cm across.

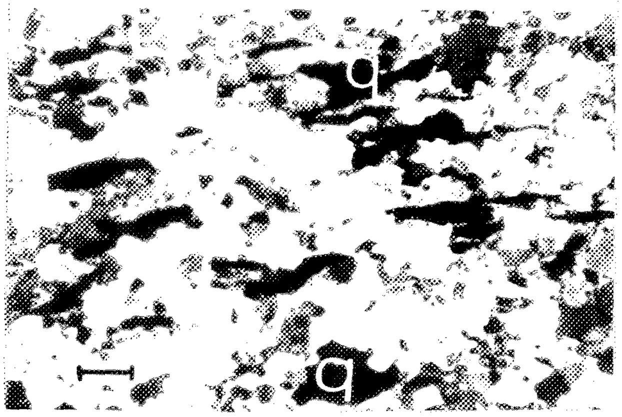


PLATE 33a.

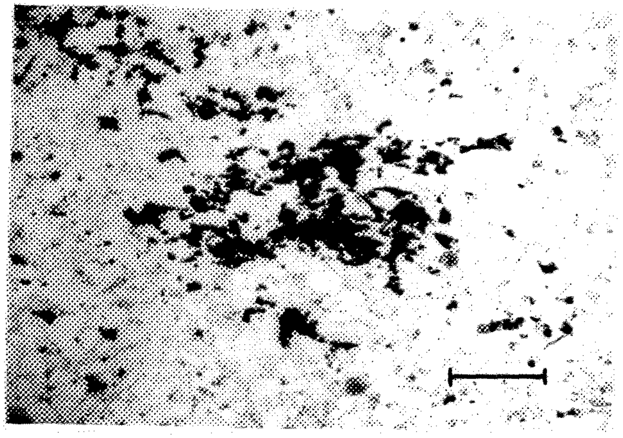


PLATE 33b.

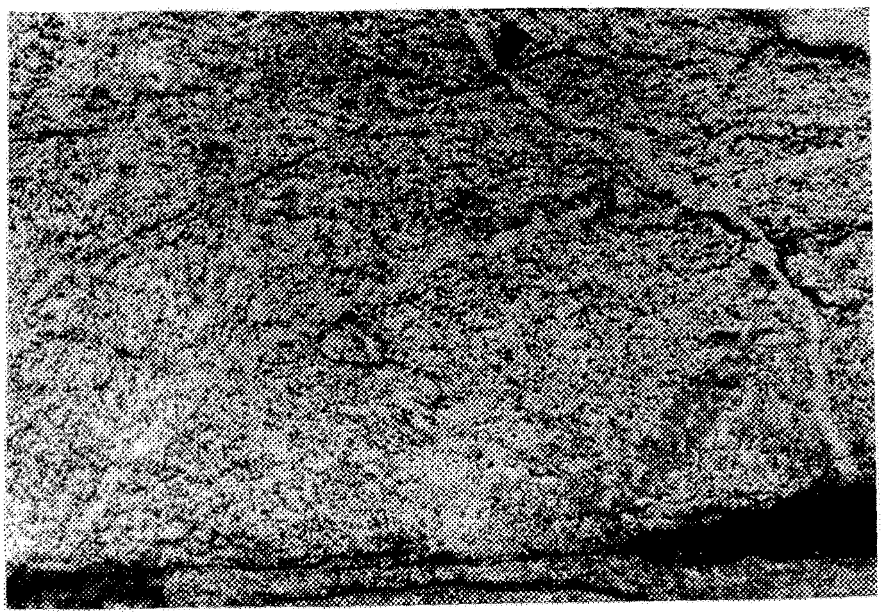


PLATE 34.

TABLE 9-1: Mineralogical characteristics of mobilizate II in dyke amphibolite II.

DYKE AMPHIBOLITE IIc (dioritic) (thin section OS-26-F1a)

Note: This sample is the only leucosome-dyke assemblage containing a marked enrichment of mafics bordering the leucosome. This may, at the outset, considered to be either a melanosome, or simply marginal recrystallization.

	Leucosome	Melanosome (?)	Dyke Host
Thickness (mm):	50	1-5	-
Typical grain size:	1.5 mm	0.5	0.4
% mafics:	trace	40	20
Plagioclase			
Typical grain size:	1.5 mm	0.4	0.4
Zoning:	absent	absent	absent
Alteration:	absent	absent	absent
Myrmekite:	not seen	not seen	not seen
Mode of occurrence:	hypidiomorphic, inequigranular grains forming mosaics with qz	irregular to hypidiomorphic grains, roughly equigranular	
Quartz			
Typical grain size:	1.5-2 mm	0.3	0.3
Orientation:	parallels veins	none	none
Extinction:	undulose	even	even
Mode of occurrence:	elongated, interstitial lobate and irregular grains	polygonal and lobate grains	
K-Feldspar:	minor quantities (<3 %) seen only in dyke host (paleosome?)		
Mafic Minerals			
Biotite			
%; grain size:	trace; o.5	40; 1	1; 0.
Mode of occurrence:	isolate flakes	clusters of flakes, paralleling vein	isolated flakes, sometimes clustered, defining S2a
Hornblende			
%; Grain size:	absent	absent	3; 0.6
Mode of occurrence:			irregular to hypidiomorphic grains
Clinopyroxene			
%; grain size:	absent	absent	1; 0.5
Mode of occurrence:			irregular grains associated with hornblende

TABLE 9-2: Mineralogical characteristics of mobilizate II in dyke amphibolite II.

DYKE AMPHIBOLITE IIb (thin section OS-21-3; host rock of dyke is granite IIa).
Note: The vein is seen to be an offshoot of mobilizate II from granite IIa (Sederholm effect).

	Leucosome	Dyke Host
Thickness (mm):	20	-
Typical grain size:	2.5 mm	0.5
Plagioclase		
Typical grain size:	o.5 mm	0.5
Zoning:	absent	absent
%:	2	20
Alteration:	absent	absent
Myrmekite:	present	absent
Mode of occurrence:	small xenomorphic interstitial grains	xenomorphic grains
Quartz		
Typical grain size:	2 mm	0.2
Orientation:	none	none
Extinction:	weakly undulaose	even
Mode of occurrence:	interstitial irregular and seriate to lobate patches; mortared polygons juxtaposing K-spar.	polygons (minor)
K-Feldspar		
Typical grain size:	3 mm	0.5
%:		
%:	~50	~5
Grid twin:	present	absent
Perthite:	common	common
Mode of occurrence:	large interlocking xenomorphic grains with interstitial quartz	xenomorphic perthitic grains
Mafic Minerals		
Clinopyroxene		
%; grain size:	trace; 0.8	>40; 0.8 (often 1.5 mm)
Mode of occurrence:	isolated, interstitial (with qz)grains	oriented hypidiomorphic grains
Biotite		
%; grain size:	trace; 0.4 mm	10; 0.8
Mode of occurrence:	isolated flakes, interstitial, with cpx	oriented flakes

TABLE 9-3: Mineralogical characteristics of mobilizate II in dyke amphibolite II.

DYKE AMPHIBOLITE IIb (thin section OS-3-4; host rock is granite I).

Note: This sample is from a dyke intersected and altered by mobilizate IIb. Here, the dyke is 1 cm thick, and is bounded on three sides by mobilizate. The amphibolite is bordered by a continuous, 1 mm thick alteration zone, marked by an increase in size and % of (fresh) hornblende.

	Leucosome	Alteration Zone	Dyke Host
Thickness (cm):	mobilizate IIb vein: 50	0.1	-
Typical grain size:	1 mm	0.4	0.4
% mafics:	1	40	30
Plagioclase			
Typical grain size:	1 mm	0.4	0.4
Zoning:	absent	absent	absent
Alteration:	slight-moderate	absent	absent
Myrmekite:	common	not seen	not seen
Mode of occurrence:	xeno.- to hypidiomorphic inequigranular grains	equigranular hypidiomorphic grains	
Quartz			
Typical grain size:	1 mm	0.3	0.3
Orientation:	none	none	none
Extinction:	undulose	even	even
Mode of occurrence:	lobate irregular patches	polygons	polygons
K-Feldspar			
%:	roughly 40	absent	absent
Typical grain size:	1 mm		
Grid twin:	common		
Perthite:	string (present)		
Mode of occurrence:	xenomorphic grains forming mosaics with qz-plag.		
Mafic Minerals			
Hornblende			
%; grain size:	1mm; 0.4	40; 0.7	25;0.3
Mode of occurrence:	isolated grains	idiomorphic grains in contact with one another	networks of euhedra
Biotite			
%; grain size:	note seen	5; 0.6	2; 0.3
Mode of occurrence:		ragged, chloritized flakes with quartz inclusions (replaces hornblende)	

TABLE 9-4: Mineralogical characteristics of mobilizate II in dyke amphibolite II

DYKE AMPHIBOLITE IIb (even grained amphibolite; thin sections ON-4-2i,ii. Host rock is granite I)

Note: Amphibolite dykes may contain in situ mobilizate II leucosomes, or may be cross-cut by migrant mobilizates originating from the dyke's host rock. In neither case are definite melanosomes seen. Note that in the case of migrant mobilizates, the dyke may be recrystallized where in contact with the leucosome.

	Leucosome	Dyke Host
Thickness (cm):	2	-
Typical grain size:	2 mm	0.8
% mafics:	2	45
Plagioclase		
Typical grain size:	1.5 mm	0.6
Zoning:	absent	absent
Alteration:	absent to slight	absent
Myrmekite:	not seen	not seen
Mode of occurrence:	hypidiomorphic grains	hypidiomorphic grains
Quartz		
Typical grain size:	2 mm	0.4
Orientation:	some grains oriented parallel to segregation	none
Extinction:	even	even
Mode of occurrence:	polygonal to irregular/lobate interstitial grains	polygons
K-Feldspar		
Typical grain size:	3 mm	absent
Grid twin:	poorly developed	
Perthite:	some grains have f.g. patchy plagioclase	
Mode of occurrence	mosaics of xenomorphic grains	

Ratio of plag/K-spar/qz:
-ON-4-2i: (50-90)/(0-5)/(50-10)
-ON-4-2ii: 0/20/80

Note: Thin section ON-4-2i contains two veins; one is a plagioclase-quartz assemblage, the other consists almost entirely of plagioclase. Section ON-4-2ii contains one vein, a quartz-microcline assemblage. Both thin sections were made from the same hand sample. All leucocratic veins in the sample parallel the biotite foliation and are lensoid in shape.

TABLE 9-5: Mineralogical characteristics of mobilizate II in dyke amphibolite II.

DYKE AMPHIBOLITE IIb (thin sections OS-21-3i, ii)

	Leucosome	Dyke Host
Thickness (cm):	2	0.5
Typical grain size:	5 mm	0.5
% mafics:	10	25

Note: the neosome is zoned, as follows:

ZONES:
a) central, coarse grained leucosome (2 cm thick)
b) marginal fine grained zone (5 mm thick), depleted in hornblende, but, like the leucosome, with clinopyroxene
c) dyke host, with hornblende and clinopyroxene. Pyroxenes fade out over a thickness of 2 to 3 cm
d) unaffected hornblende-plagioclase dyke amphibolite

Zone a) is the in situ mobilizate (host gneiss of the dyke is granite IIa)
Zones b) and c) are probably melanosome margins, source of the mobilizate
Zone d) is the paleosome

	(a)	(b)	(c)	(d)
Plagioclase				
Typical grain size:	5 mm	0.4	0.4	0.4
Zoning:	not seen in any component			
Alteration:	none	none	none	none
Myrmekite:	absent	absent	absent	absent
Mode of occurrence:	xeno.- to hypidmorphic grains,	in b,c,d: roughly equigranular polygons		
Quartz				
Typical grain size:	3-4 mm	0.4	0.4	0.4
Orientation:	unoriented in all components			
Extinction:	weakly to strongly undulose (larger, mortared grains)	even in b,c,d		
Mode of occurrence:	interstitial, seriate to lobate masses/grains	in b,c,d: polygons		
K-Feldspar:	absent in all components			
Mafic Minerals				
Hornblende				
%; grain size:	absent	absent	35; 0.5 mm	40; 0.5
Mode of occurrence:		in b,c,d: as idiomorphic grains/grain networks		
Clinopyroxene				
%; grain size:	10; to 3 cm	15; 0.4	10--->1%; 0.4	absent
Mode of occurrence:	Large irregular grains, minor alteration to biotite	in b and c: elongated xenomorphic grains, showing textural evidence of the transformation: hbl ----> cpx		
Biotite				
%; grain size:	absent	0-5; 0.3 mm	0-5; 0.4	2; 0.4
Mode of occurrence:		in b,c: retrograde flakes		

TABLE 9-6. Characteristics of migrant mobilizate II mineralogy.

Note: Migrant mobilizate II is defined as leucosome material which generated during migmatization II found in a lithology other than its source paleosome.

Host Rock: Granite I; Paleosome: (Source): Paragneiss
(Thin sections ON-3-F1d and OS-13 Block)

	Leucosome	Host Rock	Paleosome
Thickness (cm):	1 to 30 (may form irregular networks)	-	-
Typical grain size:	0.8 mm	0.4	0.6
% mafics:	3 (garnet)	1-5	5-25
K-Feldspar			
Typical grain size:	1 mm	Section OS-13 shows a depletion of K-spar in the granite I host and in the paleosome.	
Perthite:	not seen		
Mode of occurrence:	irregular grains forming mosaics with qz-plag.		
Plagioclase			
Typical grain size:	0.6	0.5	0.5
Zoning:	absent	absent	absent
Alteration:	slight to moderate	slight	slight
Myrmekite:	common	rare	rare
Mode of occurrence:	inequigranular, irregular grains	equigranular, hypidiomorphic grains	
Quartz			
Typical grain size:	1	0.4	0.4
Orientation:	unoriented	none	none
Extinction:	even to undulose in all components		
Mode of occurrence:	irregular and lobate grains and patches	equigranular rounded grains	inequigranular lobate grains
Mafic and Accessory Minerals			
Garnet			
%; grain size:	3; 5-12 mm	present as in leucosome, in diffuse mobilizate patches	(not seen in either sample
Mode of occurrence:	porphyroblasts with numerous qz inclusions		
Biotite			
%; grain size:	tr.; 0.4	1-5; 0.4	10; 0.5
Mode of occurrence:	isolated fresh to chloritized flakes	isolated flakes defining S2a	isolated to clustere flakes paralleling S2a

TABLE 10. Characteristics of mobilizate IIb-paleosome mineralogy.

GRANITE I (thin sections, OS-3-Block i,ii, OS-3-2.

Note: mobilizate IIb has no associated melanosome, however, mafic overprinting of the paleosome is not uncommon.

	Leucosome	Paleosome	Overprint Zone
Thickness (cm):	1 to 100	-	0 to 150
Grain size (mm):	1	0.5	0.5
% mafics:	0 to 5	5	5
K-Feldspar			
Typical grain size:	0.8	0.4	0.4
Grid twin:	common (weakly perthitic)	common	common
Antiperthite:	not seen	present	present
Mode of occurrence:	irregular grains forming mosaics with qz + plag.		
Plagioclase			
Typical grain size:	0.6	0.4	0.4
Zoning:	absent	absent	absent
Alteration:	absent to moderate	absent to slight	
Myrmekite:	common	common	common
Mode of occurrence:	irregular to hypidiomorphic grains, forming mosaics with qz-K-spar	granular mosaics with qz-K-spar	
Quartz			
Typical grain size:	1	0.5	0.5
Orientation:	moderate to strong, paralleling S2c	none	none
Extinction:	even to weakly undulose in all components		
Mode of occurrence:	elongated irregular parallel plates	lobate to polygonal grains	
Mafic and Accessory Minerals			
Biotite:			
%; grain size:	0 to tr.; 0.4	1; 0.2-0.4	same
Mode of occurrence:	flakes associated with clusters of hornbl.	isolated flakes defining schistosity	
Hornblende:			
%; grain size:	0-5; 0.5-10	0-5; 0.5	0-5;0.5-10
Mode of occurrence:	Altered aggregates	granoblastic grains	ragged clots

5-Mobilizate III

Mobilizate III occurs as concordant to cross-cutting (Plate 35, Fig. 34) pegmatite veins, from a few centimetres to several metres wide, here and there swelling to thicknesses up to and exceeding 20 m. With the local exception of concordant pegmatites veins, mobilizate III localization is rarely controlled by host rock structural features, tending to fill, instead, fractures. However, mobilizate III pegmatites locally are seen to segregate in interboudin dilation zones (Fig. 31) and may follow S2c shear surfaces (Fig. 27d), thereby paralleling mobilizate IIb veins. Where pegmatite veins are seen to fill fractures, renewed movement along these surfaces develops S3 shear schistosity in the crystallized mobilizate (Figs. 9, 26), indicating that the pegmatites were intruded during deformation III. Where filling joint sets, the pegmatites assume a trellis pattern (Plate 36). In addition to their occurrence as discordant veins, the local presence of host rock inclusions (Plate 37) demonstrates the intrusive nature of mobilizate III. As such, these pegmatites are clearly allochthonous: melanosome seams are never seen and pegmatites match host rock leucocratic mineralogy only by coincidence. As described in section IIB-3, and outlined in Table 11, mobilizate III ranges from granitic to trondhjemitic in composition, and pegmatitic to granitic in texture. Where, by chance, mobilizate III vein material is compositionally similar to in situ mobilizates seen in their host rocks, the pegmatites may be distinguished by the absence of melanosomes and the tendency of mobilizate III to recrystallize host rocks and inclusions.

Recrystallization of host rocks and their in situ mobilizates is, with the possible exception of diffuse mafic-clot bearing zones bordering some mobilizate IIb veins (Plates 32b,c), a feature unique to migrant pegmatoids infiltrating rocks of different lithology than their paleosome source. Host rock alteration is seen within a semi-continuous zone (where present) from 1 to ~30 cm thick, adjacent to the pegmatite. These zones typically contain metacrysts of the same mafic mineral(s) occurring in the host rock. For example, hornblende porphyroblasts may border pegmatites in hornblende-bearing granite I (Plate 38a), while biotite clots are more likely to be developed in a biotite-bearing granite I (Fig. 32). Recrystallization of this sort is typical of allochthonous leucosomes, consequently, similar recrystallization phenomena were described where granitic leucosomes from granitic host rocks infiltrate amphibolite dykes (Plates 20a,b). Of particular significance is the biotitization of concordant amphibolite by both granitic (Fig. 34) and trondhjemitic (Fig. 11, Plate 36) pegmatites. Table 12 summarizes mineralogical changes shown by concordant amphibolite recrystallized by trondhjemitic mobilizate III. This example demonstrates that metasomatism and silicification may occur in addition to recrystalliztion of mafic mineral phases already present in the host rock (ex. Plates 38a,b).

Although mobilizate III usually retains a primary granoblastic texture (Table 7b), locally weak tectonic fabrics are developed, particularly in pegmatites located in S3 shear zones (Figs. 9, 26). Plate 39a shows well developed elongated quartz patches, paralleling S3 in the thin granitic pegmatite illustrated in Fig. 9. These oriented quartz plates are lobate to plate-like in form, and consist of serrated quartz mosaics, partly enveloping perthite megacrysts.

Both granitic and trondhjemitic pegmatites, and "granite III", locally contain from 5 to 30% magnetite. Plate 39b shows a magnetite rich trondhjemitic pegmatite, illustrated in Plate 14, in which magnetite and finer grained serrate to polygonal plagioclase-quartz-(micocline) mosaics are interstitial to xenomorphic plagioclase megacrysts.

FIGURE 34.

Discordant offshoot of pegmatitic mobilizate III rich in potash feldspar and quartz, cutting concordant amphibolite II dykes in granite I. Note thin offshoots of the pegmatite from the discordant vein, and the sporadic occurrence of mobilizate II material from granite I paleosome, segregating in dilational stretched points in the amphibolite dykes. Plate 35 shows an inclusion of granite I within the same mass of pegmatite, some 8 m wide.

FIGURE 35.

Recrystallization of amphibolite inclusions in pegmatitic mobilizate III (granitic). A biotite rich rim surrounds a pale, relatively fine grained zone (plagioclase-biotite-quartz-opaques-apatite; medium grained, essentially unaltered amphibolite occurs at the centre. Small inclusions are completely altered to biotite; intermediate sized enclaves lack the unaltered central core. Modal compositions of these zones are presented in Table 12, for amphibolite recrystallized by trondhjemitic mobilizate III. Part of this figure is photographically reproduced as Fig. 22-11 in Owen and Dimroth (1980).

PLATE 35.

Crosscutting mobilizate III pegmatite, roughly perpendicular to the streaky S2a foliation in the host charnockitic gneiss. To right of hammer head are 7 cm long beige coloured potash feldspar porphyroblasts, forming a coarse grained concordant layer in the host gneiss. Location: OS-29/30.

PLATE 36.

Trellis pattern outlined by joint-filling trondhjemitic mobilizate III pegmatite veins, in concordant amphibolite. Despite the tronhjemitic mineralogy of the pegmatite, the leucosome is identified as mobilizate II, not mobilizate II, since semi-continuous biotite reaction rims border the leucosome. c.f. Fig. 34 for similar type of reaction. Location: ON-7.

PLATE 37.

Inclusion of host granite I in mobilizate III pegmatite. This inclusion is oriented parallel to the host rock foliation. Distance between the inclusion and host rock is about 3 m. The granite I contains thin, closely spaced amphibolite dykes (c.f. Fig. 6), ragged relicts of which extend for some 1 to 2 m into the pegmatite. The leucocratic granite I is replaced for 10 to 30 cm along the inclusion's length by the granitic pegmatite. Same pegmatite mass as illustrated in Figs. 6 and 33. Location: OS-30.

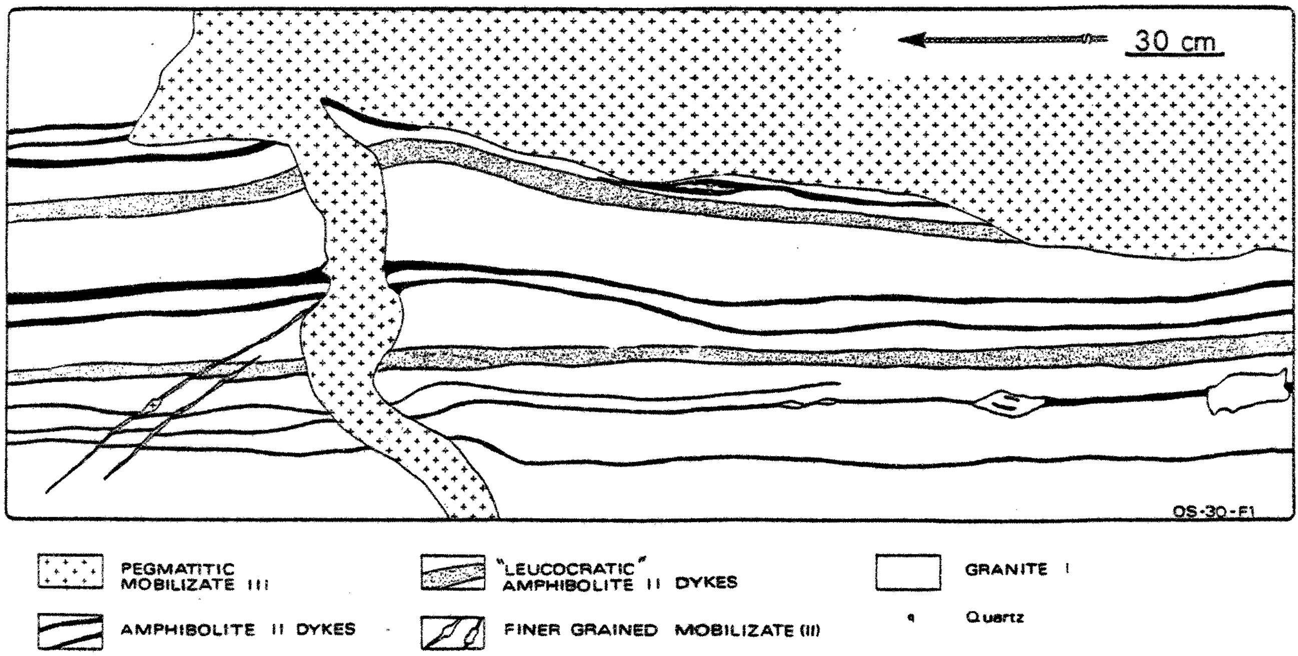


FIGURE 34.

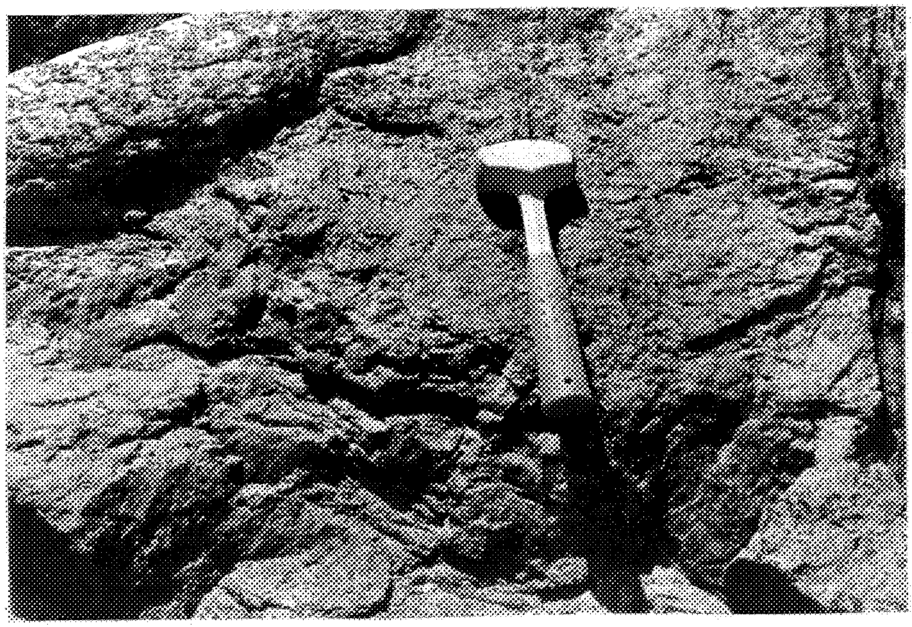


PLATE 35.

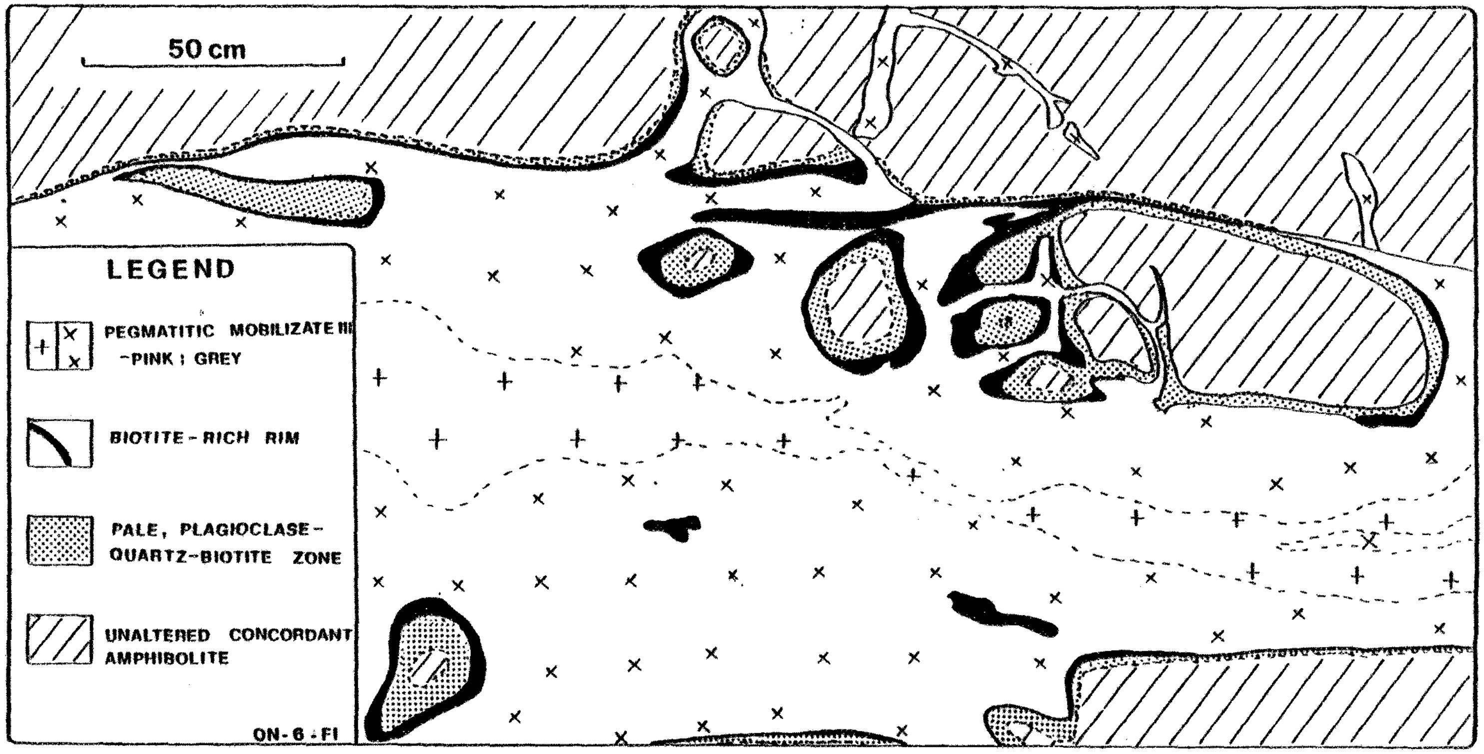

50 cm
LEGEND
PEGMATITIC MOBILIZATE III
-PINK : GREY
BIOTITE-RICH RIM
PALE, PLAGIOCLASE-QUARTZ-BIOTITE ZONE
UNALTERED CONCORDANT AMPHIBOLITE
ON-6-FI

FIGURE 35.

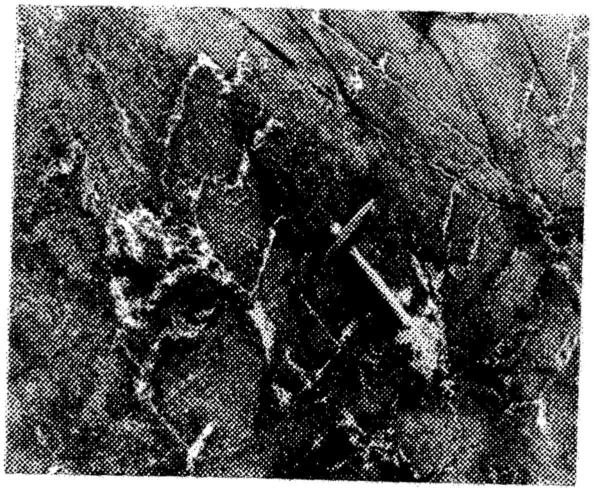


PLATE 36.

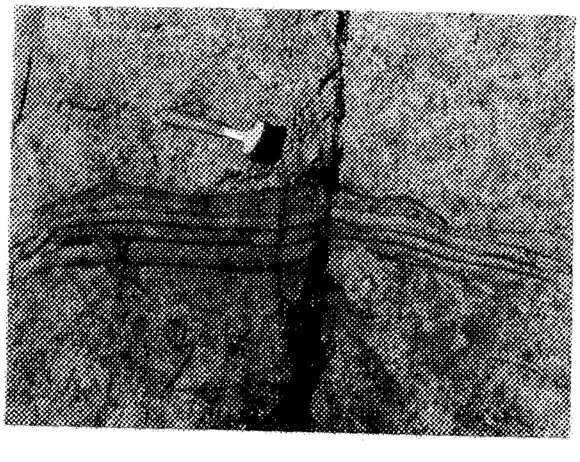


PLATE 37.

PLATE 38.

a. Hornblende clots developing in a recrystallized zone adjacent to a discordant granitic mobilizate III vein in granite I. This vein is oriented at a shallow angle to the outcrop surface, therefore the thickness of the recrytallization zone is exaggerated (actual thickness ~3 cm, roughly equal to the pegmatite vein's thickness). Location: ON-2.

b. Photomicrograph of ragged hornblende clot in recrystallized granite I described in Plate 38a. Thin section ON-2-1b. Bar: 2 mm. Plane polarized light.

PLATE 39.

a. Tectonic recrystallization of granitic mobilizate III sheared by S3. Potash feldspar (dark grey) megacryst is partly enveloped by quartz plates (white). Thin seciton OSF-1. Refer to Fig. 9 for location. Bar: 2 mm. X-nicols.

b. Magnetite rich trondhjemiitc mobilizate III. Twinned plagioclase and serrate quartz (white to dark grey) have interstitial magnetite (black). Refer to Plate 14 for outcrop aspect. Thin section ORM-4-7. Bar: 2 mm. X-nicols.

PLATE 38a.

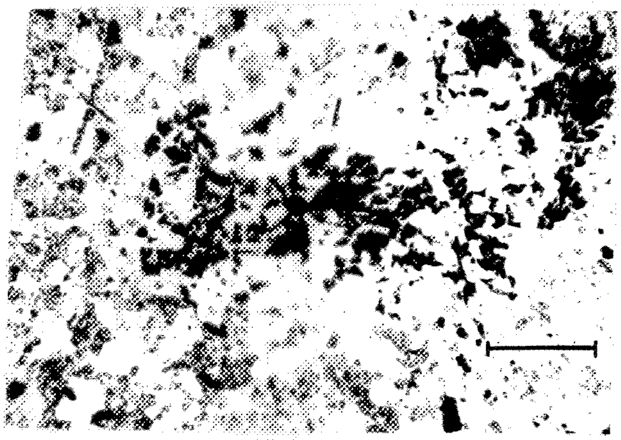


PLATE 38b.

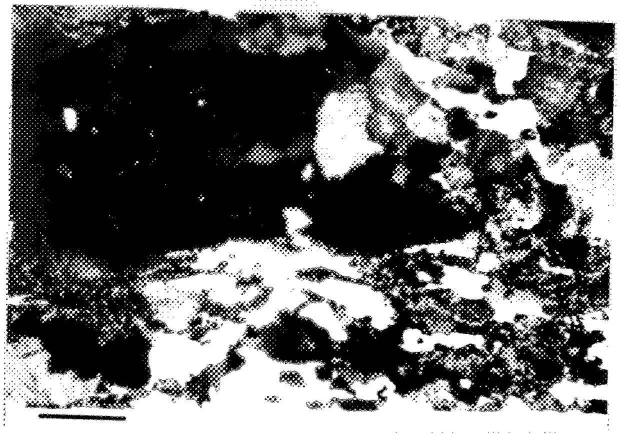


PLATE 39a.

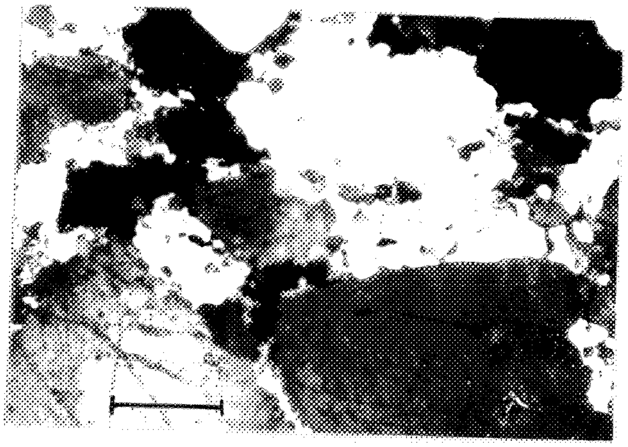


PLATE 39b.

TABLE 11. Mineralogical characteristics of mobilizate III.

Note: all varieties of mobilizate III pegmatites may be found in all rocks of age groups I. II and III. Thus, the pegmatites may be described without considering their host rocks. The veins may be described in terms of their mineralogical end members: granitic (thin sections OS-31-2, ORM-3-5, OSF-1, ON-2-1a,b, ORM-3-7) and trondhjemitic (OS-1- , ON-7-F1b, ON-6-3i,ii, ORM-4-8, ON-6-6.) Recrystallization effects are noted.

	Granitic	Trondhjemitic
Vein/dyke thickness:	2 cm to tens of m	2 cm to a few m
Typical grain size:	2 to 30 mm	2 to 30 mm
Recrystallization Effects		
a) conc. amphibolite:	biotitization	biotitization
b) granite I:	form'n of ragged mafic clots	not seen
c) paragneiss:	biotitization	not seen
K-Feldspar		
Typical grain size:	5 mm	0.5 mm
Grid twin:	common	present
Perthite:	present (patch, string)	absent
Mode of occurrence:	large interlocking irregular grains	small interstitial grains
Plagioclase (twinned)		
Typical grain size:	1 mm	5 mm
Zoning:	none	none
Myrmekite;	common	present
Alteration:	absent to slight	absent to slight
Mode of occurrence:	subidiomorphic grains	subidiomorphic grains
Ratio K-spar/qz/plag	50/40/10	50/45/5

(note: in each case, the ratio of qz:dominant feldspar may vary considerably. The proportion of the subordinate feldspar is ~constant however)

	Granitic	Trondhjemitic
Quartz		
Typical grain size:	5 mm	5 mm
Mode of occurrence:	interstitial masses	interstitial masses
Important Accessory Minerals		
Magnetite:	0 to 15 %	0 to 15 %
Apatite:	0 to 1 %	0 to 4 %
Hornblende, biotite	0 to 2 %	0 to 1 %

Note: mineral grain sizes described are, on average, small, since relatively fine grained pegmatites were sampled for thin section.

TABLE 12. Comparison of mineralogy and mineral proportions shown by recrystallized concordant amphibolite bordering trondhjemitic mobilizate III. Recrystalization zoning in this example is similar to that depicted in Fig. 34. Thin sections ON-6-3 (i,ii).

Zones:
a) Trondhjemitic mobilizate III
b) Biotitized zone
c) Biotitized zone, relatively leucocratic compared with b), and finer grained.
d) Unaltered concordant amphibolite host

Mineral	Zone a)		Zone b)		Zone c)		Zone d)	
	%	mm	%	mm	%	mm	%	mm
Quartz	24.0	10	14.0	2.0	25.9	0.4	8.5	0.4
Plag.	66.0	10	10.6	1.4	36.8	0.6	28.5	0.7
Biotite	5.2	3.6	68.6	7.2	21.8	0.4	3.5	1.0
Hornbl.	-	-	-	-	-	-	54.0	0.6
Opaques	0.2	0.1	-	-	14.5	0.8	5.0	0.4
Apatite	4.2	0.6	6.6	0.5	0.9	0.05	0.5	0.0
K-spar	0.2	0.4	-	-	-	-	-	-
	99.8		99.8		99.9		100.0	

Note: point count data presented in Appendix 1.

V. DISCUSSION

Mechanisms and Possible Conditions of Migmatization in the Study Area

Genetic interpretation of the mesoscopic occurrences, petrography, and modal compositions of the different generations of mobilizates will be based on the method outlined in Table 4. Insofar as the low metamorphic grade parent rocks of the migmatites of the Old Gneiss Complex are unknown, comparison of parent rock-migmatite bulk compositions is not possible, thus , from the outset, it is not possible to distinguish between an open and closed system, sensu strictu, for individual generations of leucosome generation. Rather, the scale dependence of the concept of closed versus open systems is called upon in our arguments, and this is indicated, as discussed at length in sections II and IV, by the observations listed in Table 4, namely, the presence/absence of melanosomes, and mobilizate and plagioclase compositions. Exceptions to a "closed system" environment, on a metre-(outcrop)scale, have been described, and provisions for this are made in Table 4. In fact, distinction between allochthonous and autochthonous leucosomes is amongst the genetic conclusions afforded by research. However, given the scale dependence of the concept, some leeway is justified, and it was possible after preliminary field observations to distinguish between leucosomes of small scale (cm- to m-scale, therefore, essentially autochthonous) mobility and those of clearly intrusive (allochthonous) origin.

Insofar as more data are available for migmatization II leucosomes, these will be evaluated forthwith. The in situ origin of mobilizates II is demonstrated by the mineralogical similarity of these leucosomes with their source paleosome, by the presence of well developed melanosomes, and by melanosome-leucosome plagioclase compositions. Furthermore, from the outset of field examination, it was noted that leucosomes denoted as "mobilizate II" showed a mobility range restricted to a few metres, that is , mobility on an outcrop scale. This corresponds with a closed environment of migmatization, according to our definition above. However, in order to meet the definition of closed system in the strictest sense, we must approach the problem directly. If all the material in the neosome may be volumetrically accounted for by segregating neosome components from the adjacent paleosome, a closed system is indicated. Given a closed system, all leucosome material is generated in and segregated from the adjacent melanosome and/or nearby paleosome. However, melanosome thicknesses are usually greatly exceeded by leucosome volumes, indicating leucosome mobility along the length of the vein. For example, given 1 mm thick melanosomes with a fivefold degree of mafic mineral enrichment over and above the paleosome, we may expect a leucosome thickess not exceeding 1 cm, given a degree of leucocratic mineral depletion in the melanosome roughly equal to the degree of mafic mineral enrichment. However, mobilizate IIc veins commonly attain thicknesses exceeding 10 cm, and are, nevertheless, bordered by melanosomes <5 mm in thickness. As also demonstrated by discordant offshoots from melanosome-seamed concordant veins (Plate 17e), mobilizate II material is clearly mobile on a decimetre to metre scale. Therefore, for vein morphologies, melanosome-leucosome mass transfer calculations are generally not applicable. In one location in the St. Fulgence paragneiss sequence, an isolated zone in arkosic quartzite shows evidence of preferential migration of the feldspar component of the arkose, which segregates to form coarse grained granitic pegmatoid. The pegmatoid is surrounded by a continuous quartzite zone leached of feldspar: this may be considered to be a restite zone (Plate 40). As such, this isolated pegmatoid is ideal material for a mass transfer calculation.

Figures 35a,b are reduced representations of photographic enlargements of thin sections ON-3-F4a,b, sampled from the arkosic quartzite and leached quartz illustrated in Plate 40. From these photographic enlargements, the volume % of feldspars in each thin section was determined by measuring the surface area covered by

PLATE 40.

Formation of granitic pegmatoid clot in arkosic quartzite. The leached zone surrounding the pegmatoid is roughly outlined. Location: ON-3. Bar: 10 cm. See text.

FIGURE 36.

Sketch of photographically enlarged thin sections of arkosic quartzite (ON-3-F4a) and leached quartzite (ON-3-F4b), illustrated in Plate 40.

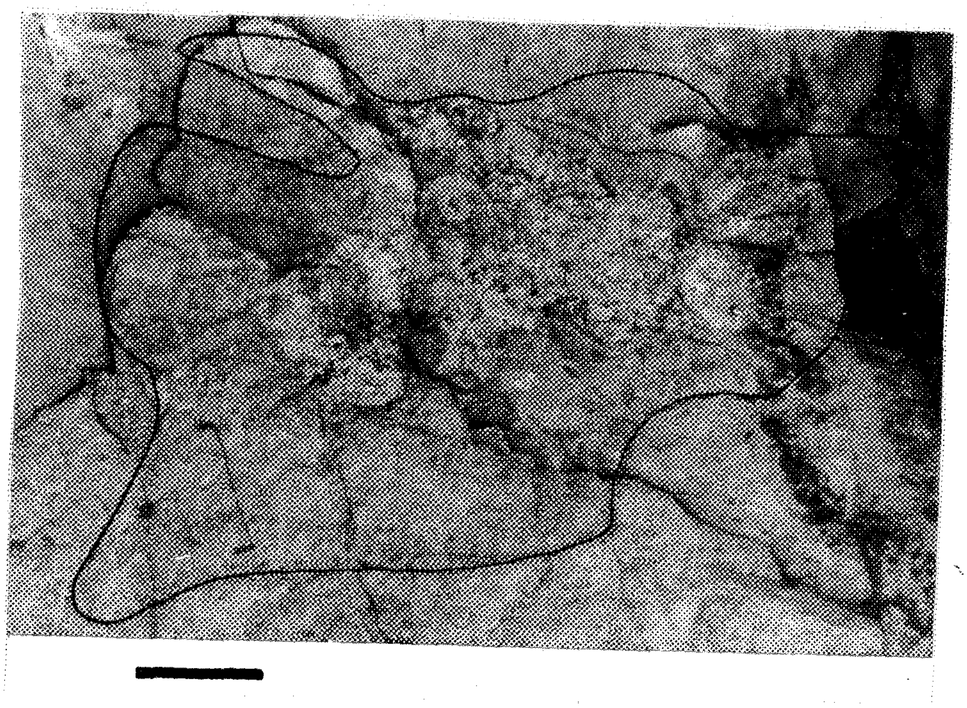


PLATE 40.

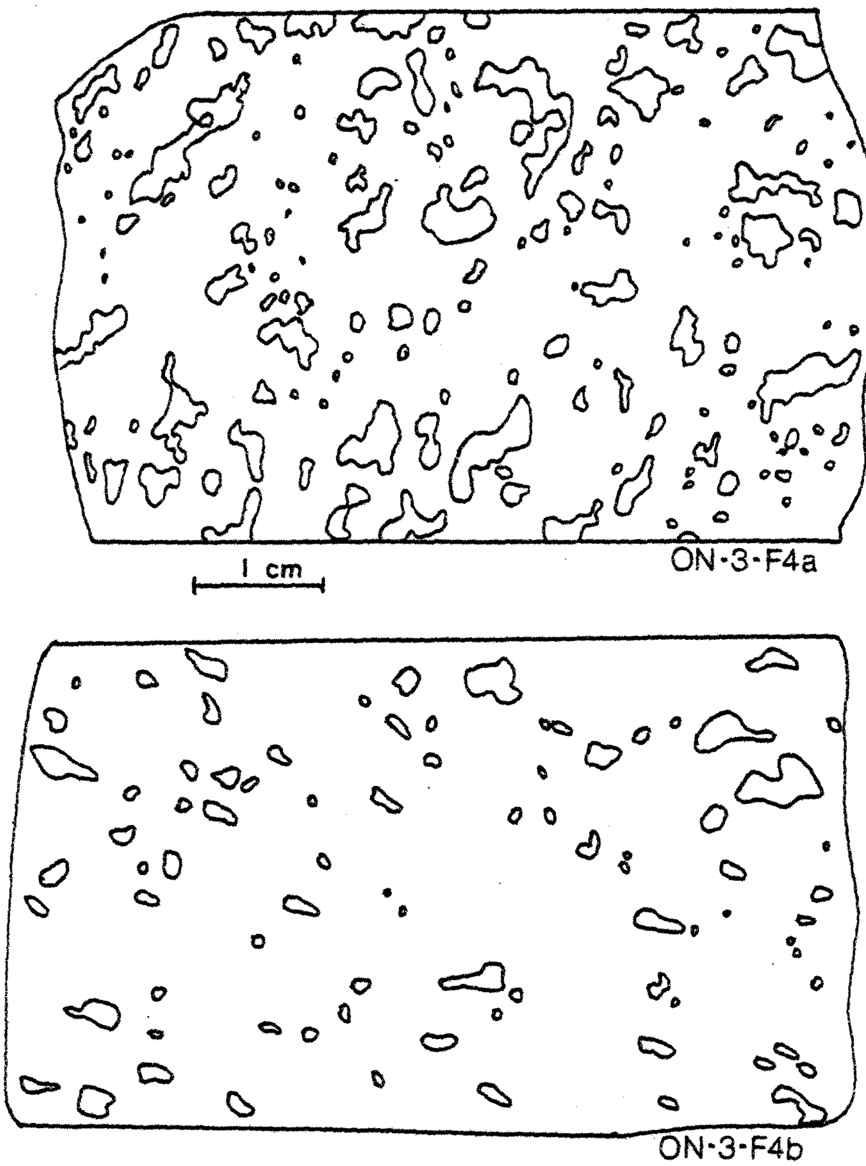


FIGURE 36.

feldspars and comparing this result with the thin section area. The method has been shown to be accurate to within 0.5% (Dimroth and Owen, 1979, unpublished data). By this method, it is seen that the host arkosic quartzite, as represented by thin section ON-3-F4a, contains 14.4% total feldspar. The leached quartzite surrounding the pegmatite core (Plate 40) contains 5.9% total feldspar. Although quartz may be easily distinguished from potash feldspar in the pegmatite (Plate 40), not all of the quartz may be recognized in the photograph, therefore the present method is not applicable. However, the potash feldspar content of the pegmatitic mass is visually estimated at 60% (ie. 40% quartz).

From an 8" x 10" enlargement of Plate 40, and after conversion to outcrop scale, it is seen that the leached zone has an outcrop surface area of ~1,224 sq. cm., and the pegmatite has an area of ~427 sq. cm. The accuracy of these determinations relies, of course, on the precision of the line delineating the leached zone from the arkosic quartzite. Although the two zones are quite distinct, based on feldpar content, the contact between the two is fairly diffuse.

The total difference of feldspar content between the host arkose and the leached quartzite within the restite zone is given by:

(1) (14.4 - 5.9) / 100 X 1,224 = 104 sq. cm.

Referring to Plate 40, it is clear that the leached zone of quartzite ("restite") envelopes the mobilizate. It is reasonable to assume that the thickness of this restite zone, measured along lines radiating from the centre of the mobilizate, is statistically controlled by the diffusion constant of the migrant leucocratic minerals. Also, mobilizate thickness is controlled by the quantity of material diffused along any given direction. As such, the geometry of the mobilizate is not controlled by structures in the paleosome (Plate 40; no structural control on mobilizate localization is apparent). In this case, the volume enclosed by the restite is simply an enlargement of that enclosed by the mobilizate. These volume relations may be described as follows:

(2) $$\frac{\text{Volume (restite + mobilizate)}}{\text{Volume (mobilizate)}} = \frac{V1 + V2}{V2} \sim f^{3}$$

where "f" is the linear enlargement factor.

Assuming that the outcrop surface depicted on Plate 40 is representative of any two-dimensional section through the neosome, we have:

(3) $$\frac{\text{Surface (restite + mobilizate)}}{\text{Surface (mobilizate)}} = \frac{S1 + S2}{S2} \sim f^{2}$$

Substituting with values obtained from the photographic enlargement of Plate 40, we now have:

(4) $$V1 \sim \left(\frac{1651}{427}\sqrt{\frac{1651}{427}} - 1\right) V2 \sim 6.6\ V2$$

Furthermore: (5a) $$\text{Volume (feldspar extracted from restite)} = V'1 = \frac{14.4 - 5.9}{100}\ V1$$

(5b) $$\text{Volume (feldspar in mobilizate)} = V'2 = \frac{60}{100}\ V2$$

Dividing and substituting values from (4) we have:

(6) $$\frac{V'1}{V'2} \sim \frac{(14.4 - 5.9)}{60} \times 6.6 \sim 0.93,$$ that is, ~93 % of the theoretical volume of mobile feldspa

This result demonstrates that the system was closed to the mobile components constituting mobilizate II.

A concordant offshoot from a cross-cutting coarse grained mobilizate IIc pod generated in granite I late during migmatization II is seen to have melanosome plagioclase (An 28) considerably more calcic than leucosome plagioclase (An 12-15). In conjunction with other features noted above, we are led to conclude that polyphase mobilizate II leucosomes are anatectic in origin. This conclusion is in accordance with the demonstrated fluid nature of mobilizate II leucosomes, the recrystallization of host rocks by mobile mobilizate II veins, and the clustering of the leucocratic mobilizate components about the cotectic of the system albite-quartz-orthoclase (Fig. 37).

This conclusion may be independantly verified by considering the metamorphic conditions prevalent during migmatization II. Sample OBH-1, from the Ha! Ha! Bay paragneiss sequence (Fig. 1), contains the paragenesis garnet-cordierite-sillimanite-quartz-microcline-(biotite) (Plate 41a). Figure 38 outlines the positions of phase boundaries of mineral assemblages of this paragenesis; these phase boundaries are sensitive to the Mg/Mg + Fe ratio of ferromagnesian minerals in the paragenesis (Hensen and Green, 1971), consequently, given the Mg:Fe ratio of cordierite, the PT conditions of the above mineral assemblage may be estimated. A straight line relationship exists betweeen different cordierite compositions and the β refractive index (Miyashiro, 1957). The β refractive index of cordierite from sample OBH-1 was determined to be 1.546 by oil immersion. Although the powdered cordierite contained quartz, the two minerals are easily distinguished since the cordierite contains penetration twins, and has, of course, a biaxial optic-axis figure for β sections. This corresponds with an Fe content of approximately 40% for metamorphic cordierites (Fig. 39). The paragenesis garnet - cordierite - sillimanite - quartz - microcline - (biotite) in thin section OBH-1 shows evidence of prograde-retrograde reactions. Both the paleosome and leucosome (mobilizate IIa) show similar textural features. Two types of almandine (almandine-pyrope?) garnet are present: an earlier generation of garnets, completely altered to chlorite, subsequently to sericite. and larger, more abundant porphyroblastic garnets, with inclusions of sillimanite, quartz, and opaques + dark green isotropic spinel (Plate 41a). There is good textural evidence for the retrograde reaction (Fig. 38, curve 3):

(7) cordierite + almandine + K-feldspar + V-----> biotite +
quartz + sillimanite

Here, the forward reaction products occur as platy intergrowths of biotite and quartz (Plate 41b), and sillimanite and quartz (Plate 41c). An earlier generation of sillimanite is indicated insofar as idiomorphic sillimanite crystals locally occur as inclusions in biotite-quartz platy intergrowths (Plate 41) and in porphyroblastic garnet. As such, considerable quantities of sillimanite survived the prograde (reverse) reaction (7), above, by being isolated in garnets and, to a lesser extent feldspar and biotite. The virtual absence of muscovite, and the predominance of K-feldspar and sillimanite in the paragneisses indicate the source of this early sillimanite: the reaction (Fig. 36, curve 2)

(8) muscovite + quartz-----> K-feldspar + aluminosilicate + V

The small amounts of muscovite locally seen in the paragneisses is of retrograde origin. Locally, muscovite forms by pressure-solution alteration between mortar-textured garnet or feldspar porphyroblasts, or by sericitization of feldspar, or chlorite. Reaction (8) sillimanite is common in melanosomes bordering mobilizate I veins in the paragneiss.

A relict of the retrograde reaction (7) is illustrated as Plate 41d. Here, garnet porphyroblasts mimic the retrograde biotite-quartz platy intergrowths. These same garnets may contain retrograde biotite (Plate 41e).

As such, the anatectic conditions responsible for migmatization II fall close to the reaction (7) phase boundary as shown in Fig. 37 (curve 3). Given a cordierite Fe-content of approximately 40%, we conclude anatectic conditions in the order of 750 to 800 C, at about 5.5 kb.(1) These conditions represent a culmination of metamorphism in the study area. Retrograde mineral reactions affecting parageneses formed in equilibrium during peak metamorphic conditions include, in addition to reaction (7), the subsolidus transformation of anatectic (?) clinopyroxene to an intergrowth of hornblende and quartz (Plate 25) in concordant amphibolite, the mantling of orthopyroxene by hornblende in charnockite (Plate 10),

---

(1) These represent maximum PT conditions. PH_2O may well have been less than Ptotal: for PH_2O = 0.4 Ptotal, T ~ 700-750°C, P ~ 5 kb for this composition of cordierite. The survival of prograde sillimanite (reaction 8) during/following mobilization II suggest low PH_2O, by virtue of the lack of sillimanite muscovitization by reaction with $K^+ + H_2O$. K-feldspar rich mobilizates II indicate a high K^+ activity; aqueous fluids liberated during mobilization II may have largely been taken up as fluid inclusions in quartz and feldspar and in hydrating pyroxenes.

exsolution features and the mantling of microcline by albite juxtaposing oligoclase (Plate 23a), and various alteration processes: incomplete biotitization , chloritization, uralitization, and saussuritization. Equally important is the partial tectonic recrystallization of paleosome and neosome components of rocks of age groups I and II, leading variously to the development of granoblastic, mortar, augen, and flaser textures (Table 7).

Wyllie (1977, p. 65) has demonstrated that, "in the presence of excess H20, curves for the beginning of melting of granite, tonalite and gabbro (amphibolite)...are not widely separated, and they are exceeded by most of the paths of metamorphism". Consequently, given the proposed anatectic origin of mobilizate II segregations in rocks of age groups I and II, one may tentatively conclude that the trondhjemitic mobilizate II leucosomes in concordant amphibolite, and in some dyke amphibolites, are also anatectic. However, a metamorphic segregation mechanism may not be excluded, since, as indicated in section III, anatexis of rocks relatively poor in potassium nevertheless yields partial melts which crystallize considerable quantities of potash feldspar. Helz (1976) describes the partial melting of tholeiite, olivine tholeiite, and alkaline basalt at 5 kb, 680 to 1,045 C, at f02 of the quartz-fayalite-magnetite and the hematite-magnetite buffer. Except for Na/Ca ratios, the composition of the partial melts does not vary considerably with the bulk composition of the starting material for degrees of partial melting <70%. Basalts and amphibolites devoid of potash feldspar yield first partial melts generated from the sodic and potassic components of paleosome plagioclase (Wyllie, 1977). Significant melting of hornblende, at pressures of 5 kb, does not occur until ~1,000 C (Helz, 1976). The invariable presence of both hornblende and biotite in autochthonous concordant amphibolite leucosomes demonstrates that PT conditions attained during migmatization II lay within the stability fields of both minerals in this lithology. Textural evidence suggests that all biotite in concordant amphibolite is primary, and the survival of hornblende during migmatization is indicated by the rarity of clinopyroxene and the absence of olivine, both which would be common had reaction (9) taken place on a widespread scale.

(9) hornblende (a)-----> hornblende (b) + augite + olivine + melt
(Wyllie, 1977; Helz, 1976)

Although olivine is indicated in the forward reaction, it becomes a significant product only in advanced stages of melting (Wyllie, 1977), therefore its absence within amphibolites in the study area does not preclude the possibility that the clinopyroxenes locally seen in mobilizate II (Plates 25 and 30) are anatectic. The demonstrated presence of retrograde biotite in mobilizate II in paragneiss (Plate 41b) indicates that in all rocks excepts amphibolites, anatexis was initiated by prograde dehydration reactions, resulting in anhydrous equilibrium mineral assemblages at the height of metamorphic conditions (eg. garnet-sillimanite-cordierite-quartz-feldspars). Excess water conditions during migmatization II are not indicated for concordant amphibolite. At 5 to 6 kb, the melting interval for amphibolite below the hornblende-out curve is from about 750 to 1,000 C, with the inception of clinopyroxene at about 960 C (Wyllie, 1977, Fig. 8). Within this field, hornblende + plagioclase + melt + V coexist, with plagioclase exiting at about 900 C. Without excess water, but with sufficient water to maintain hydrous minerals in the amphibolite, at 5 kb small quantities of water-undersaturated melt are generated at about 950 C, clinopyroxene being introduced at this point, and hornblende exiting at about 1,000 C (Wyllie, 1977, Fig. 9). These latter conditions do not produce the mineral assemblages commonly seen in concordant amphibolite leucosomes. Consequently, it may be concluded that migmatization II in the study area produced leucosomes in concordant amphibolite whose composition was controlled by the plagioclase and lesser amounts of quartz in the paleosome. Except for clinopyroxene bearing leucosomes, a process of metamorphic segregation is indicated for amphibolites during migmatization II. This is further substantiated by the quartz-rich nature of these mobilizates (Fig. 37), given the quartz-poor amphibolite paleosome.

Having considered the origin of migmatization II leucosomes, the genesis of mobilizate I may now be discussed. As indicated in Fig. 37, mobilizate I veins show marked differences in plagioclase:potash feldspar contents in different paleosomes. Furthermore, these points do not cluster near the granitic minimum melting cotectic shown superimposed on the plagioclase-quartz-potash feldspar diagram (Fig. 37). Unfortunately, melanosomes are poorly developed in most mobilizate I neosomes, therefore a comparison of the albite content of melanosome plagioclase with leucosome plagioclase could not be undertaken. Nevertheless, the quartz-plagioclase-(microcline) rich nature of mobilizate I in granite I, compared with the quartz-microcline rich mobilizate IIa material within the same sample (ON-2-6) indicates that these two generations of leucosomes have different origins. More specifically, in the absence of compositional and morphological data afforded by mobilizate II material, we may tentatively ascribe a process of metamorphic segregation for generating mobilizate I veins. As in the case of mobiliate II, an in situ origin is reflected by the presence of relict melanosomes, and the compositional similarity between leucosomes and paleosomes. Thus, while granodioritic veins occur in granite I, trondhjemitic veins occur in concordant amphibolite. Note the similarity of mobilizate I and II compositions in amphibolite (Fig. 37; only the quartz : plagioclase ratio varies). Equilibrium metamorphic mineral assemblages formed during migmatization I appear to have survived subsequent anatectic conditions, insofar as only the mobilizate II component of any gneiss is, as a result of crystallization from a partial melt, coarse grained. As a consequence of polygonization of mineral mosaics by tectonic recrystallization, the spatial distribution of mobilizate I grains is not genetically significant, therefore the type of investigation proposed by Kretz (1966, 1969) is not applicable to this material. However, the presence of sillimanite as the dominant melanosome mineral, and its sporadic occurrence in mobilizate I in paragneiss, indicates that the prograde reaction (2) occurred during or prior to mobilizate I genesis. The absence of granoblastic garnet and cordierite, and the presence of prograde biotite indicate that PT conditions of reaction (7) were not attained. Therefore, subanatectic conditions of ~650 to 700 C and 3.5 to

4.5 kb are indicated for migmatization I, as represented schematically on Fig. 38. Thus, migmatization I may be placed within the framework of a major period of prograde metamorphism and related deformation, spanning deformations I to IIc (Table 1).

Allochthonous leucosomes include mobilizate III pegmatites and granitoids, and relatively rare microcline-bearing quartz rich veins seen in some amphibolite dykes (eg. Table 9-4). The quartz rich nature of the latter indicates a possible origin by external metasomatism (Table 4). However, the extreme rarity of such veins indicates that this mechanism was operative on a very restricted scale. On the other hand, mobilizate III pegmatites and granitoids are clearly intrusive (Plate 42). The compositional range of these intrusives, from granitic to trondhjemitic, and the local occurrence of cross-cutting pegmatites, and pegmatites-granitoids (Fig. 22) indicate polyphase mobilizate III injection. A plutonic source for this material has not been identified, however, the large volumes of granitic pegmatite along the eastern part of the ON-section demonstrates the volumetric importance of mobilizate III, and indicate mobility of considerable scale, possibly in the kilometre range. Morphologically, mobilizate III pegmatites do not create the typical features of migmatitic terrains: veined gneisses, agmatites, nebulites etc. are not seen. Nonetheless, the effects of pegmatite injection are widespread. Paleosomes and inclusions are cross-cut and recrystallized. Granulite-grade mineral assemblages (eg. orthopyroxene-bearing assemblages) are absent from mobilizate III leucosomes, therefore pegmatite injection probably occurred at amphibolite or upper amphibolite grades, reflecting diminishing metamorphic conditions following the culmination during migmatization II.

PLATE 41. Textures of the paragenesis garnet-cordierite-microcline, retrograding to biotite-sillimanite-quartz, in paragneiss. Thin section OBH-1. Plane polarized light except for 41a. All bar scales are 1 mm. All photos from mobilizate IIa except for 41b (paleosome).

a. Overview of the mineral assemblage garnet (g), cordierite (c), sillimanite (s), quartz (q), perthitic microcline (p), and biotite (b). M=myrmekitic intergrowth of quartz and plagioclase. Biotite at upper right of photo shows same retrograde platy quartz-biotite intergrowth as shown in 41b. Note prograde (reaction 2, see text) sillimanite inclusions in garnet. Some garnet porphyroblasts have been outlined to aid distinction from extinct cordierite, perthite, and quartz.

b. Retrograde platy quartz-biotite intergrowth. Note inclusions of prograde sillimanite. "Hollow" sillimanite cross sections contain quartz, and are probably retrograde (reaction 7, see text).

c. Platy sillimanite-quartz intergrowth. This is probably a longitudinal section of "hollow" sillimanite cross sections as seen in 41b.

d. At left in photo, garnet (dark grey) contains streaks of quartz (white), thereby mimicking the biotite (even grey)-quartz platy intergrowth at extreme left. At right centre of photo is sillimanite (medium speckled grey).

e. Sillimanite (medium speckled grey) inclusions in garnet (dark grey). Retrograde biotite (even grey, basal cleavage) is seen in garnet.

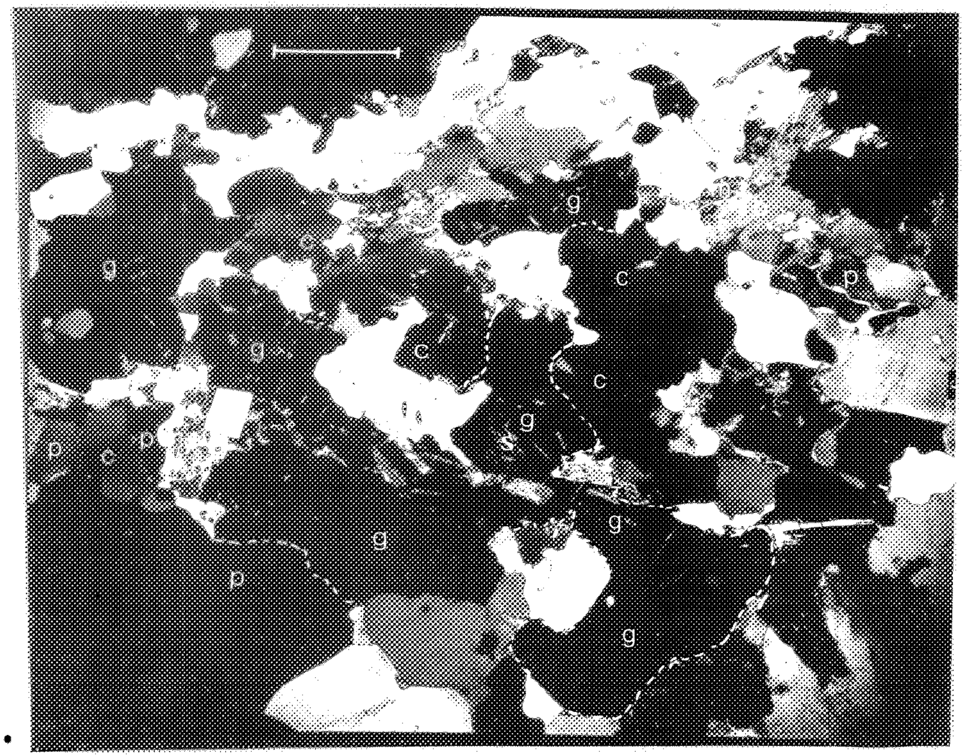


PLATE 41a.

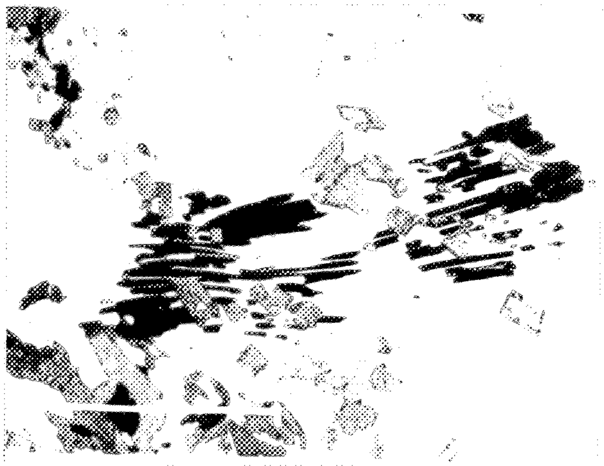


PLATE 41b.

PLATE 41c.

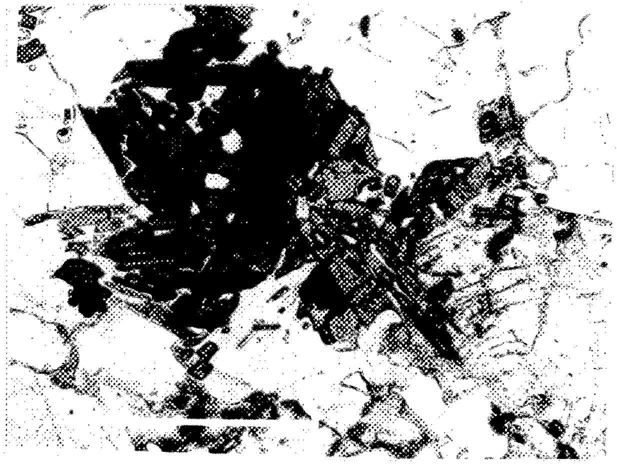


PLATE 41d.

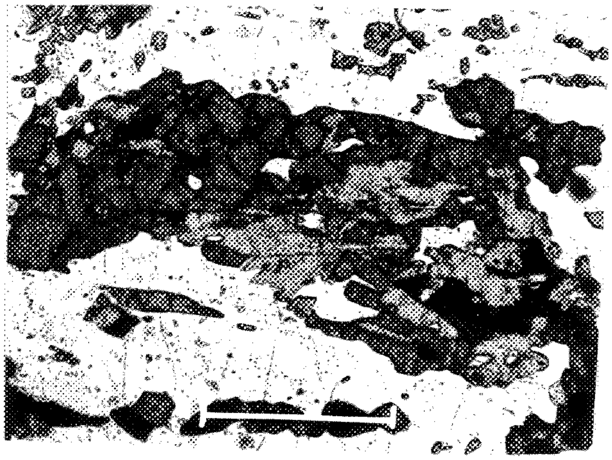


PLATE 41e.

FIGURE 37.

Quartz-plagioclase-potash feldspar ratios of mobilizates I and IIa in different paleosomes. Superimposed on the graph is the cotectic of the hydrous artificial system quartz-albite-anorthite-orthoclase (Winkler, 1979). The cotectic passes through the composition of mobilizate IIa in granite I, which contains sodic oligoclase. In the absence of analyses of these leucosomes, it can nevertheless be seen that mobilizate IIa leucosomes cluster near the cotectic, whose position is highly pressure dependant. Note that concordant amphibolite leucosomes fall on the plagioclase-quartz join. The quartz-albite-potash feldspar (H_2O) system does not, in itself, adequately explain natural rock partial melting: missing is the anorthite component, however, given a range of plagioclase compositions for leucosomes of different parentage (ie albitic oligoclase in granitic gneiss leucosomes to labradorite in amphibolite leucosomes), it is useful to compare quartz:feldspar contents of leucosomes for different paleosomes on the same two-dimensional diagram. Winkler's cotectic is determined at $P(H_2O)=5$ kb; temperatures noted on graph.

FIGURE 38.

Proposed anatectic conditions operative during migmatization II (heavy stippling). Schematic representation of tentative metamorphic conditions of migmatization I is shown as fine stippling. Curves 1 and 4 after Dallmeyer and Dodd (1971). Curves 2 and 3 after Holdaway and Lee (1977). Note that the position of curve 4 is highly variable, according to whole rock composition, $P(H_2O)$, $P(CO_2)$, etc. See text for explanation.

FIGURE 39.

Approximate iron content of cordierite from the paragneiss sequence at Ha! Ha! Bay. A β refractive index of 1.546 was determined by oil immersion. Graph after Miyashiro, 1957, for metamorphic cordierites. Cordierite from a sample of paragneiss provided by G. Woussen from ORM-2 has a β refractive index of 1.546 + 0.001. This method provides but a rough estimate of cordierite Fe:Mg ratio, since the β refractive index varies with the contained water content.

PLATE 42.

Cross-cutting granitic pegmatite dykes (mobilizate III), just west of the ON section.

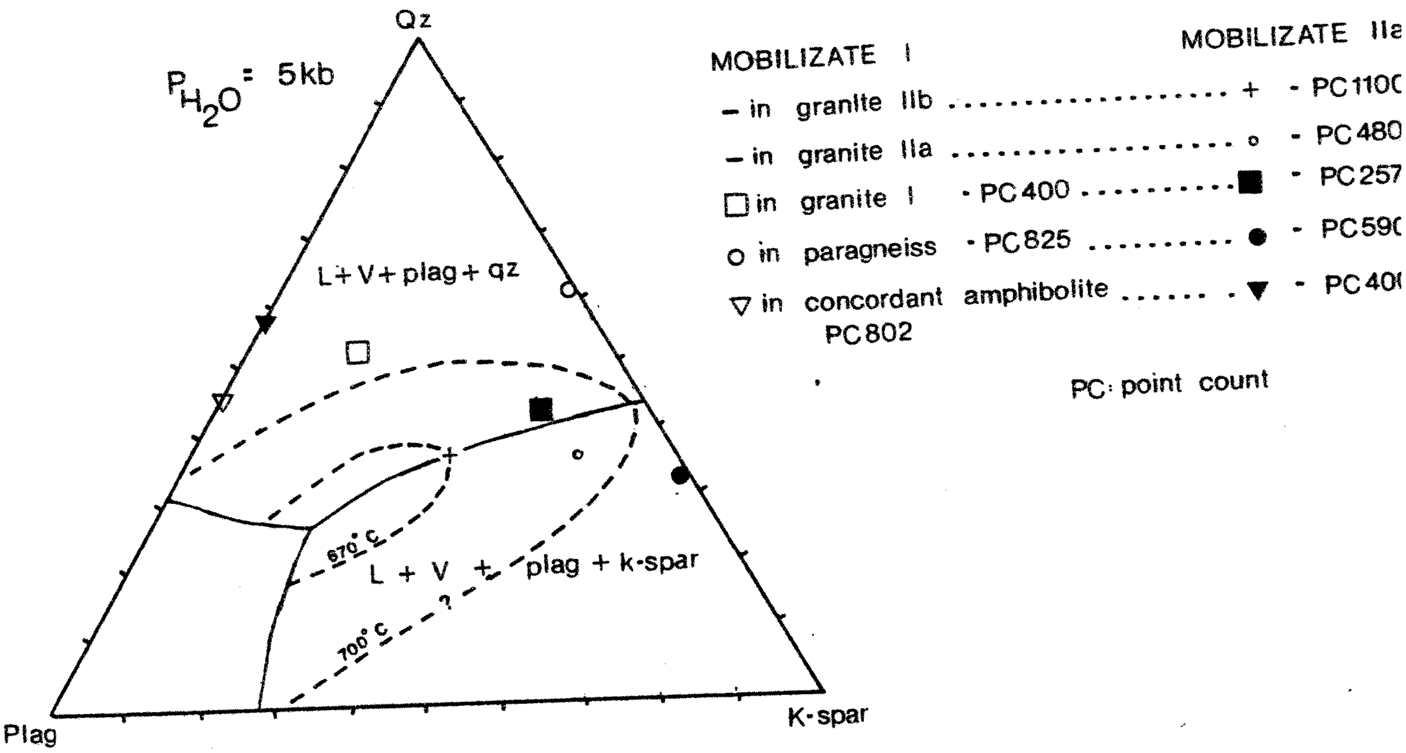

Qz
P_{H_2O} = 5kb
L+V+plag+qz
L + V ± plag + k-spar
670° C
700° C
?
Plag
K-spar
MOBILIZATE I
MOBILIZATE IIa
– in granite IIb .... + - PC110
– in granite IIa .... ∘ - PC480
□ in granite I - PC400 .... ■ - PC257
○ in paragneiss - PC825 .... ● - PC59
▽ in concordant amphibolite ...... ▼ - PC40
PC802
PC: point count

FIGURE 37.

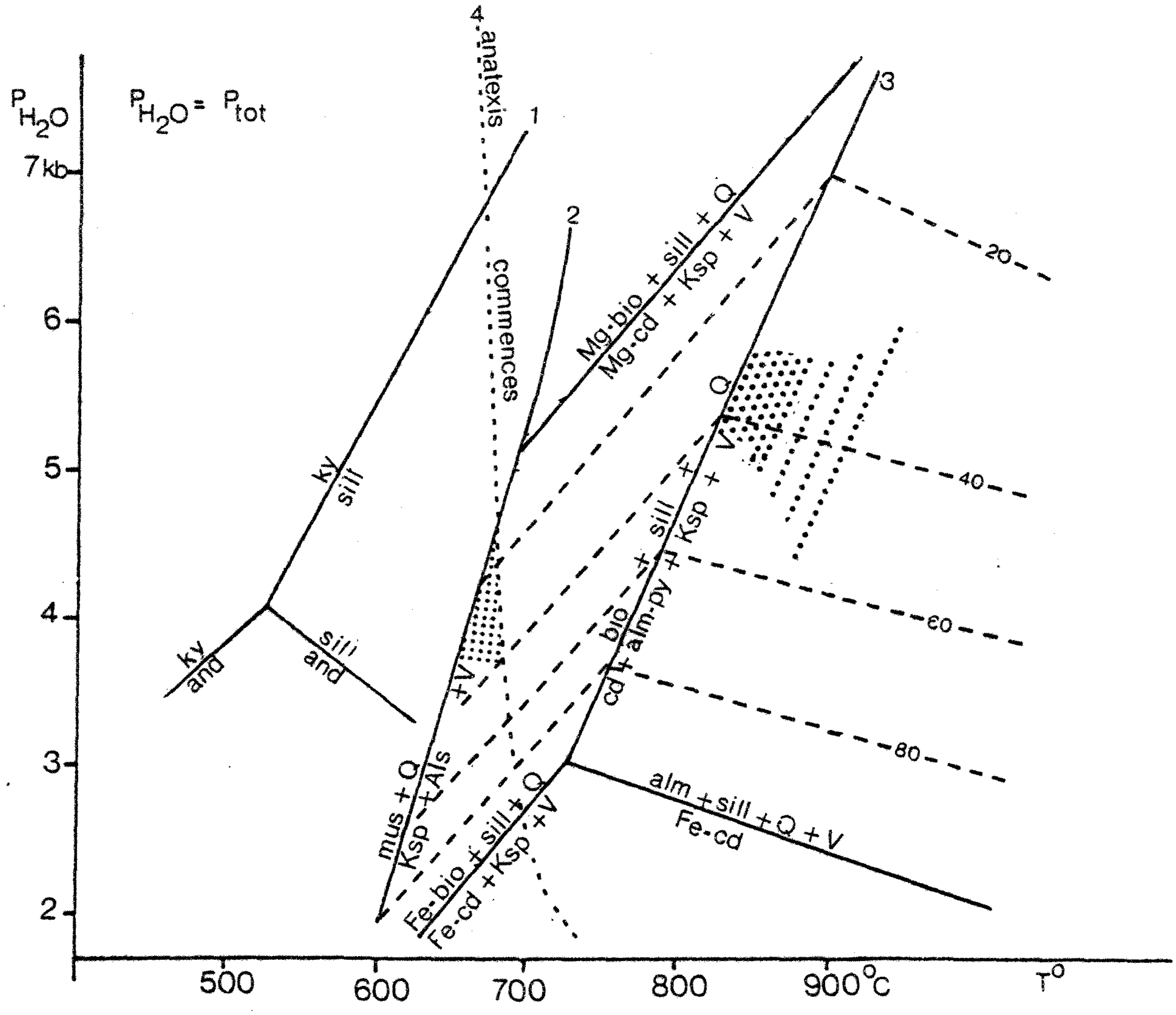

P_{H_2O}
$P_{H_2O} = P_{tot}$
7 kb
6
5
4
3
2
500
600
700
800
900°C
T°
1
2
3
4
anatexis
commences
ky
sill
ky
and
sill
and
Mg-bio + sill + Q
Mg-cd + Ksp + V
mus + Q
Ksp + Als + V
Fe-bio + sill + Q
Fe-cd + Ksp + V
bio + sill + Q
cd + alm-py + Ksp + V
alm + sill + Q + V
Fe-cd
20
40
60
80

FIGURE 38.

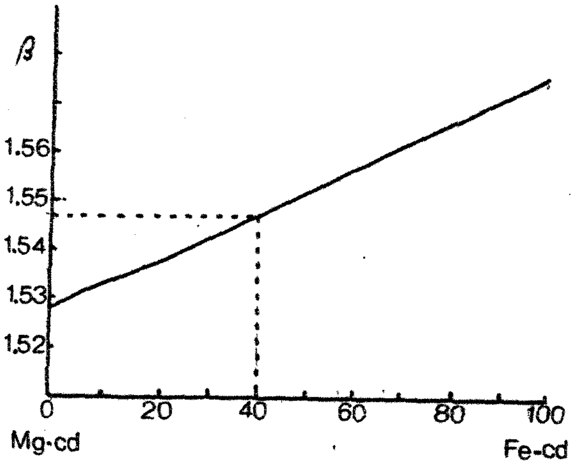


FIGURE 39.

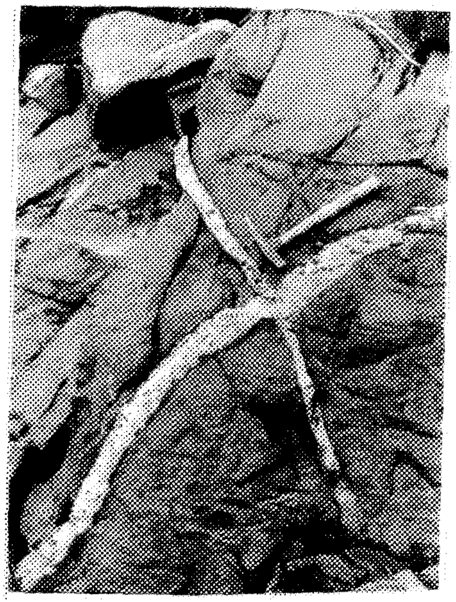


PLATE 42.

VI. CONCLUSIONS

Mechanisms and Possible Conditions of Migmatization in the Study Area

Three periods of leucosome generation may be recognized in rocks of age groups I and II of the migmatitic Old Gneiss Complex. Recognition of different mobilizate generations relies on cross-cutting relationships and the relation of mobilizate localization to tectonic structures in paleosomes and host rocks. Petrographic parameters may be summarized on the basis of a limited number of these observations, so recognition of different generations of mobilizates may be extrapolated to the general case.

The presence of relict melanosomes, and the similarity of leucosome and paleosome mineralogy indicate that mobilizate I formed in situ. These leucosomes do not approximate minimum melt compositions expected from their various paleosomes, therefore it is suggested that mobilizate I veins are products of metamorphic segregation.

Migmatization II consists of polyphase leucosome mobilization. Early mobilizate II veins (mobilizate IIa) are localized in flexural openings of the dominant S2a schistosity in the study area. These veins are tightly folded by F2b. Mobilizate IIb veins are localized along strain slip shear surfaces paralleling axial planes of F2c folds which refold F2b. The last leucosomes mobilized during migmatization II form coarse grained discordant pods which cross-cut F2b folds and S2c axial surfaces. These mobilizate IIc pods have concordant offshoots which, like mobilizate IIa, have well developed melanosomes. From one of these veins, melanosome plagioclase is markedly more calcic than plagioclase in the adjacent leucosome. This fact, coupled with the fluid nature of mobilizate II leucosomes, which not uncommonly form discordant veins and may infiltrate brecciated interbands occurring locally in their paleosome source rocks, indicates that these segregations are anatectic. The similarity of leucosome mineralogy with expected minimum melt compositions generated from their respective paleosomes, and mass transfer considerations support this conclusion, indicating anatexis in a closed system. Mobility of leucosomes ranges from a few centimetres to several metres. Conditions of anatexis may be estimated from the paragenesis cordierite-garnet-microcline, retrograding to biotite-sillimanite-quartz. The cordierite has an Fe:Mg ratio of ~4:6, therefore, migmatization II conditions are believed to have been in the range of 750 to 800 C, at about 5.5 kb (15 to 20 km). With the exception of refractory amphibolites, anatexis was initiated by dehydration reactions. Concordant amphibolite leucosomes are trondhjemitic, and formed largely by metamorphic segregation within the stability boundaries of biotite and hornblende. The latter mineral locally breaks down to clinopyroxene+(?)melt, indicating peak anatectic conditions, developed locally, exceeding 800 C, still at 5 to 6 kb. However, even where anatexis was locally achieved, plagioclase and quartz controlled partial melt compositions: no potash feldspar was generated by the breakdown of amphibolite hornblende under anatectic conditions. It may be concluded that amphibolites for the most part segregated mobilizate II leucosomes by the process of metamorphic segregation while granitic rocks and paragneisses concomitantly suffered partial melting during migmatization II.

Mobilizate III consists of granitic to trondhjemitic pegmatites and granitoids, clearly of polyphase and allochthonous origin. These appear to have been injected after the culmination of metamorphic conditions, corresponding to migmatization II.

Placed within a regional framework, the clue to the tectonic environment of multiple migmatization seen in the study area lies in the evidence for a major period of extension, corresponding with injection of dyke rocks, followed by regional compression and anatexis. Such a tectonic environment may be represented by back island arc tensional zones, or, perhaps more likely, by crustal doming (extension) followed by compression (plate collision?). Further light will be shed upon this issue as the tectonic significance of the genesis and diapirism of the Grenville anorthosite-mangerite suite is determined.

VII. FUTURE WORK

A considerable amount of work is required to permit concise definition of the physical-chemical environment and controls of partial melt compositions during migmatization II. Specifically, particular attention should be placed on determining mineral compositions in the paleosome-neosome components of the migmatites. Determination of the relative compositions of key minerals-hornblende, clinopyroxene, plagioclase-provide s a strong indication of which minerals were included in anatectic processes, and the role(s) they played therein. Bulk analyses of leucosomes projected on the An-Ab-Qz-Or-(H2O) quaternary diagram may further confirm an anatectic origin for mobilizate II leucosomes. Analysis of solid solution minerals, especially cordierite, affords good control on estimates of PT(X) metamorphic conditions.

It is unlikely that much progress may be made concerning the origin and conditions of formation of mobilizate I leucosomes. Resolution of this problem should probably proceed by comparison with mobilizate II leucosomes formed in the same paleosomes. Neither is it likely that a better understanding and definition of early tectonic structures (F1 or earlier) is possible, at least within the study area. However, better exposures may occur elsewhere; G. Woussen has indicated that early nappe-like folds may be present in the Old Gneiss Complex. Analysis of these early folds should focus on deformation features shown by mobilizate I veins, which record and identify the oldest structures in the migmatities.

Finally, in the long run, the goal of this, and other research, should be to determine a plausible and preferred origin for the Grenville province. The resolution of this problem may lie both in determining the tectonic setting of the proposed anatectic conditions described in this report, and the relation of this environment to the generation of the plutonic bodies-anorthosite, mangerite, charnockite-typifying the Grenville province.

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APPENDIX 1: Point count results.

Material	Section	Mineral	Count	%	Where undertaken	
					Add'l Count	Total %
Granite IIb						
paleosome	OS-11-4	qz	176	34.9		
		K-sp	110	21.8		
		plag	128	25.4		
		bio	78	15.5		
		opq	11	2.1		
			503	99.7		
mobilizate IIa		qz	263	40.5		
		K-sp	309	47.5		
		plag	78	12.0		
		bio	-	-		
			650	100.0		
paleosome	OS-25-F1a	qz	129	28.6		
		K-sp	160	35.5		
		plag	116	25.7		
		hbl	45	10.0		
			450	99.8		
mobilizate IIa		qz	143	31.2		
		K-sp	91	20.2		
		plag	191	42.4		
		hbl	25	5.5		
			450	99.3		
Granite IIa						
paleosome	OS-20-1	qz	83	35.3		
		K-sp	96	40.8		
		plag	42	17.8		
		bio	14	5.9		
			235	99.8		
mobilizate IIa		qz	180	37.5		
		K-sp	241	50.2		
		plag	57	11.8		
		bio	2	0.4		
			480	99.9		
Charnockitic gneiss	ORM-3-8	qz	209	26.1		
		K-sp	428	53.4		
		plag	64	8.0		
		opx	72	8.9		
		bio	10	1.2		
		hbl	9	1.1		
		opq	9	1.1		
			801	99.8		

Material	Section	Mineral	Count	%	Where undertaken	
					Add'l Count	Total %
Granite I						
paleosome	ON-1-1	qz	339	33.9	343	33.9
		K-sp	362	36.2	318	33.8
		plag	232	23.2	296	26.3
		hbl	46	4.6	31	3.8
		bio	4	0.4	2	0.3
		opq	17	1.7	17	1.7
			1000	99.9	1007	99.8
mobilizate IIa		qz	239	43.4	42	43.2
		K-sp	202	36.7	38	36.9
		plag	105	19.1	19	19.0
		hbl	4	0.7	1	0.7
			550	99.9	100	99.8
melanosome "a" (Fig. 29)		qz	377	47.0	94	47.1
		K-sp	83	10.3	26	10.9
		plag	114	14.2	26	14.0
		mafics:	227	28.3	53	28.0
			801	99.9	199	100.0
melanosome "b" (Fig. 29)		qz	322	40.2		
		K-sp	157	19.6		
		plag	278	34.8		
		hbl	43	5.4		
			800	100.0		
mobilizate IIa	OS-1-2b	qz	437	40.7		
		K-sp	484	45.0		
		plag	41	8.2		
		hbl	24	6.0		
			1074	99.9		
melanosome		qz	308	38.4		
		K-sp	49	6.1		
		plag	216	26.9		
		hbl	49	6.1		
		bio	126	15.7		
		opq,sph	54	6.7		
			802	99.8		

Material	Section	Mineral	Count	%	Where undertaken	
					Add'l Count	Total %
Granite I (cont'd)						
mobilizate I	ON-2-6	qz	154	38.5		
		K-sp	144	36.0		
		plag	97	24.3		
		mafics:	5	0.1		
			400	98.9		
mobilizate IIa		qz	191	42.4		
		K-sp	220	48.8		
		plag	33	7.3		
		mafics:	6	1.3		
			450	99.8		
Paragneiss						
mobilizate IIa	ON-2-4a	qz	73	27.5		
		K-sp	184	69.4		
		plag	2	0.7		
		bio,sill	6	2.2		
			265	99.8		
mobilizate I		qz	256	56.8		
		K-sp	174	38.6		
		plag	2	0.4		
		bio	18	4.0		
			450	99.8		
mobilizate IIa	ON-2-4b	qz	118	36.3		
		K-sp	192	60.5		
		plag	-	--		
		sill,bio	10	3.0		
			325	99.8		
mobilizate I		qz	218	58.1		
		K-sp	137	36.5		
		plag	-	--		
		sill,bio	20	5.3		
			375	99.9		
Concordant amphibolite						
mobilizate IIa ("spider")	ON-5-2	qz	217	54.3		
		K-sp	-	--		
		plag	149	37.3		
		hbl,opq	34	8.5		
			400	100.1		
mobilizate I		qz	169	42.0		
		K-sp	-	--		
		plag	222	55.2		
		hbl,opq	11	2.7		
			402	99.9		
mobilizate I	OS-1-5	qz	178	44.5	67	44.6
		K-sp	-	--	-	--
		plag	197	49.3	74	49.3
		bio	25	6.2	9	6.0
			400	100.0	150	99.9

Recrystallization effects of trondhjemitic mobilizate III intruding concordant amphibolite (refer to Table 12 for description of zones)

Mineral	Zone a		Zone b		Zone c		Zone d	
	Count	%	Count	%	Count	%	Count	%
qz	96	24.0	21	14.0	57	25.9	17	8.5
plag	264	66.0	16	10.6	81	36.8	57	28.5
bio	21	5.2	103	68.6	48	21.8	7	3.5
hbl	-	-	-	-	-	-	108	54.0
opq	1	0.2	minor, w. bio.		32	14.5	10	5.0
ap	17	4.2	10	6.6	2	0.9	1	0.5
	400	99.8	150	99.8	220	99.9	200	100.0

Abbreviations

qz: quartz
K-sp: potash feldspar (microcline)
plag: plagioclase
bio: biotite
hbl: hornblende
opq: opaques
sph: sphene
ap: apatite

Notes on use and interpretation of point count results

The modal compositions of paleosomes and mobilizates of the Old Gneiss Complex were determined to quantify petrographic descriptions outlined in the text. As a result of the large number of possible paleosome-mobilizate combinations resulting from polyphase migmatization in the study area, a limited number of thin sections representing each paleosome (and in situ mobilizate) were available for examination. Consequently, the modal compositions listed above are representative only of the samples studied. Furthermore, the coarse grain size of different lithologies, particularly granite II and mobilizate II, limited the total count possible per thin section, seriously compromising the statistical validity of the point count results. However, as indicated on the chart provided by Van der Plas (1965), it is seen that for major (ie >40 %) mineral consituents, a modal accuracy within a few % may be attained for point counts totalling less than 1000. Both mobilizate I vein and melanosomes bordering mobilizate II segregations are thin (1 to 6 mm),, consequently these neosome components are not entirely amenable to the point count method. In particular, melanosomes are seen to grade diffusely into the adjacent paleosome, consequently it is not possible to clearly delineate the melanosome component. Thus, in these cases, point count results are reproducible only if the researcher consistently separates neosome components along the same lines in thin section. Given the scale of melanosomes and mobilizate I veins, this clearly is not possible.

APPENDIX 2: Cross reference-Plates/file number.

PLATE	FILE LISTING (roll/shot #)
1	16/(5062)2
2	8/16
3	8/5
4	18/1
5	8/20
6	4/12
7	18/2
8	16/5
9a	8/9
9b	8/10
10	18/8
11a	18/7
11b	18/10
11c	4 x 5
11d	18/9
11e	18/11
11fi	19/0
11fii	18/6
12	8/18
13a	3/13
13b	15/12
14	17/15
15ai	19/4
15aii	19/3
15bi	18/5
15bii	19/2
15c	18/12
15d	18/13
16a	14/4
16b	13/12
17a	16/19
17b	8/2
17c	15/31
17d	15/2; 3/0
17e	14/21
18	11/22
19a	2/1
19b	14/(5062)16
20a	16/10
20b	16/16
21	19/9
22a	14/11
22b	16/(5062)36a
23a	18/19
23b	18/18
24a	11/6
24b	6/5
24c	9/8
25	4 x 5
26	18/14
27a	8/12
27b	19/10

Note: "4 x 5" indicates a 4" x 5" plate negative.

APPENDIX 2 (cont´d): Cross reference-Plates/file number.

PLATE	FILE LISTING (roll/shot #)
28a	14/17
28b	16/12
29	19/11
30a	19/12
30b	18/16; 4 x 5
31	11/4
32a	3/11
32b	8/6
32c	11/13
32d	15/30
33a	19/20
33b	19/14
34	13/22
35	13/1
36	4/9
37	13/9
38a	14/7
38b	19/15
39a	19/6
39b	19/5
40	4/7
41a	4 x 5
41b	4 x 5
41c	4 x 5
41d	4 x 5
41e	4 x 5
42	1/19