PRIMARY STRUCTURES OF THE FALCON LAKE INTRUSIVE COMPLEX, SOUTHEASTERN MANITOBA

by

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A thesis

submitted to the

University of Manitoba

in partial fulfillment of the requirements

for the degree of

MASTER OF SCIENCE

December, 1988

ISBN 0-315-51617-8

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ABSTRACT

The Falcon Lake Intrusive Complex is a composite intrusive body, approximately 10 square kilometers in area, located near the western edge of the Wabigoon Subprovince in the Superior Province of the Canadian Precambrian Shield. The complex has an elliptical shaped core, and tapering extensions to the southwest and northeast. The complex consists of a series of intrusions ranging from oldest gabbroic rocks in the extensions, through younger diorite-granodiorite in the outer areas of the core, to youngest quartz monzonite in the centre. All of the rocks of the complex are characterized by cumulate or porphyritic textures. The compositions, distribution, and relative ages of the component intrusions suggest a separate differentiating magma chamber from which the intrusions were drawn sequentially. Successive intrusions of progressively more differentiated magma were intruded more or less into the centre of its less differentiated predecessor. The initial intrusion was dyke-like, and succeeding intrusions gave the complex a more equant and cylindrical shape. Relationships throughout the complex suggest that the complex was a magma conduit in which magmas were periodically transported from a source at depth to higher level intrusive or extrusive features.

Each intrusion of the complex is characterized by its own set of primary fabric structures which may include the preferred orientation of primary minerals, layering, discordant intrusive contacts similar to angular unconformities, scour and trough-banded structures, mineral clots and segregations of various compositions, xenoliths and cognate inclusions, and breccia pipes. The form and arrangement of these primary structures. as well as relationships between structures, suggest that each intrusion initially consisted of a crystal-liquid mixture, and that magmatic flow processes were responsible for the development of the structures. The origin of the flow is related to intrusive emplacement mechanisms rather than convection processes after emplacement.

ACKNOWLEDGEMENT

The author wishes to extend a special thanks to W.C. Brisbin for his assistance and supervision during the study. Special thanks are also extended R.F.J. Scoates for providing funding for the project, and for the rewarding discussions throughout the years.

Thanks are also due to the many colleages at the University of Manitoba, both students and staff, with whom the learning process was made a little bit lighter. Thanks are also due to several of the 'ULTRAMAFIA 'at the Geological Survey of Canada for their discussions and suggestions.

Funding for this project was provided under the Canada-Manitoba Mineral Development Agreement (1984-1989), through R.F.J. Scoates from the Geological Survey of Canada.

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CHAPTER ONE

INTRODUCTION

RENAMING THE INTRUSIVE BODY

The Falcon Lake Intrusive Complex is a small composite body located in southeastern Manitoba. Previous investigators referred to the body as the Falcon Lake Stock and interpreted it as a zoned body consisting of two intrusive units with a relatively simple emplacement and crystallization history. The present study has identified six separate intrusions which, along with the recognition of numerous primary structures within each body, reflect a more complicated emplacement and consolidation history: consequently the body has been renamed the Falcon Lake Intrusive Complex.

PREVIOUS WORK

Brownell (1941), was the first to publish results of a study of the Falcon Lake body, although the area was known to prospectors since the 1890's. His study described the zoned nature of the body; an outer rim of gabbro and diorite, an intermediate zone of granodiorite and syenodiorite (monzodiorite), and a central core of quartz monzonite. The body was considered to be a composite structure formed of two portions; the inner quartz monzonite core and the outer more basic portion. The intermediate zone of granodiorite was considered to have formed "*by the emanations from the central core upon the already solidified enclosing diorite* ".

Springer (1952) and Davies (1954) regional mapping studies include brief descriptions of the rocks of the complex.

House (1955) interpreted the body's zoned nature as due to "*assimilation reaction*"between intrusive and host rocks.

Haugh's (1962) petrographic study interpreted a preferred orientation of plagioclase crystals in several areas of the body and related it to primary flow of the magmas that make up the body.

Gibbins (1967,1971) interpreted the body as a concentrically zoned, diapir-like plug. He suggested that the zoning originated by "*slow crystal-liquid fractionation, followed by rapid crystallization of the final silicate liquid due to release of an aqueous phase by resurgent boiling*".

CONCURRENT STUDIES

Several studies related to specific features within and adjacent to the complex have been undertaken since 1984. These include:

a) Halwas, (1984)– a study of the Sunbeam-Kirkland breccia pipe in the quartz monzonite core of the complex.

b) Barc,(1985)– a study of the Moonbeam breccia pipe at the granodiorite–quartz monzonite contact.

c) Chayter,(1985)– a geochemical study in the northeast of the complex.

d) Johanasson, (1985)– a gravity survey over portions of the complex.

e) Quinn, (1985)– a study of the metamorphic aureole within metasedimentary rocks along the northwestern side of the complex.

f) Fingler, in progress –a study of mineralization in and near the complex.

g) Tirschmann, in progress–a geochemical study of the complex.

OBJECTIVES AND METHODS OF THE STUDY

Previous studies of the complex have emphasized petrological aspects; textural and structural studies were limited in area or character. Just prior to the present study several previously unrecognized fabric elements were identified in the body. These elements included areas of layering and igneous laminations, a trough banded structure, dykes of inner zone composition in the intermediate and outer zones, and inclusions of outer zone compositions in the inner zones (outer-intermediate-inner zone terminology from previous investigators). The present study was initiated to document and interpret the significance of these types of fabric elements in the body.

Objectives

The objectives of this study were to;

1) Document the internal fabric elements of the body with respect to character, orientation, distribution and age.

2) Interpret the fabric elements in terms of origin, sequence, and significance with respect to the petrologic zoning observed by previous investigators of the body.

3) Establish the constraints imposed by the fabric elements on the interpretation of an emplacement history and crystallization.

Methods

Mapping of the entire body was done at a scale of 1:5000 utilizing the basic outcrop-map of Davies(1954), and air photographs. Pace and compass traverses were planned to give as complete a coverage of outcrop areas as possible. Modifications to the base map were necessary, and in most areas outcrop limits were mapped. Average exposure is approximately 25 percent of the outcrop limits shown on Map # 1.

Three areas of detailed mapping (1:1000 scale) required extensive stripping of outcrops of vegetation cover or scrubbing with a bleach solution to remove lichen (Maps # 2 and # 3).

CHAPTER TWO

PETROLOGY OF THE COMPLEX

LOCATION AND DIMENSIONS

The Falcon Lake Intrusive Complex is located in southeastern Manitoba, approximately 4 km west of the Manitoba-Ontario provincial boundary (Figure 1). The body lies within Township 9N, Ranges 16E and 17E, and can be readily accessed from Highway # 1 and Provincial Highways # 44 and # 301 (Map # 1).

The complex is approximately 5 km long and 2 km wide. Its shape in plan is approximately elliptical with a sigmoidal distortion and tapering extensions at the northeast and southwest ends of the ellipse.

GEOLOGICAL SETTING AND AGE

Rocks of the Falcon Lake Intrusive Complex have intruded into metamorphosed and deformed supracrustal rocks of the Wabigoon subprovince in the Superior Province of the Canadian Precambrian Shield. The area containing the complex lies within the westerly extension of the subprovince, in the section termed the Lake of the Woods Greenstone Belt (Blackburn et al., 1985).

The host rocks of the complex have been subjected mainly to upper greenschist grades of metamorphism, and contain folds with axial-planar schistosities that generally strike northeasterly and consistently have steep dips. The complex locally truncates these structures on steeply dipping contacts, and has apparently upgraded the metamorphic level within the bounding host rocks to amphibolite grades in a thermal contact aureole up to 1 km wide (Quinn, 1985). Igneous

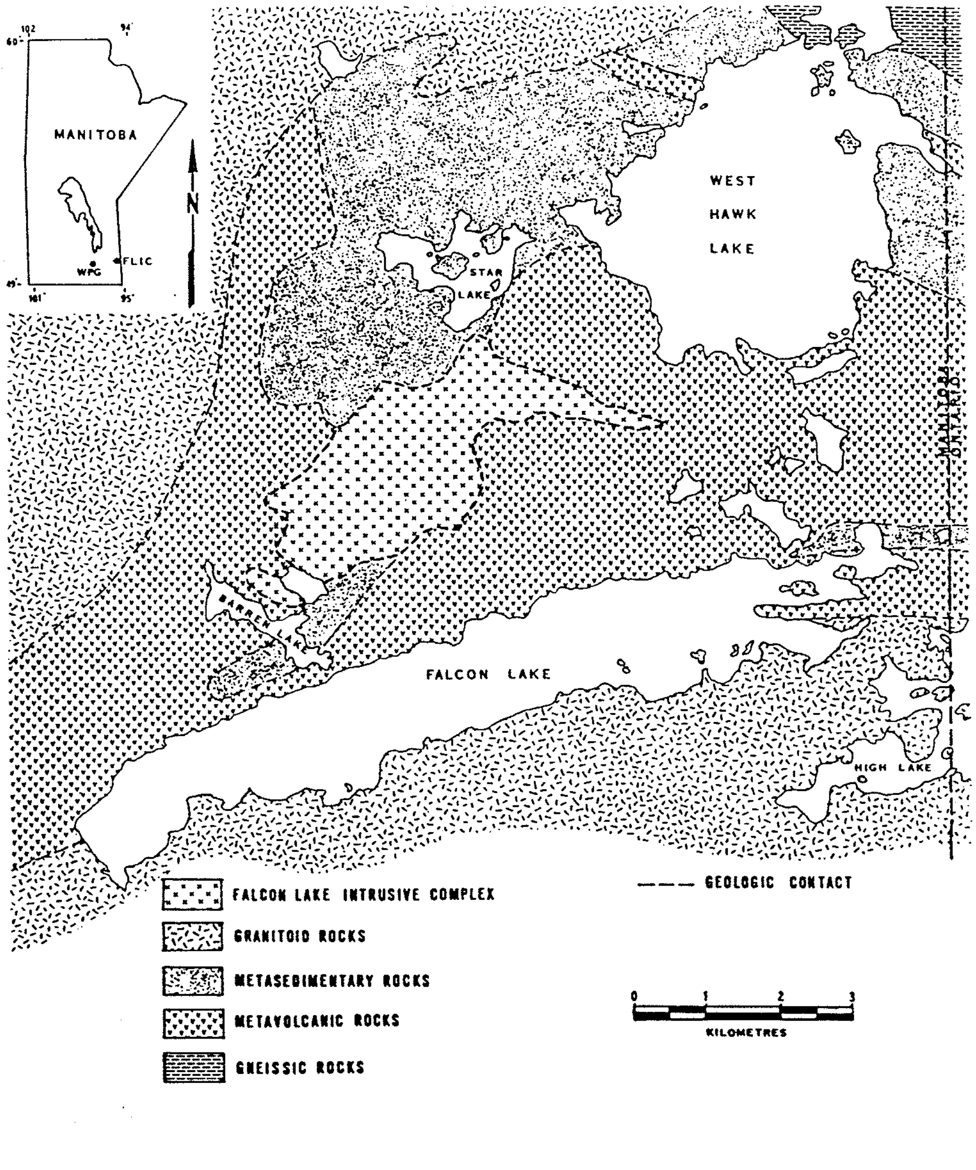


Figure 1. Location, and general geology around the Falcon Lake Intrusive Complex (modified after Lamb, 1975).

textures in the intrusive rocks next to the contacts, as well as within dykes and apophyses that extend outward up to several hundred metres into the country rocks, are medium to coarse grained. Xenoliths of schistose host rocks are common throughout the complex. These relationships indicate that the complex was emplaced after deformation and regional metamorphism, and that its present pipe-like form and approximately vertical orientation (Gibbins, 1971) represent intrusive conditions.

The ages of the supracrustal rocks in this part of the Wabigoon subprovince are as yet undetermined, however, it has been suggested by Blackburn et al. (1985), that most of the igneous rocks formed around 2.7 to 2.8 Ga, and that tectonic stability was attained by 2.5 Ga. Whole rock Rb/Sr age dating of samples from the porphyritic margin of the granitoid Rennie Batholith, about 1 km west of the complex, has given an age of approximately 2.55 Ga (Farquharson and Clark, 1968). A K/Ar age determination on biotite from the center of the Falcon Lake complex has given a minimum age of 2.3 Ga. (Wanless et al, 1968). No intrusive relationships between the complex and the batholithic rocks have been observed.

CONTACT RELATIONSHIPS

The Falcon Lake Intrusive Complex is composed of six individual intrusions (Figure 2, and Map # 1). The outer extensions of the complex consist of four intrusions, of which three (A,C,D) are gabbroic; the fourth (B) ranges from pyroxenite to melagabbro. The central part of the complex is composed of two intrusions; an outer annular ring that ranges from diorite to granodiorite (E), and an inner core of quartz monzonite (F).

Each of the intrusions that make up the complex, except the core intrusion,

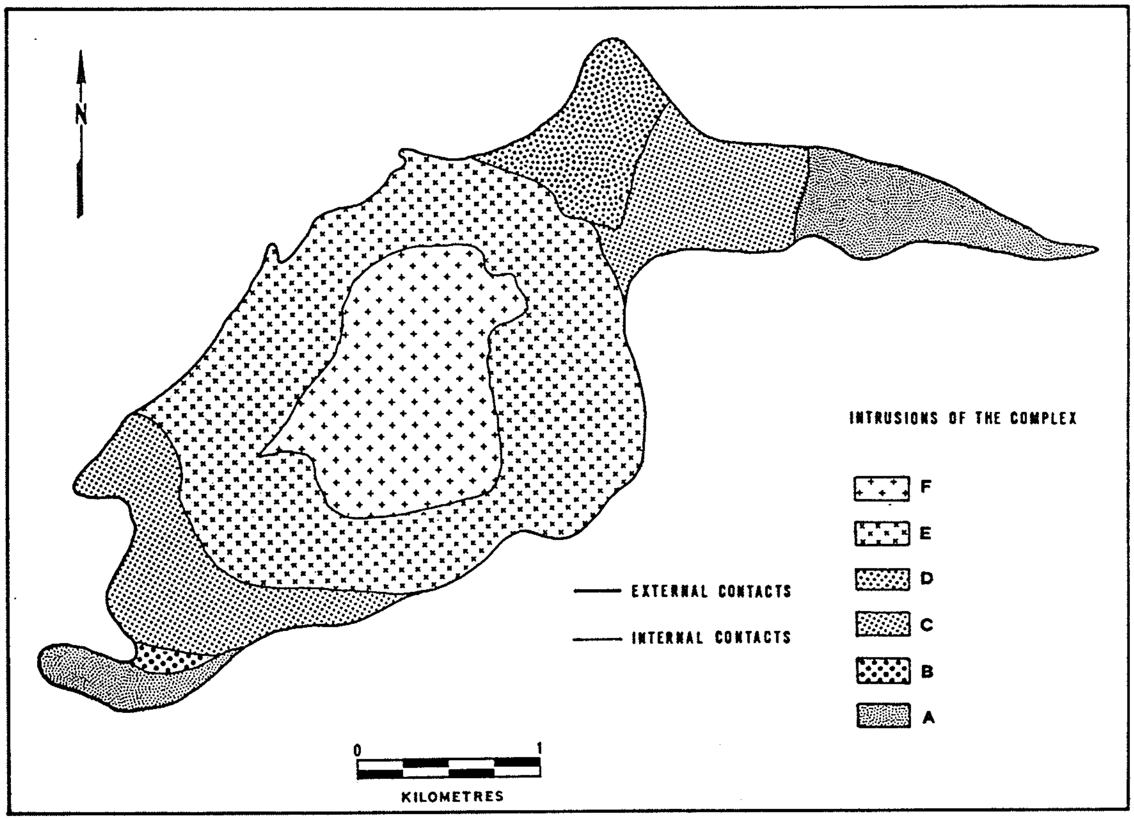


Figure 2. General geology and distribution of component intrusions of the Falcon Lake Intrusive Complex.

is in contact with metamorphosed supracrustal rocks at the present erosional level. The outer contacts are usually steep, sharp, discordant intrusive contacts; the plutonic rocks of the complex cross-cut foliated and schistose host rocks. Sheared and heavily iron-oxide stained contacts have been observed locally. In several places the contacts consist of intrusion breccias with numerous dykes and offshoots of complex material isolating angular inclusions of host rocks. Xenoliths of host rock material occur sporadically throughout the intrusions, however they are found more frequently and in significant concentrations near outer contacts.

There is little evidence of chilling in the intrusive material near the country rocks. The textures in rocks of the complex near contacts, and in dykes and apophyses that extend up to several hundred metres into the host rocks, are usually medium to coarse grained. Several small areas in the extreme easterly portion of the northeasterly extension of intrusion A contain coarse plagioclase phenocrysts in a fine grained to aphanitic matrix which may represent chilled material.

Observations made by Quinn (1985), and during the course of the present study, on the metamorphic effects of the intrusions on host rocks, suggest that the metamorphic level of the country rocks near the complex has been upgraded from greenschist to amphibolite grades in a contact aureole up to 1 km wide. The metamorphic effects appear to be more pronounced in the metasedimentary rocks than in the metavolcanic rocks.

Most of the contacts between the component intrusions of the complex have been observed in outcrop exposures along their traces. These contacts are usually steep, sharp, intrusive contacts (Figure 3). Inclusions of older complex material, as well as xenoliths of host rock material, have been found concentrated near intrusive contacts in several areas. Mesoscopically observable contact metamorphic effects and evidence of extensive reaction between the intrusions have been found in very few areas (Figure 4 and Figure 5).

The overall arrangement of the intrusions, as well as contact relationships between component intrusions, suggest an emplacement sequence for the complex, from oldest— intrusion A, to youngest— intrusion F.

LITHOLOGICAL DESCRIPTION OF THE INTRUSIONS

Although the intrusions that make up the complex display internal variations in composition, fabric elements, and the arrangement of fabric elements,each body contains distinct features that characterize that intrusion from others in the complex. The following sections are general descriptions of the rocks in each body based on field mapping observations and detailed examination of representative hand samples collected during mapping.

Intrusion A

The rocks of intrusion A are gabbroic, with subequal amounts of plagioclase and pyroxene. Texturally the rocks vary from medum grained orthocumulate and mesocumulate gabbros with rare coarse grained plagioclase and pyroxene phenocrysts (Figure 6a), to coarse grained plagioclase-pyroxene mesocumulates (Figure 6b). Cumulus pyroxene commonly occurs as euhedral rod-shaped crystals, the cumulus plagioclase as subhedral to euhedral lath-shaped crystals. One local area displays poikilitic textures, with 2 to 3 cm pyroxene oikocrysts enclosing plagioclase laths. Pyroxene also occurs in very coarse grained glomerocumulus aggregates of various sizes.

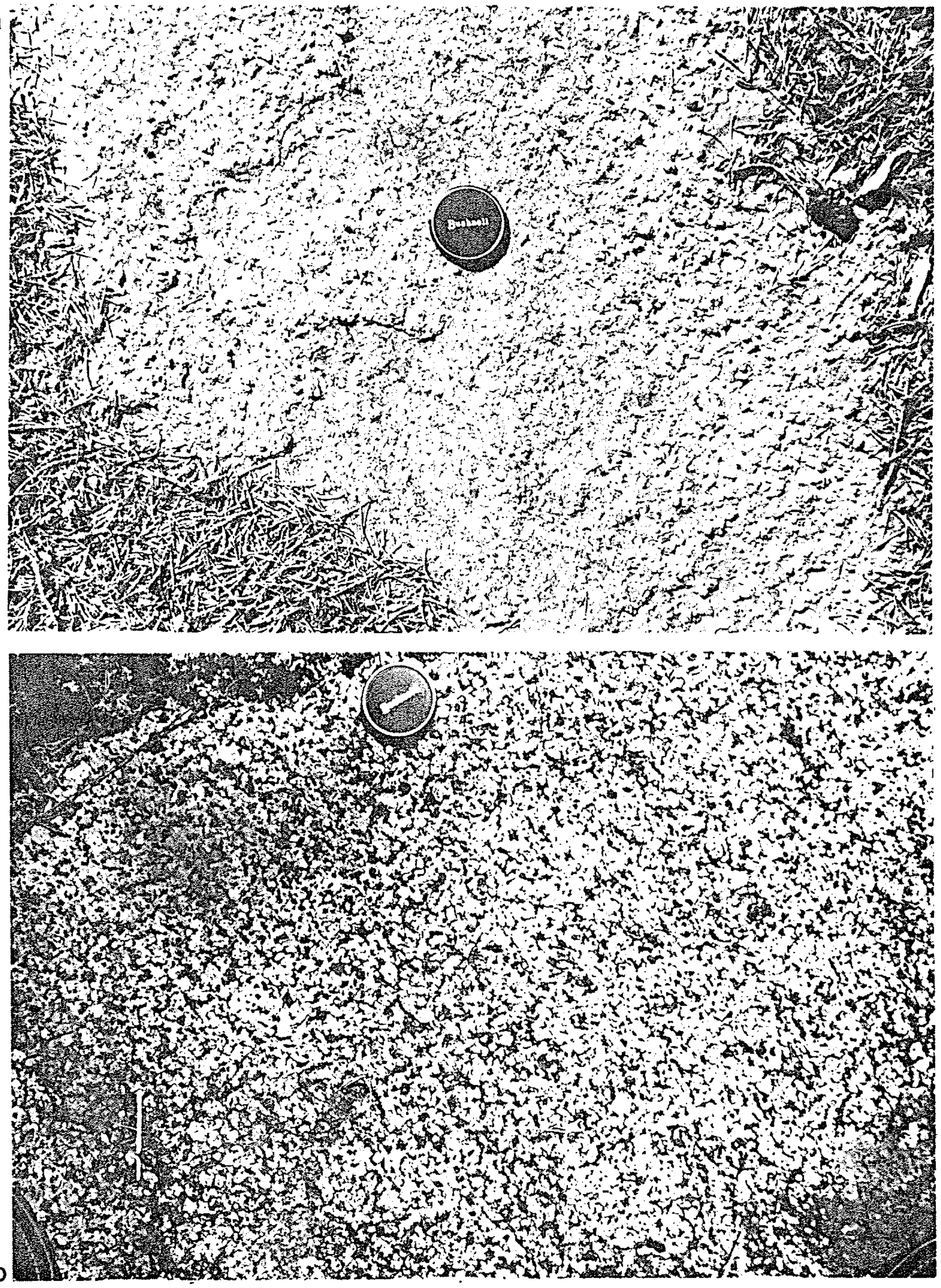
The intercumulus material is mainly composed of anhedral pyroxene and plagioclase with accessory Fe-Ti oxides and apatite. On most outcrop surfaces differential weathering has produced a knobby surface with cumulus pyroxene in

3a

3b

Figure 3. Examples of sharp intrusive contacts between component intrusions.(3a.) C–D contact in northeastern portion of complex. Intrusion C gabbro is dark (top-left), intrusion D (bottom-right) is leucocratic gabbro. In this area numerous inclusions of intrusion A gabbro (centre of photo) and metavolcanic host rocks occur within intrusion D rocks along the contact. Intrusion C rocks along this portion of the contact contain several small shears and quartz dykelets, and appear to be pervasively altered. (3b.) E–F contact in northeastern-central portion of complex. Intrusion E rocks (bottom) are coarse grained granodiorite, intrusion F rocks (top) are leucocratic quartz monzonite.

4a



4b

Figure 4. Example of thermal metamorphism between component intrusions. (4a) Altered intrusion C gabbro from near C–D contact (see also Figure 3a). The overall texture has been retained, however the primary mineralogy has been pervasively altered. (4b) Unaltered intrusion C gabbro at approximately 75 meters from C–D contact.

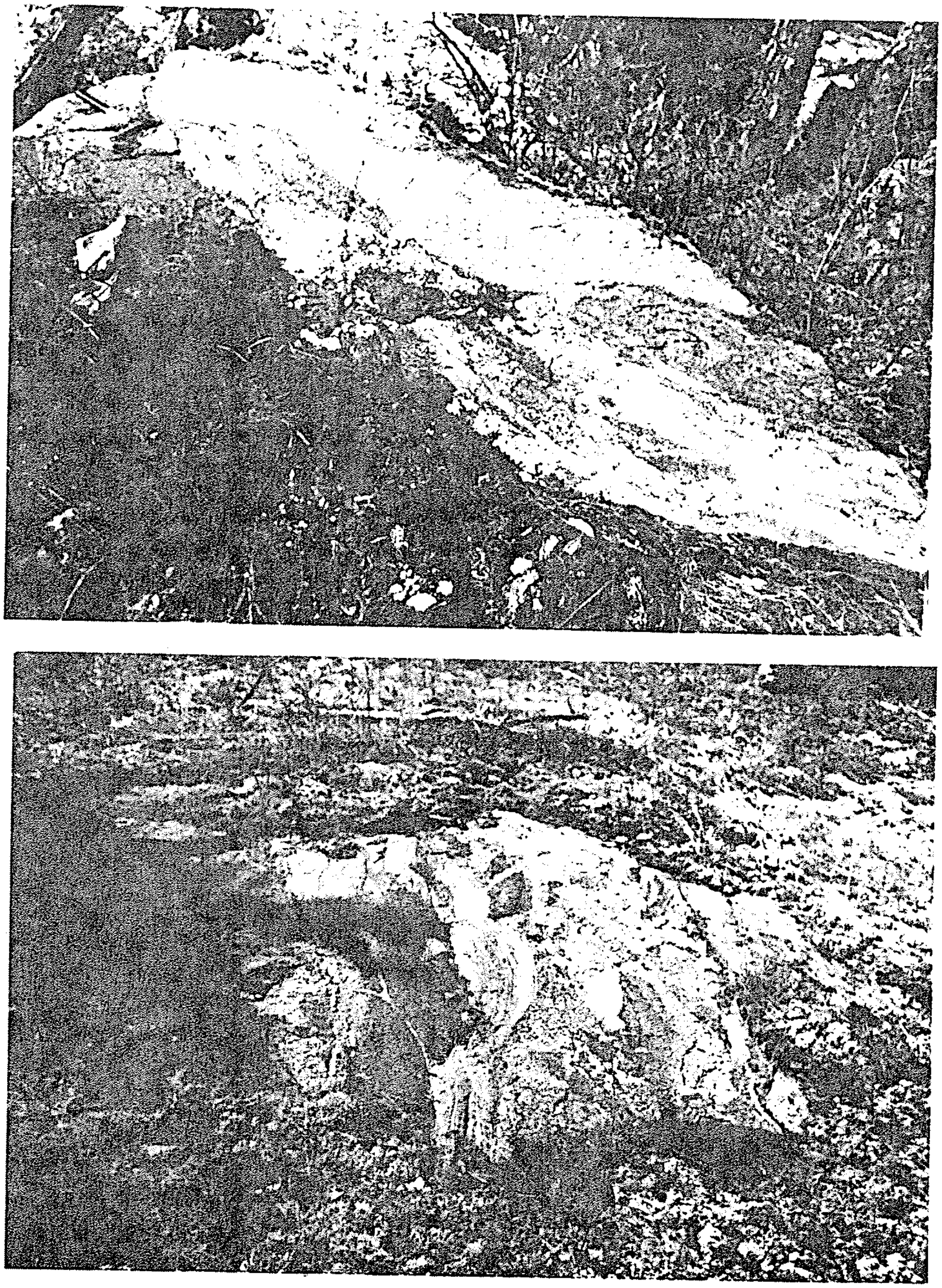


Figure 5. Rocks from a border zone (C–E contact) in the southern portion of the complex displaying an intrusion breccia with melanocratic fragments of intrusion C gabbro in a leucocratic diorite (intrusion E) matrix. Many of the fragments appear to have been partly remelted and the gabbroic material mixed with diorite. The area also contains several small scour-like structures and autointrusive dykes of leucodiorite.

high relief and cumulus plagioclase and intercumulus material in low relief.

Several small areas near outer contacts with host rocks in the northeastern portion of intrusion A contain rocks considered to be rare examples of chilled contact material . The rocks consist of .5 to 1 cm lath-shaped plagioclase crystals in a fine grained to aphanitic matrix (Figure 7). These rocks grade into coarser grained material over several metres.

The rocks of intrusion A commonly display a weakly developed, steeply dipping planar lamination oriented parallel to intrusive contacts. Wavy and swirl patterned structures are present locally, usually along irregular contacts. Well developed planar laminations and layering have been found in only one area, in the northeastern portion of intrusion A near an outer contact.

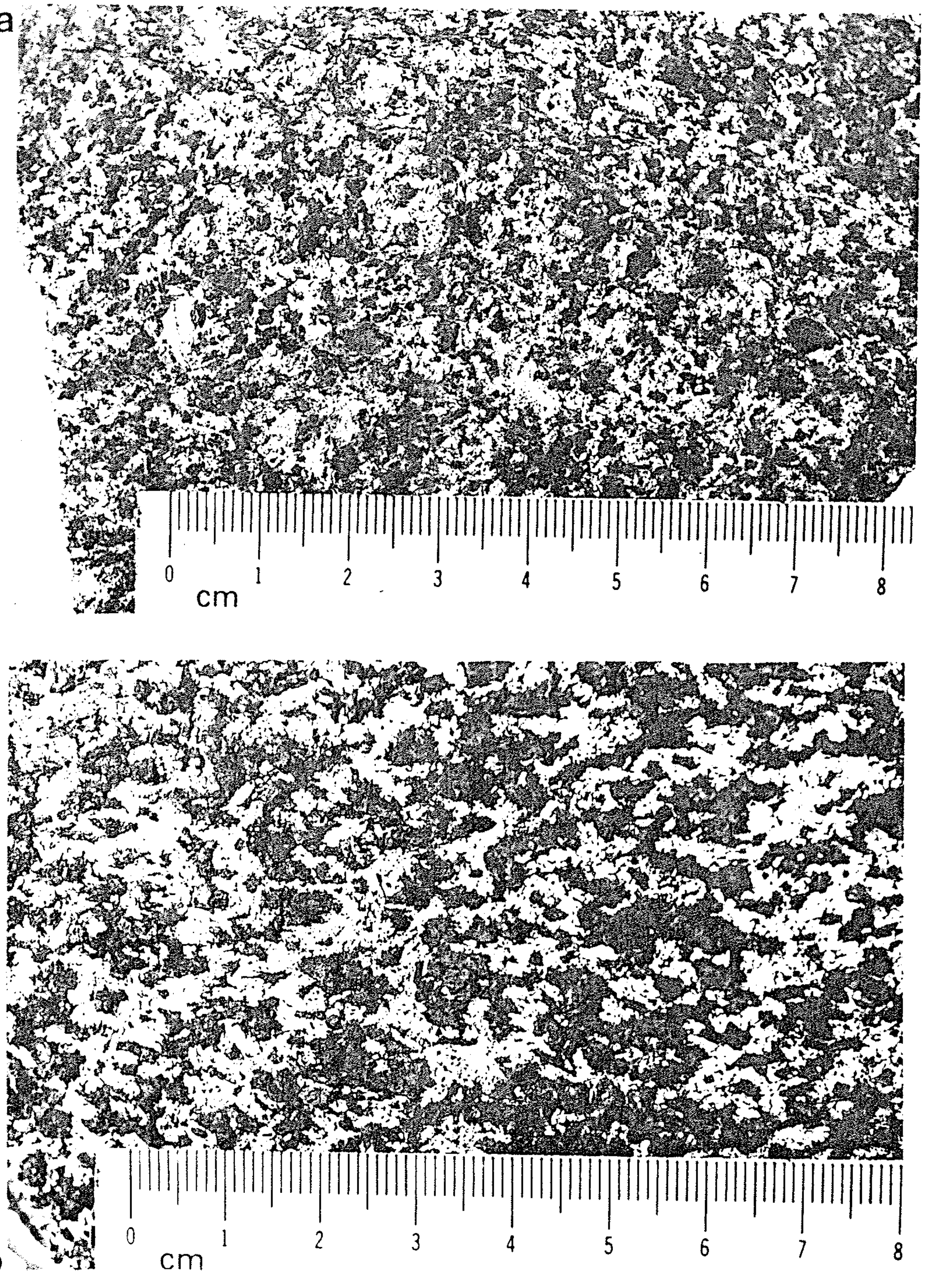
Intrusion B

The rocks of intrusion B range from pyroxenite to melagabbro. They are usually coarse to very coarse grained mesocumulates. Tabular plagioclase crystals occur sporadically throughout the pyroxenite or occur in small glomerocumulus aggregates (Figure 8.). The melagabbro contains up to 30 percent plagioclase. The intercumulus material includes pyroxene, plagioclase, and accessory Fe-Ti oxides, apatite, and spinel. The plagioclase usually weathers to a lower relief than cumulus pyroxene on outcrop surfaces.

The rocks of intrusion B display a well developed, steeply dipping planar lamination. Layering has not been positively identified, however alternations between pyroxenite and melagabbro in the few scattered outcrops are suggestive of layering, perhaps tens of metres thick.

Rocks of intrusion B have been found occupying only a small area between intrusions A and C in the southwestern part of the complex. Brownell sampled mafic-rich rocks similar to those of intrusion B in the northeastern extension of

6a



6b

Figure 6. Examples of intrusion A gabbro: (6a) medium grained intrusion A gabbro with occasional coarse phenocrysts of plagioclase and pyroxene. (6b) plagioclase-pyroxene mesocumulate gabbro.

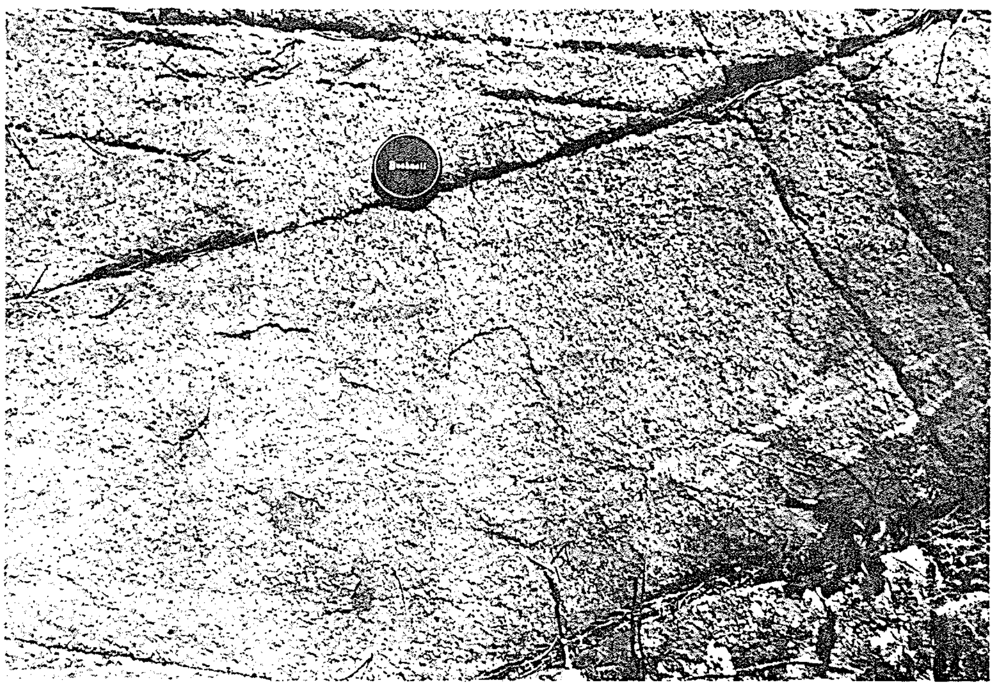


Figure 7. Intrusion A gabbro from the northeastern extension of the complex. Coarse grained phenocrysts of plagioclase in a fine to aphanitic matrix may be an example of chilled margin rocks.

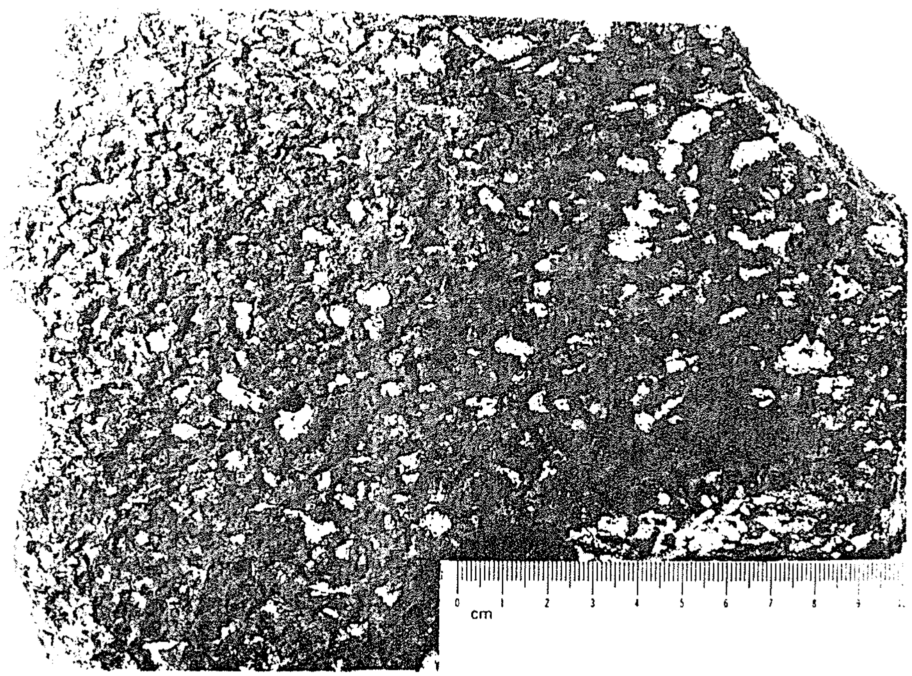


Figure 8. Example of intrusion B feldspar-bearing pyroxenite. This example also displays a small glomerocumulus aggregate of plagioclase crystals.

the complex (Brownell,1941; page 236, Table 2, line J-K, sample 75). These rocks however were not observed during the course of the present study. The designation of this small area of pyroxenitic rocks as a separate intrusion in this study is based on its characteristic composition, characteristic fabric, and the presence of this material as distinct inclusions within later intrusions. The rocks of this intrusion also appear to have a distinctive geochemical signature (N.Halden, personal communication).

Intrusion C

The most common rocks found in intrusion C are unlayered, coarse grained, mesocumulate leucogabbros (Figure 9.). Local variations to anorthositic gabbro and pyroxene-hornblende gabbro occur rarely. Plagioclase is the predominant cumulus mineral, and usually occurs as coarse grained equant crystals. Pyroxene also occurs as a cumulus mineral. Intercumulus material includes plagioclase, pyroxene, hornblende, and accessory Fe-Ti oxides and apatite. On weathered surfaces the equant,cumulus plagioclase crystals are usually of higher relief than the cumulus pyroxene and intercumulus minerals.

Small areas of layered rocks have been found sporadically throughout intrusion C. An extensive area of layering (approximately 300 by 300 metres) has been found in the southwestern portion of this body. The layered rocks range in composition from anorthositic gabbro, through pyroxene-hornblende gabbro, to pyroxenite. Grain sizes range from fine to very coarse, and textures from orthocumulate to adcumulate. Detailed descriptions of the layering, layering related structures, and other primary fabric elements found in this intrusion will be dealt with in later sections.

The unlayered rocks usually display a weakly defined planar lamination; the layered rocks usually display well developed planar and lineate laminations.

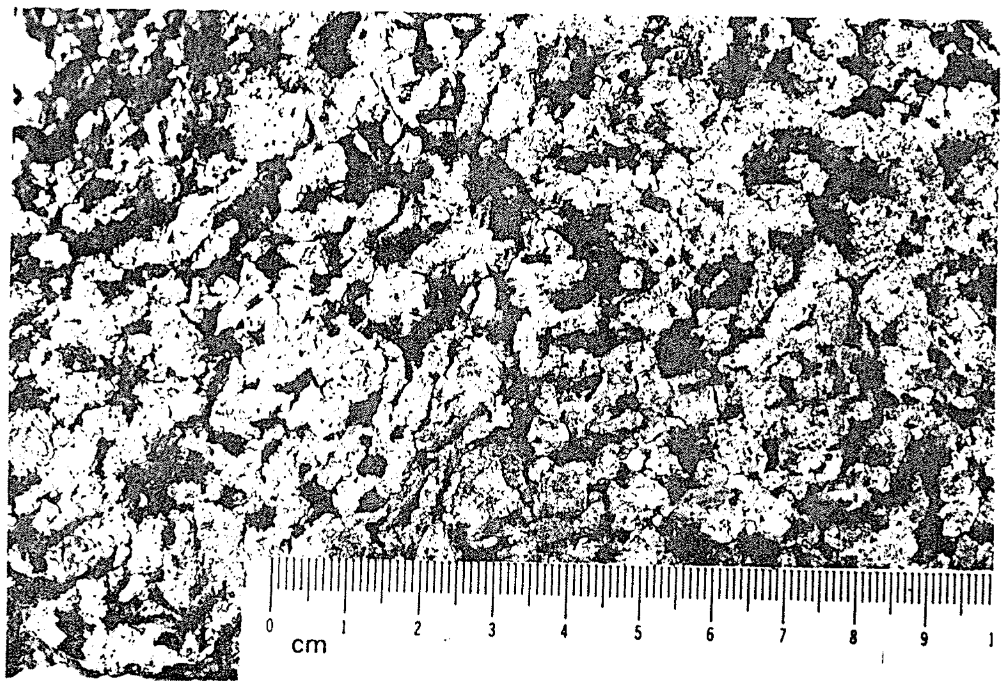


Figure 9. Example of average unlayered intrusion C gabbro. These rocks with equant plagioclase crystals display a weakly defined planar lamination.

Local areas and individual horizons in the layered rocks display wavy and swirl patterned structures. The laminations are usually steep and parallel to layering and to nearby contacts.

Contact metamorphic effects have been observed in intrusion C along a portion of the contact with intrusion D (see Figures 3a,and Figure 4.). The rocks have retained the overall texture of unaltered gabbro, however the plagioclase has been pervasively sausseritized and the mafic minerals altered to fibrous amphiboles, biotite, and iron-oxides. These altered rocks grade into visually unaltered rocks within 25 to 30 metres of the contact.

Intrusion D

Most of intrusion D is layered. The layered rocks range in composition from anorthositic gabbro, through hornblende-magnetite gabbro, to hornblende-pyroxenite. Medium to coarse grain sizes are prevalent. Textures range from orthocumulate to mesocumulate. Adcumulate textures are rare.

The unlayered rocks are usually coarse grained leucocratic hornblende-gabbro and display orthocumulate to mesocumulate textures.

Plagioclase is the predominant cumulus mineral and typically occurs as lath-shaped crystals or in mixtures of lath-shaped and equant crystals (Figure 10). Cumulus pyroxene and hornblende are predominant in local areas. Magnetite and apatite form appreciable amounts of the rock (usually more than 5%), and appear to have been cumulus minerals locally. The high magnetite content of this body gives it an anomalously higher response on magnetometre surveys than other gabbros of the complex (C.D.Anderson, personal communication).

The intercumulus material includes plagioclase, pyroxene, hornblende, magnetite and apatite, and accessory Ti-spinel, quartz,and alkali feldspars.

All of the rocks of intrusion D display some form of steeply dipping planar

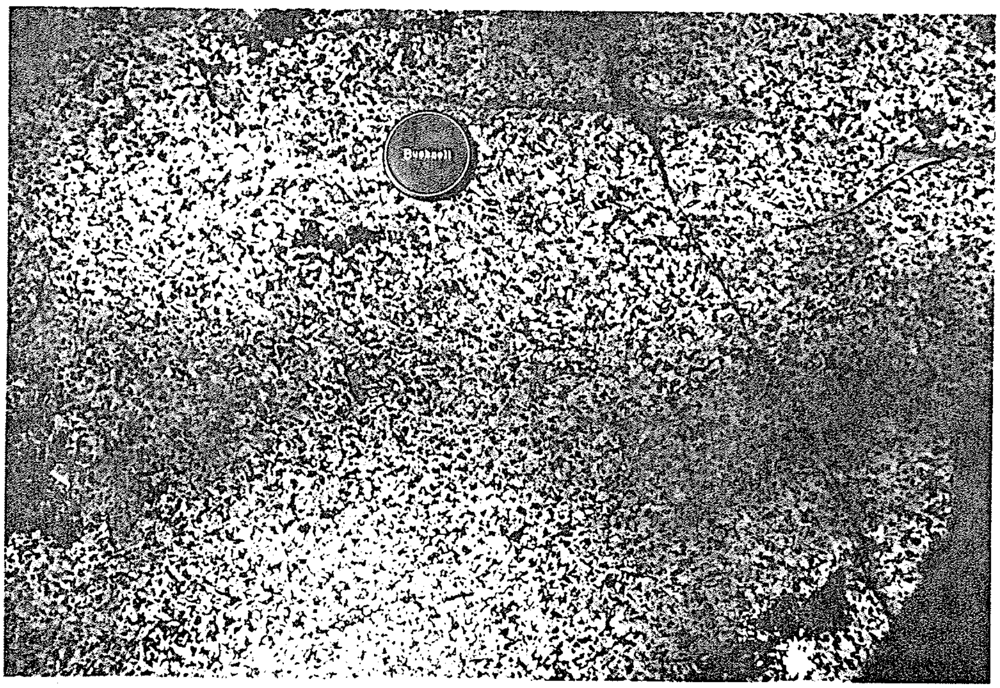


Figure 10. Example of unlayered intrusion D gabbro. This example is from an area that contains numerous small mafic-mineral clots and displays a weakly defined planar lamination and local wavy and swirled patterns.

lamination that is parallel to layering and nearby intrusive contacts. Local areas and individual horizons in the layered rocks display lineate laminations, or wavy, swirled, and occasionally streaky patterns. Mafic-mineral clots and other mineral segregations are common throughout the layered rocks of this intrusion.

Detailed descriptions of the layering ,layering structures, and other primary fabric elements found in this intrusion will be dealt with in later sections.

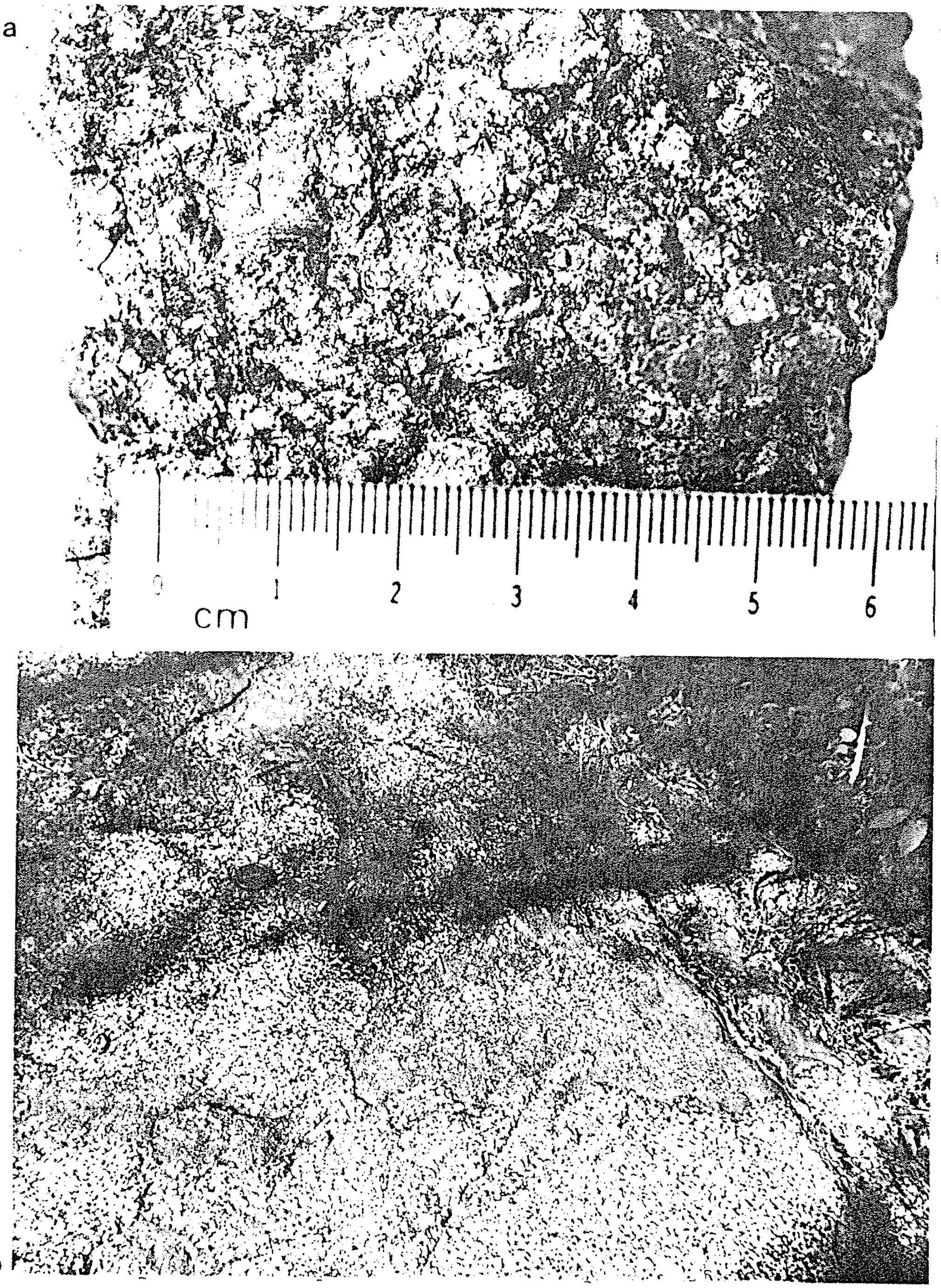
A local border zone has been developed along the northern contact of intrusion D and host metasedimentary rocks (meta-arenite and meta-wackes). This area consists of a mixture of coarse grained plagioclase crystals and fine grained host material (Figure 11a). Inclusions of this mixed material have been found several hundred metres away from this contact, well within the body of this intrusion (Figure 11b.)

Intrusion E

Intrusion E appears to be concentrically zoned, grading from diorite and quartz diorite near outer contacts to monzodiorite and granodiorite inward. The rocks are porphyritic; the outer diorites usually display hiatal textures (Figure 12a) the inner rocks a more seriate texture (Figure 12b). Plagioclase is the predominant component, occuring as coarse phenocrysts and in the groundmass. Hornblende is the predominant mafic component; pyroxene is present but rare. The proportions of biotite, alkali feldspars, and quartz show a general increase toward the granodiorite portion of the intrusion.

A steeply plunging mineral lineation displayed by the coarse phenocrysts is present throughout most of this intrusion. Planar laminations are locally present near outer contacts and in areas of layering. Small layering sequences occur sporadically throughout this intrusion. The northeastern portion of this intrusion, where it is in contact with intrusions C and D, contains a more extensively layered

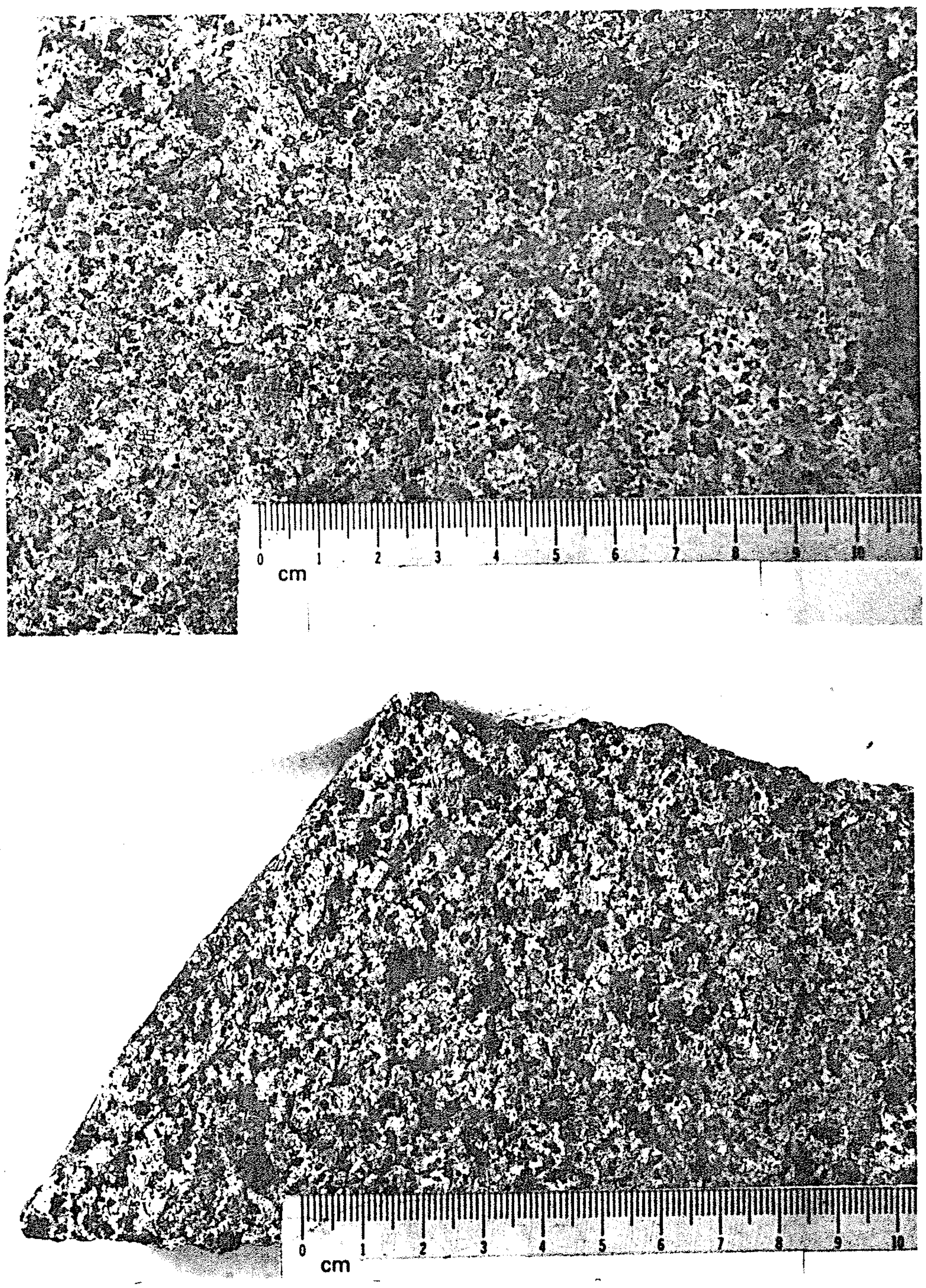
11a



11b

Figure 11. Examples of contaminated intrusion D rocks from within contact border zone and an inclusion of contaminated gabbro and host rocks from within the body: (11a) mixture of coarse grained magmatic material (mostly plagioclase crystals) and fine grained host material. (11b) inclusion of mixed material found several hundred meters from the contact.

12a



12b

Figure 12. Examples of intrusion E rocks: (12a) outer area diorite displaying porphyritic-hiatal texture, (12b) inner area granodiorite displaying a more seriate texture.

area.

Along the northern contact between intrusion E and host rocks is a small area of diorite that contains up to 5% magnetite (Figure 13). Several magnetite-rich iron formations in the nearby host rocks have been intruded by dioritic material, and the high-magnetite diorite in this area likely reflects contamination by this material. The contaminated rocks grade into normal diorite over several metres.

Intrusion F

Rocks of intrusion F occupy the central core of the complex, and are in contact with only granodioritic rocks of intrusion E at the present erosional level. The rocks are quartz monzonite with subequal amounts of plagioclase and alkali feldspars, less than 5% mafic minerals (usually biotite), and approximately 10% quartz. They are porphyritic with coarse phenocrysts of feldspars in a fine to medium grained groundmass (Figure 14).

A steeply plunging mineral lineation has been found in intrusion F (Haugh,1961), but is poorly displayed mesoscopically on horizontal outcrop surfaces. Layering has been found only near outer contacts in the northeastern portion of this intrusion.

TEXTURAL AND COMPOSITIONAL TRENDS

Several textural and compositional trends in the rocks of the complex became apparent during the course of the present study. The following section is a summary of these trends and interpretations these trends have led to.

The outer mafic intrusions (A,B,C,D) are generally coarse grained, and usually display cumulate textures. Cumulate textures give way to porphyritic textured rocks in intrusion E. Intrusion F is porphyritic throughout. The ubiquitous presence of cumulate and porphyritic textured rocks implies that the intrusions

Figure 13. Example of contaminated diorite with up to 5% magnetite. The unusually high magnetite concentration may be due to assimilation of magnetite-iron formation material from nearby host rocks.

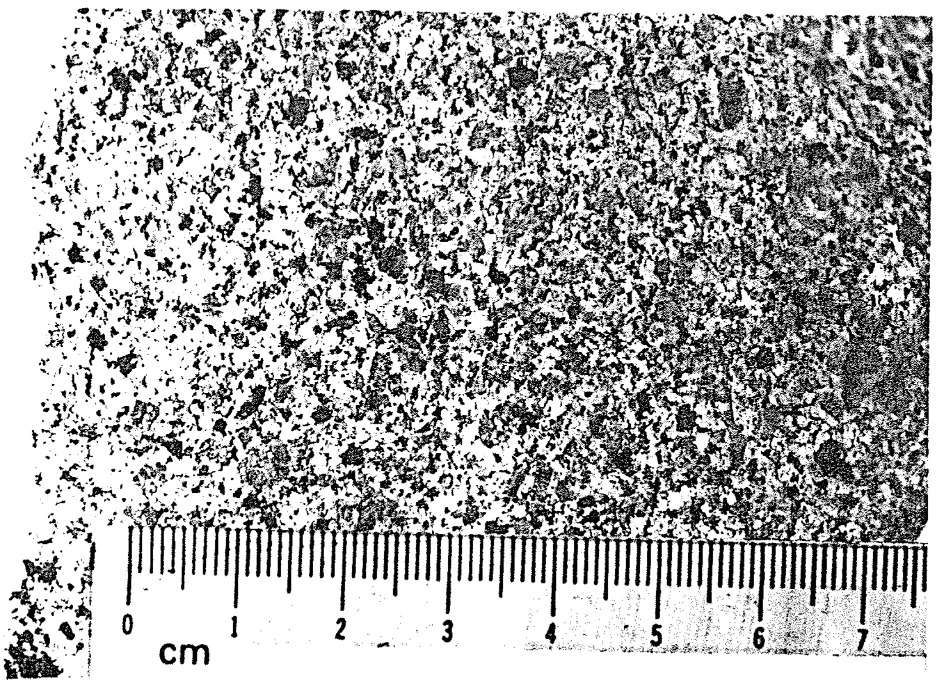


Figure 14. Example of porphyritic quartz monzonite.

of the complex consisted of magmas that were crystal-liquid mixtures throughout much of their histories. The absence of rocks displaying other than cumulate or porphyritic textures at outer intrusive contacts implies that the intruding magmas contained some proportion of crystals during emplacement. The presence of two major groupings of grain sizes, coarse grained cumulus and phenocryst minerals in finer grained intercumulus and groundmass materials, implies that crystallization occured in several stages.

Plagioclase is usually the predominant cumulus and phenocryst phase throughout the complex. It is also a major intercumulus and groundmass component. Plagioclase ranges in composition from approximately An_{70} to An_{45} in the outer gabbroic intrusions, and from approximately An_{45} to An_{25} in the dioritic rocks. Zoned plagioclase phenocrysts in the quartz monzonite intrusion have cores of approximately An_{20}.

Alkali feldspars, usually microcline, occur in small amounts in the gabbroic rocks and in the outer diorite of intrusion E. They show an increase in abundance toward the granodiorite portions of intrusion E, and may comprise up to approximately half of the feldspar component of the quartz monzonite (intrusion F). The alkali feldspars commonly mantle plagioclase phenocrysts in the central parts of the complex, and myrmekitic intergrowths between adjacent feldspars are common.

Quartz occurs in minor amounts in the outer mafic rocks. It shows a general increase in abundance toward the more felsic rocks in central parts of the complex, and locally may form up to 20% of the quartz monzonite core rocks.

The major ferromagnesian mineral in the outer mafic rocks apparently was clinopyroxene; now largely converted to hornblende or uralite, biotite and iron-oxides. Relect pyroxene-crystal forms and cores of aegirine-augite are common.

Cumulus pyroxene was the predominant mineral in intrusion B and in several local areas in the gabbroic rocks.

Primary hornblende first appears in significant amounts in local areas of intrusion C, and may comprise up to half of the mafic component of intrusion D. Hornblende is the predominant mafic mineral in the outer dioritic portions of intrusion E, however, biotite gradually becomes predominant as the rocks grade into granodiorite. The quartz monzonite (intrusion F) usually contains less than 5% mafic minerals.

Accessory minerals in the mafic rocks include Fe-Ti oxides (usually magnetite), apatite, and Ti-spinels. Magnetite and apatite occur in significant amounts in intrusion D, where they appear to have been cumulus . One small area in the northwestern portion of intrusion E contains up to 5% magnetite, but its concentration in this area likely reflects contamination by material from nearby iron formations in host rocks.

Allanite is a common accessory mineral in the more felsic rocks. Sulphide minerals and precious metals occur in rare areas of the mafic rocks, and are associated with breccia pipes and shear zones in intrusions E and F.

Most of the rocks of the complex are relatively fresh and unaltered, and observed mineralogical changes likely reflect late-stage magmatic alteration (deuteric alteration), or very local contact metamorphism and reaction between the intrusions. Previously recognized cataclastic textures (House, 1955) likely represent presolidification movement.

An overall compositional trend is shown by rocks of the complex; from outer mafic rocks to inner felsic rocks. This trend may be related to a common source for the magmas, possibly a differentiating magma chamber at depth. The concentric zoning trend of intrusion E, from outer diorite to inner granodiorite, suggests that differentiation processes may have taken place after emplacement of this magma.

CHAPTER 3

PRIMARY FABRIC STRUCTURES OF THE COMPLEX

INTRODUCTION

Although each intrusion of the complex displays its own set of primary structures, they are usually best displayed in the more mafic rocks. These structures provide insight into processes related to the emplacement, crystallization, and consolidation of the complex.

MINERAL ORIENTATION STRUCTURES

All of the rocks of the complex display some form of preferred orientation of mineral constituents. The preferred orientation structures,involving just the cumulus and phenocryst minerals, form the basis of linear and planar structures in the rocks.

Mineral lineations reflect the linear alignment of long axes of primary minerals in the rocks (Figure 15a). In the Falcon Lake complex most of the porphyritic rocks (intrusions E and F) display a linear alignment of feldspar phenocrysts. These mineral lineations are steep, usually near vertical, and their presence is difficult to determine mesoscopically on horizontal outcrop surfaces.

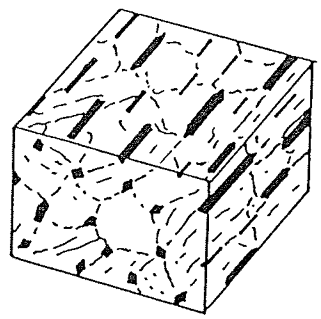
Planar laminations reflect the planar alignment of primary minerals (Figure 15b), similar to metamorphic foliations. The long axes of primary minerals lay within a plane, but do not show a linear alignment. Planar laminations are prevalent throughout most of the cumulate textured rocks (intrusions A,B,C,D), but are weakly defined in many areas, especially where the cumulus plagioclase crystals are equant rather than lath-shaped. Well defined planar laminations are prominent fabric elements in layered rocks throughout the complex. The near perfect combined planar alignment of primary minerals and the linear alignment of their long axes in those planes (Figure 15c) has led to the development of a lineate lamination (Jackson,1967) in some of the layered rocks. Rapid and somewhat irregular changes in the orientation of the planar laminations produce wavy, swirled, and occasionally streaky patterns in the rocks. Rocks displaying these structures occur in specific areas of both layered and unlayered rocks; in individual horizons in layer sequences,in areas of disrupted layering, in association with irregular intrusive contacts, and around inclusions.

The varied forms of these preferred orientation structures, as well as their varied arrangement, suggest that they were produced by fluctuating flow conditions. This flow appears to have acted upon a crystal-bearing magma.

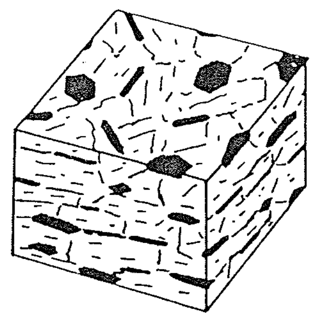
LAYERING AND LAYERING ASSOCIATED STRUCTURES

Layering occurs within each intrusion of the complex, but is usually better displayed by the more mafic rocks and near intrusive contacts (Figure 16). Layering has been found in only one area of intrusion A, in a large trough-like structure in the northeastern extension of the complex. Repeated variations from pyroxenite to melagabbro between the few scattered outcrops of intrusion B may represent layering tens of metres thick. Intrusions C, D, and E contain most of the layering discovered so far in the complex, including extensive areas that display complex layer configurations and layer-related structures. Layering in quartz monzonite of intrusion F appears to be restricted to its outer contact in the northern portion of the intrusion.

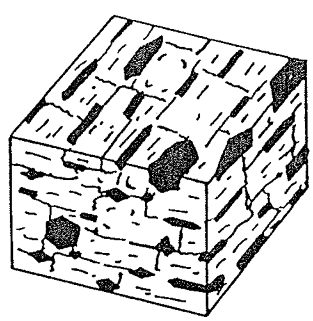
The scale and continuity of the layering varies considerably. Layers range in thickness from a few millimetres to tens of metres. Some layers occur as



15a



15b



15c

Figure 15. Illustrations of anisotropic fabrics displayed by rocks of the complex (modified after Best,1982): (15a) mineral lineation– linear alignment of long axes of primary minerals; (15b) planar lamination– a planar alignment of primary minerals ; (15c) lineate lamination– combination of linear and planar alignments.

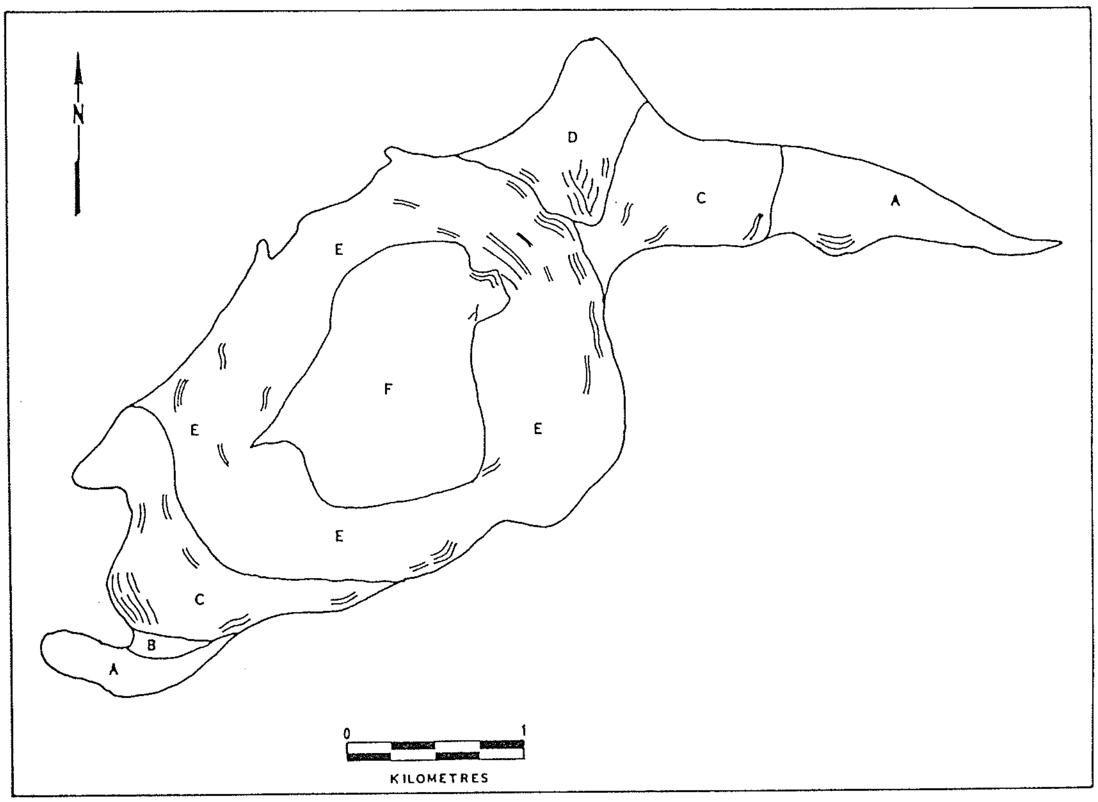


Figure 16. General distibution of layering found to date within the complex.

individual entities in wide expanses of uniform unlayered rocks, but most occur in packages or sequences containing several layers. Some layers and layer units can be traced along strike for several hundred metres; others disappear within a single outcrop.

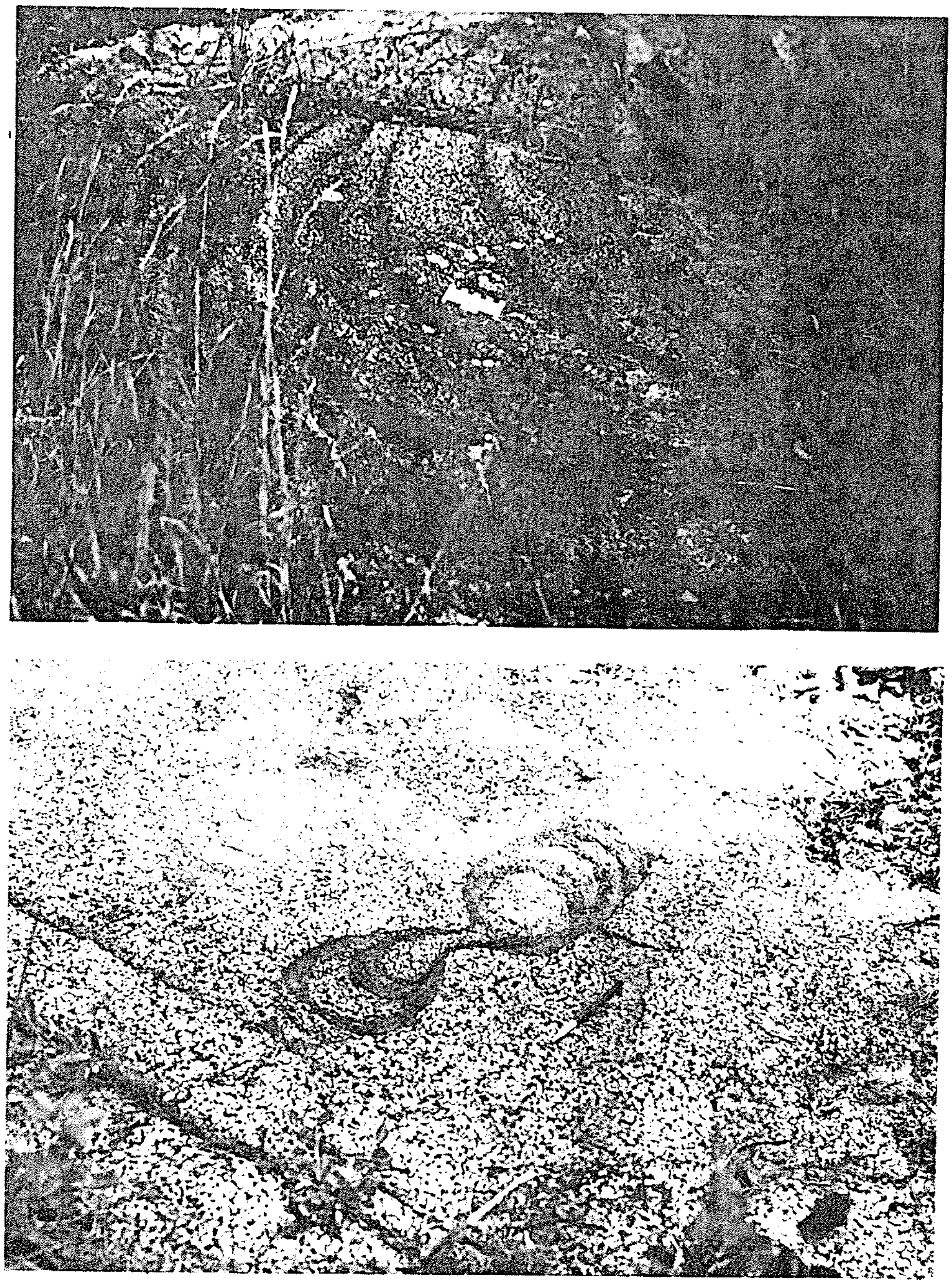
The layers are usually steeply dipping and have strikes arranged in a concentric pattern within each intrusion (Figure 16). The layering tends to be parallel to neighbouring intrusive contacts, and is accompanied by planar laminations. Although planar laminations are prevalent throughout the layered rocks, individual horizons and local areas vary from displaying only mineral lineations to lineate laminated or wavy and swirl patterned structures. Local variations in the attitude of layering and mineral alignments including near-horizontal orientations have been observed. The layers are usually straight planar structures, however, curviplanar layers and trough-structures, as well as several unusual structures, are common in several areas (Figure 17).

Most of the layers in the complex are modally graded; from mafic-rich bases to feldspar-rich tops (Figure 18). The compositional gradations are commonly accompanied by grain size gradations that produce sedimentary-like reverse graded beds; the feldspars are usually coarser grained than the mafic minerals. Ungraded layers of uniform rock may alternate with modally graded layers (Figure 19.), or with unimodal-mafic layers and laminae (Figure 20). Alternating mafic-rich and feldspar-rich bands also occur (Figure 21).

Sharp layer contacts are common throughout the complex, gradational contacts are uncommon. Topping directions of layers and layer-related structures consistantly face inward toward the center of each intrusion.

Most of the areas of layering in the complex display structures similar to those formed in sedimentary environments. Some layers have wavy forms and

17a



17b

Figure 17. Examples of curviplanar layers: (17a) Curviplanar layers forming a small,steeply plunging trough-structure in gabbro from intrusion C. (17b) An unusual ' figure 8' structure in gabbro from intrusion D.

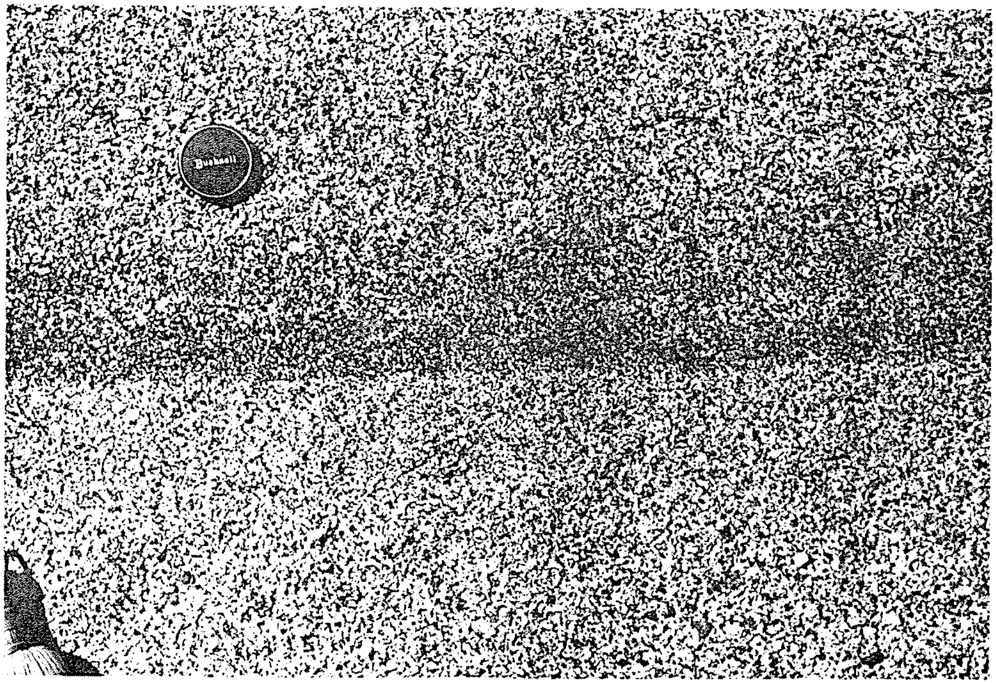


Figure 18. Example of modally graded layer in granodiorite of intrusion E. The mafic-rich base grades into uniform rock over 10 cm.

Figure 19. Example of alternating modally graded layers and uniform rock layers (granodiorite from intrusion E).

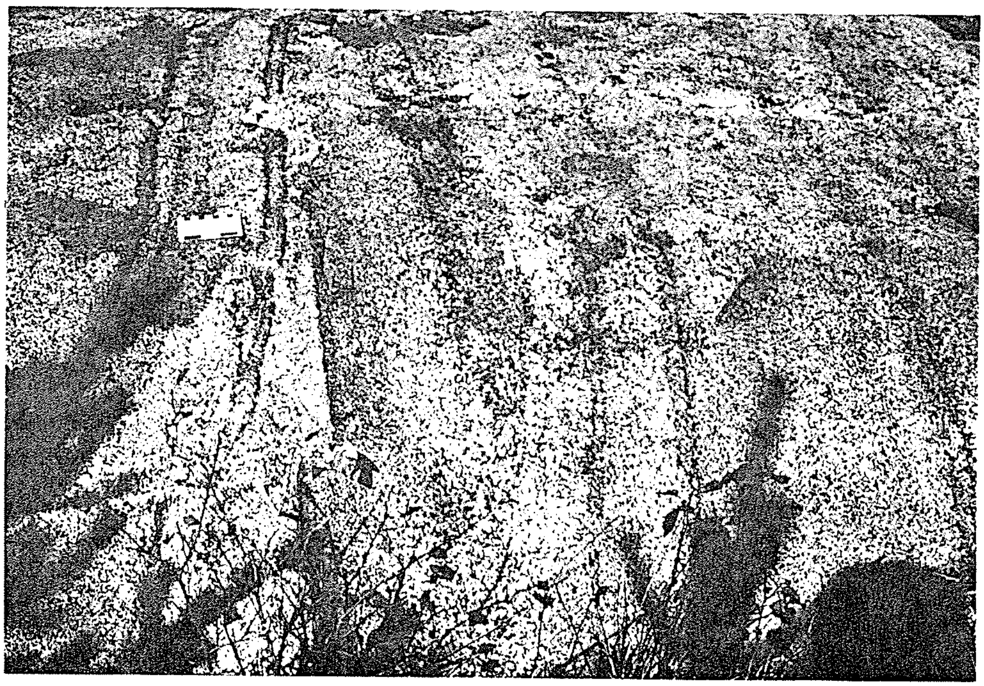


Figure 20. Example of a sequence of alternating layers of uniform rock, unimodal-mafic layers and laminae, and modally graded layers (gabbro from intrusion C). The modally graded layer near the center of the photo (arrow) marks a contact between two layer subunits; the layers on the left dip at approximately 65 degrees to the left, the layers on the right are near vertical.

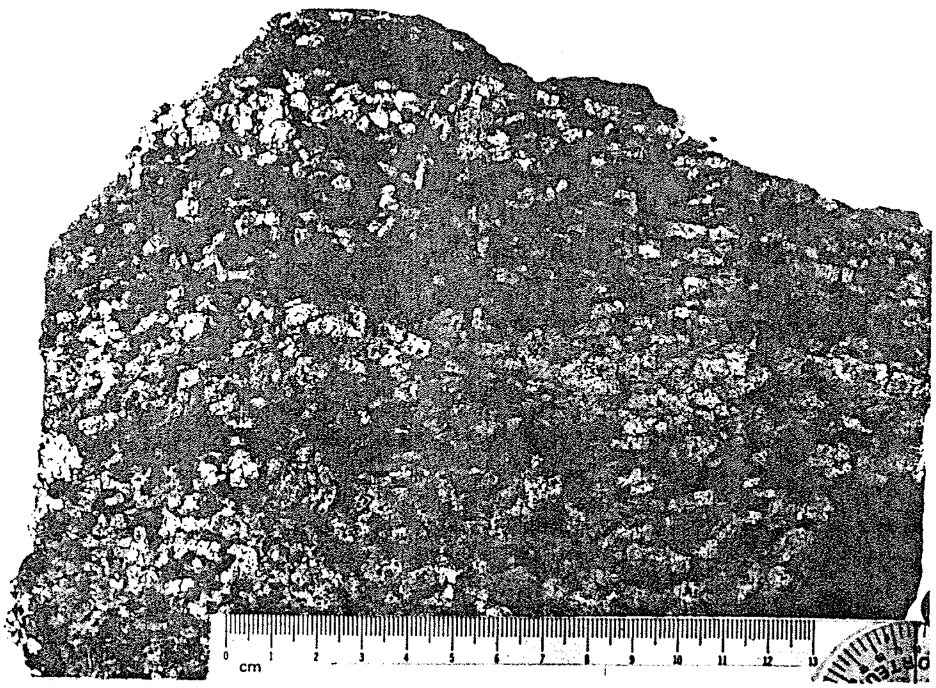


Figure 21. Example of alternating mafic-rich and feldspar-rich bands from intrusion D. This example also displays a well developed planar lamination.

appear to pinch and swell along strike, some appear to have been disturbed by the presence of inclusions (Figure 22), and others appear to have been rolled or folded (Figure 23). In some layer sequences, layers appear to join with then separate from adjacent layers. This joining and bifurcation of layers in a horizontal outcrop (Figure 24a) has been correlated with similar layering on a vertical exposure (Figure 24b).

There are also structures in the layered areas that suggest that previously consolidated or partially consolidated rocks have been subjected to periods of sedimentary-like erosion. These structures include discordant contacts between layer sequences that are similar to angular unconformities (Figure 25), and trough-banded structures similar to scour channels (Figure 26). The scale of development of these structures varies from features with dimensions of less than a metre, to others that are so large that they cannot be observed in their entirety in several adjacent exposures (Figure 27). In most examples of unconformities the older rocks have been eroded at a high angle to layering, and the new layers formed parallel to the erosional surface. In several areas the new layering has formed in a buttress configuration against the unconformity surface; mapping in these areas suggest that the new layering forms part of a large-scale trough-banded structure. Several small sequences of layering contain structures similar to cross-bedding in sedimentary rocks.

Most trough-banded structures occur near outer intrusive contacts of the intrusions or along unconformity surfaces in the layered rocks. Layering of the younger material in the troughs usually forms in a buttress configuration against well defined margins of what were likely scour channels. Several trough structures, however, contain a series of curviplanar layers that grade laterally into uniform unlayered rocks. A small trough has also been found at the base of a thin layer

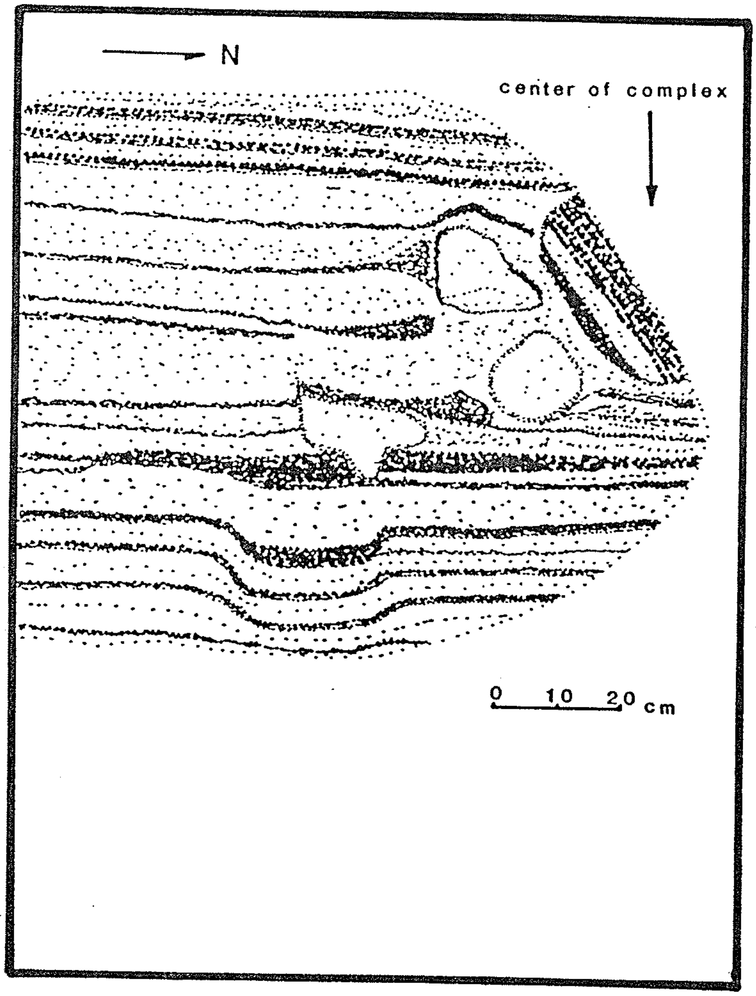
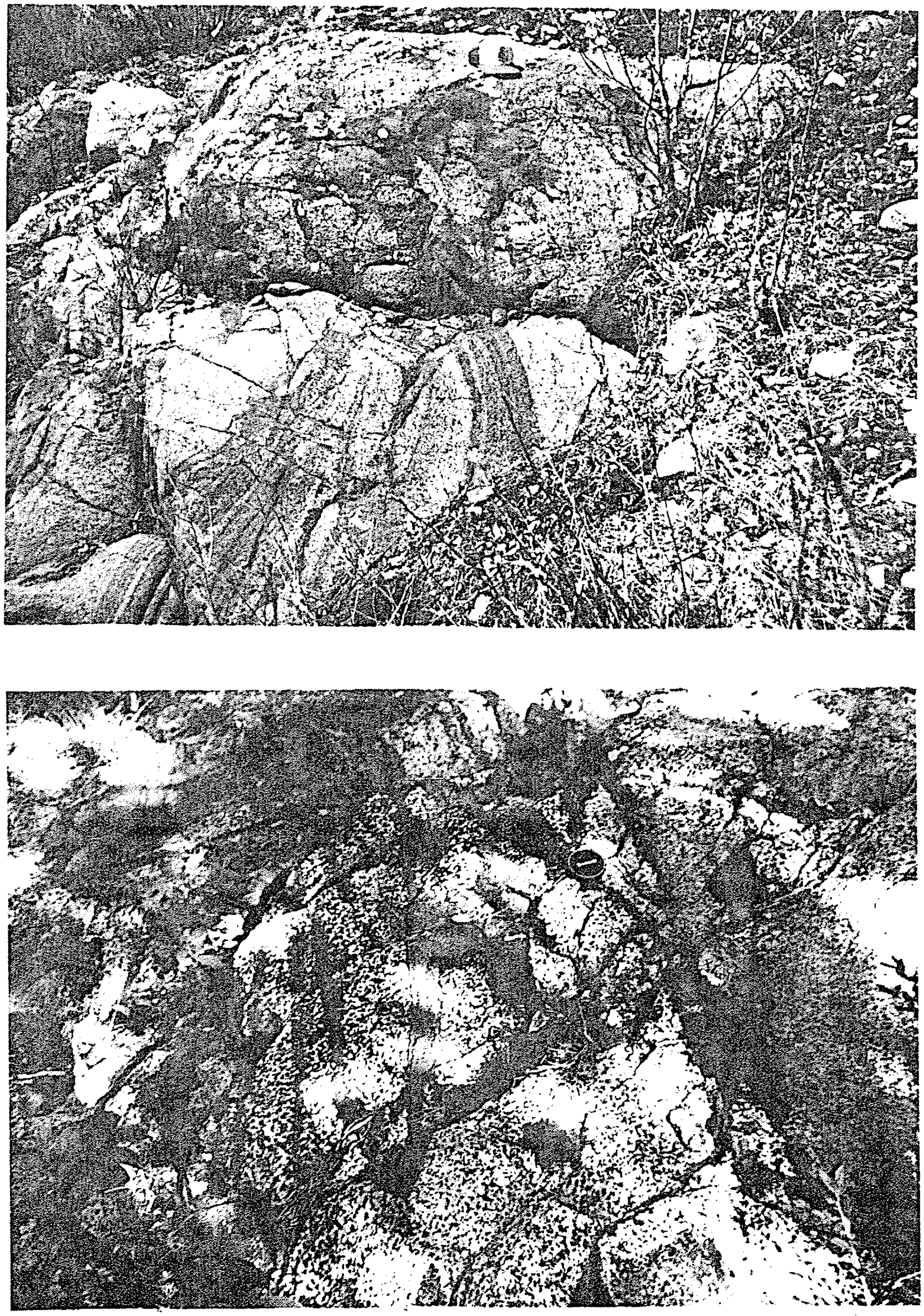


Figure 22. Example of inclusions within a layer sequence. The layering has been disturbed, and the planar laminations have become wavy and swirled around the inclusions.

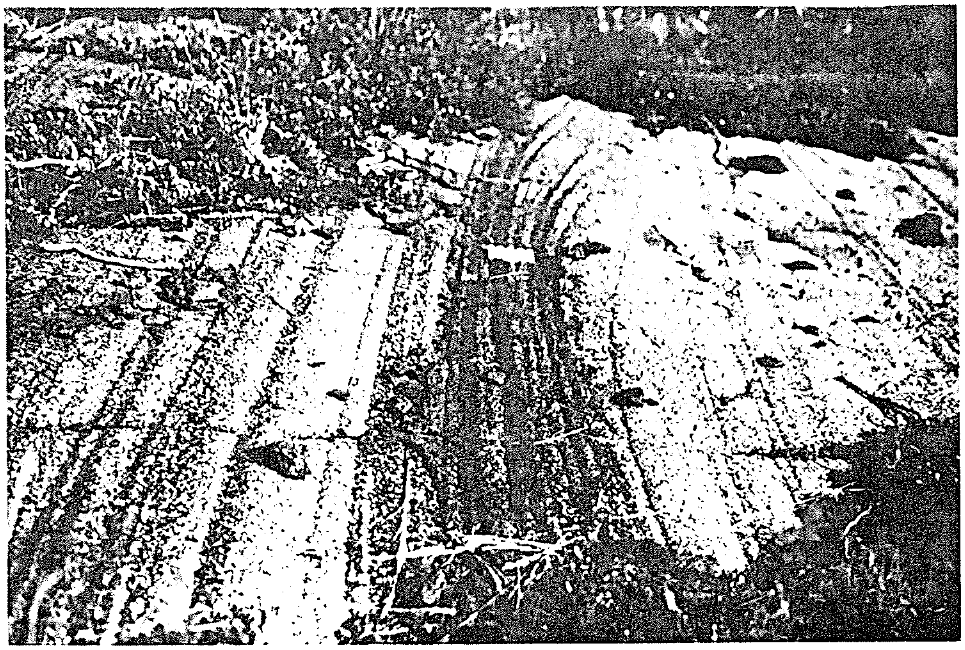
23a

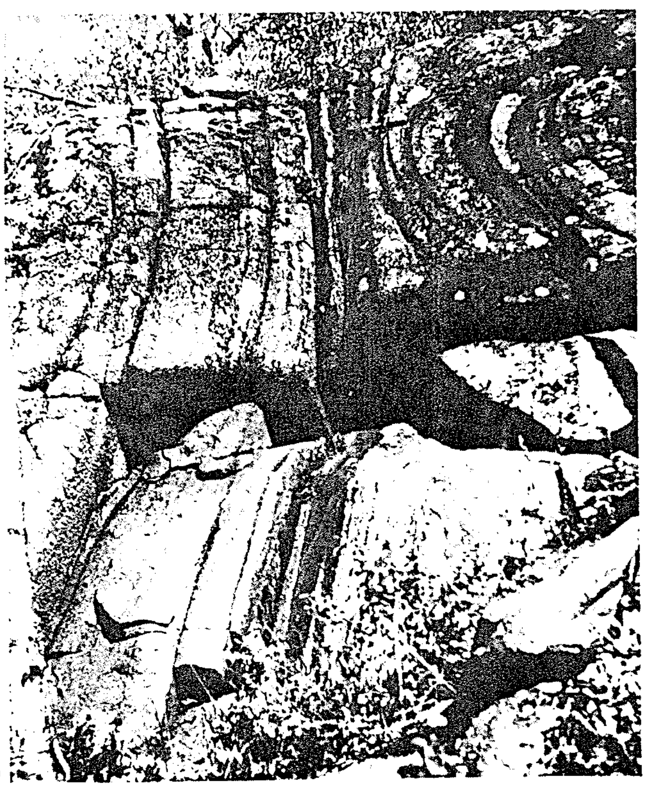


23b

Figure 23. Examples of folded layers. (23a) A folded sequence of layers from a trough structure in intrusion A; (23b) Several folded layers from along an unconformity in intrusion D.

24a





24b

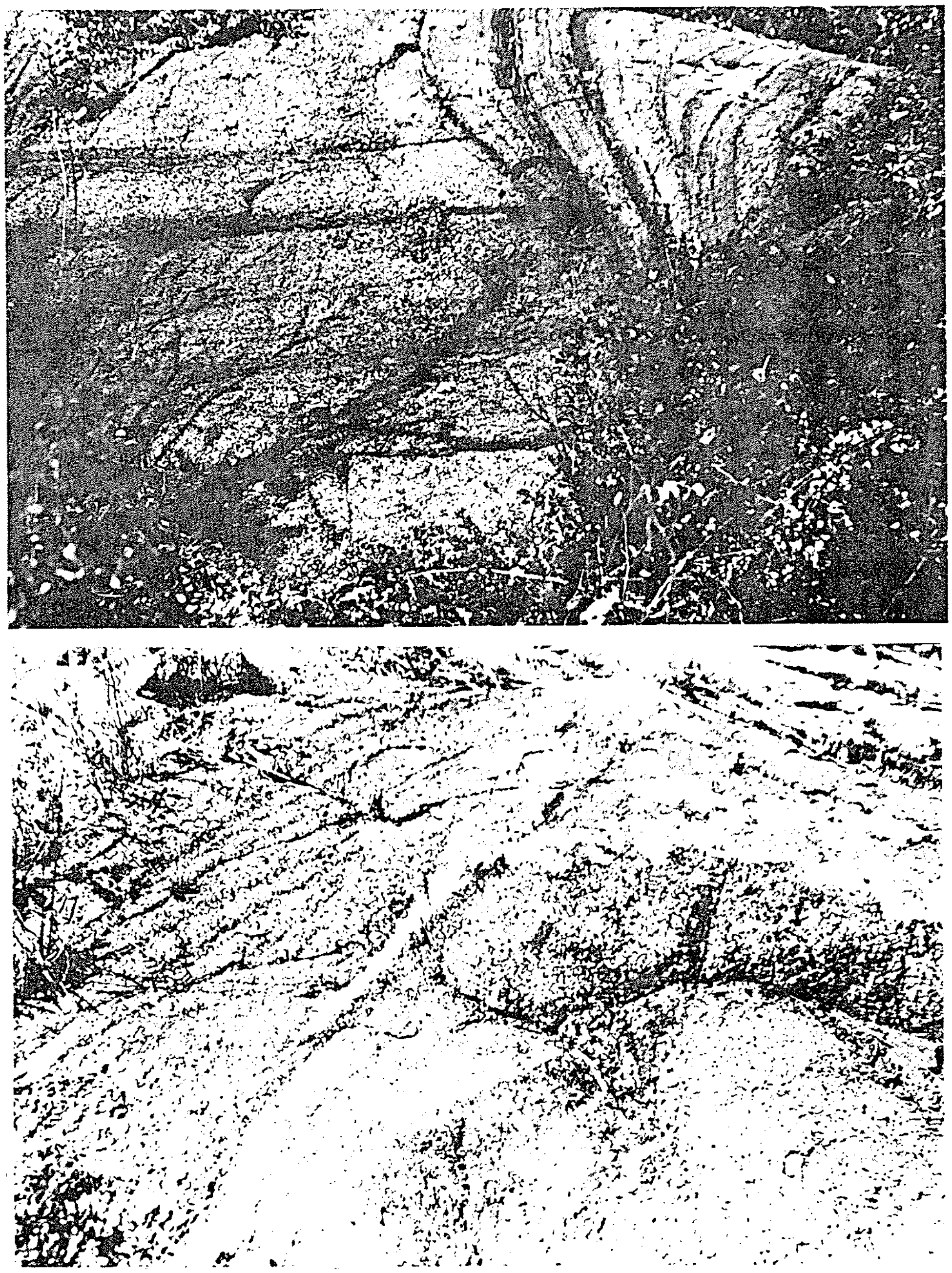
Figure 24. Joining and bifurcating of mafic-rich layers: (24a) Oblique view of horizontal outcrop surface with a sequence of modally graded layers (left), mafic-rich layers that show joining and bifurcation (centre), and paired mafic laminae (right); (24b) View of vertical outcrop surface correlated with rocks in Figure 24a. The thick mafic-rich layer near the center of the photo is made up of several individual layers that join and bifurcate along their traces. The curviplanar layers at the right of the photo have been interpreted to be part of a coincident trough structure or a slump structure.

sequence (Figure 28), well within intrusion E. The trough structures usually plunge steeply and parallel to the intrusive contacts and unconformities. Several diffuse troughs in diorite along the southern contact of intrusion E with host rocks, however, have been found to have shallow plunges normal to the intrusive contact.

One area of layering contains several small-scale fault structures that suggest that brittle or quasi-brittle fracturing occurred concurrently with layer formation (Figure 29). The presence of this type of fracturing, as well as the occurrence of angular layered cognate inclusions (Figure 30) within individual horizons of layered rocks, suggest that fracturing and erosional processes occured concurrently with layer formation within specific areas of the complex.

The origin of the layering and layering-related structures is problematic. The variable orientations of the layering, as well as the numerous scour and truncation structures, preclude an origin by simple crystal settling or *in situ* crystallization and differentiation in a static magma chamber. They do, however, suggest that magmatic flow was a prevalent process at the time of their formation. Crystal-liquid segregation and crystal sorting stimulated by magmatic flow, and accretion of material against steep side-walls or in steep solidification fronts are processes possibly responsible for the formation of the layering. Periodic erosion by turbulently flowing magmas was likely responsible for the scours and unconformities. The form and relationships between the various structures suggest that hydraulic conditions similar to those in sedimentary environments were likely responsible for the layering and other structures, and point to periods of fluctuating flow conditions, as well as changing directions of flow, before complete consolidation of each intrusion. The origin of the layering and layering related structures will be discussed in more detail in later sections.

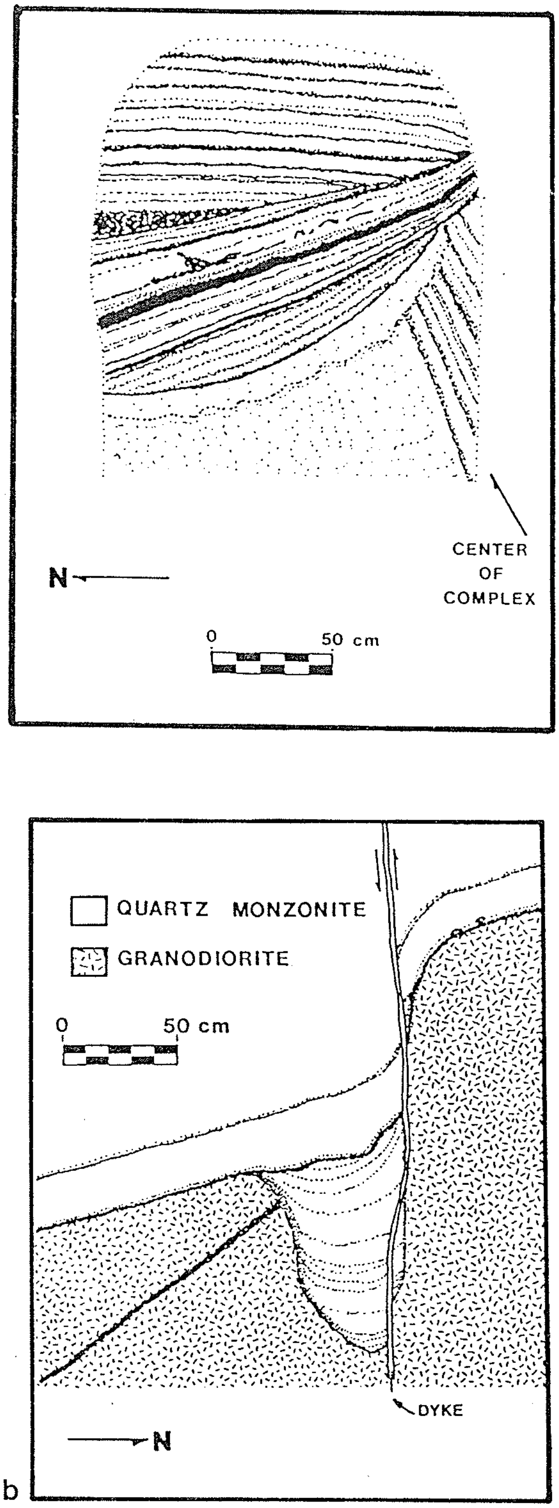
25a



25b

Figure 25. Examples of discordant contacts similar to unconformities: (25a) Oblique view of unconformity between Unit 1 (left) and Unit 2 (right) from Southwest Detailed-Study Area. The layers of Unit 2 form part of a large-scale trough structure. (25b) Oblique view of unconformity between layer Units 2 and 3 from Southwest Detailed-Study Area.

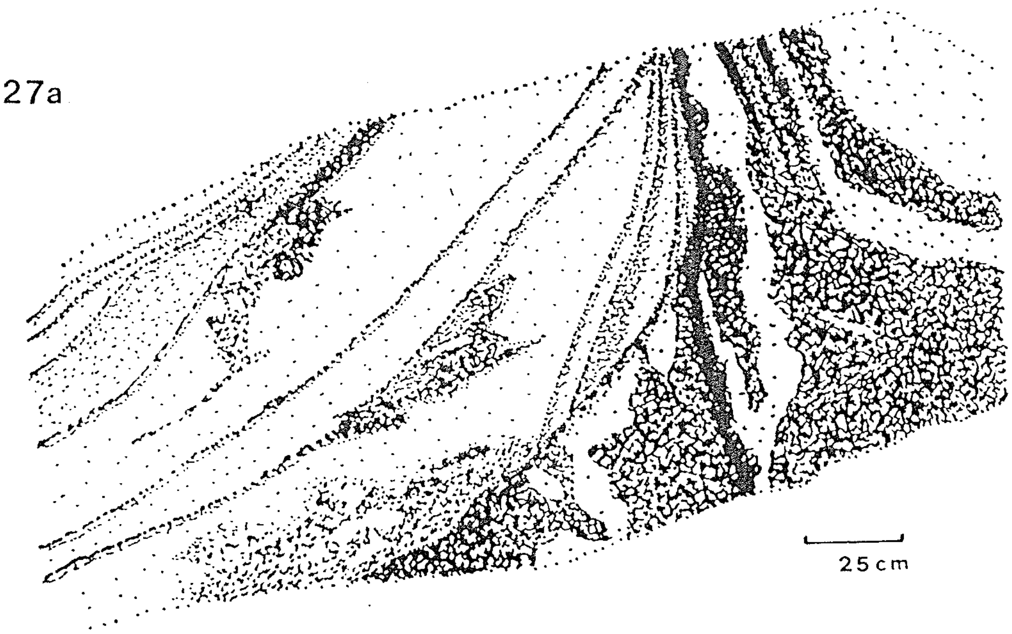
26a

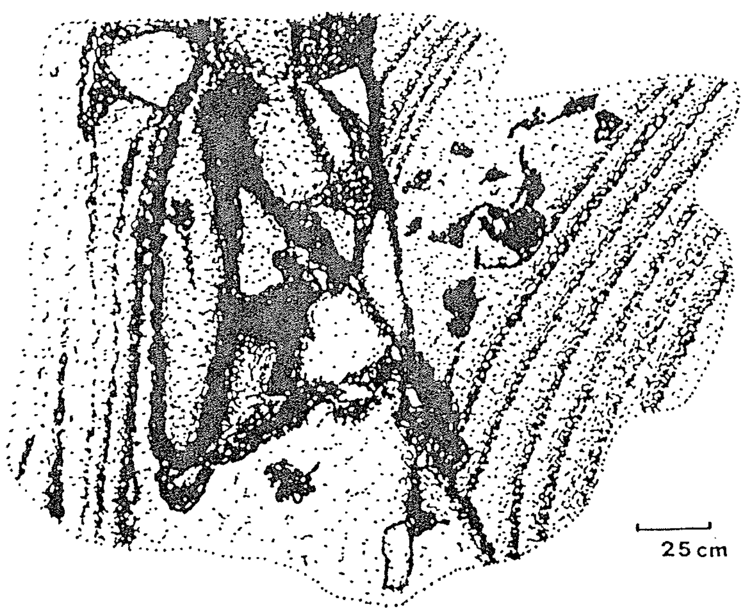


26b

Figure 26. Examples of trough-banded structures similar to scour channels: (26a) Plan view of part of a trough-structure formed against an unconformity (see figure 25a); (26b) Illustration of trough-structure in quartz monzonite (intrusion F) formed against the contact with granodiorite (intrusion E).

27a

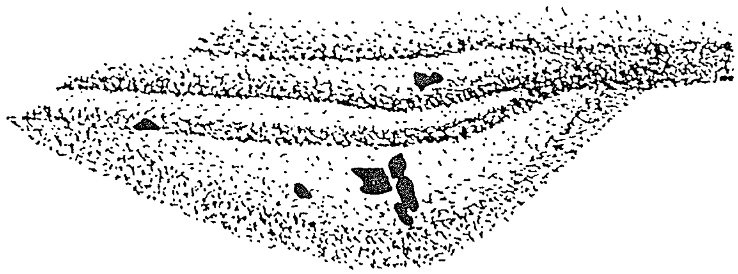




27b

Figure 27. Examples of outcrops along a large-scale unconformity: (27a) Illustration of part of an unconformity between layer Units 1 and 2 from intrusion D ; (27b) Illustration of part of the unconformity between layer Units 1 and 2 in intrusion D (approximately 100 meters south of Figure 27a). The layering of Unit 1 (right) has been truncated and layering of Unit 2 developed parallel to this unconformity. The first several layers in this area of the contact have been disturbed and folded .

28 a



28b

Figure 28. Plan view sketch (28a) and oblique photograph (28b) of a trough-structure formed at the base of a 20cm thick layer sequence in granodiorite of intrusion E. The layering contains several small xenoliths of host rock material concentrated in the trough and along the layer sequence.

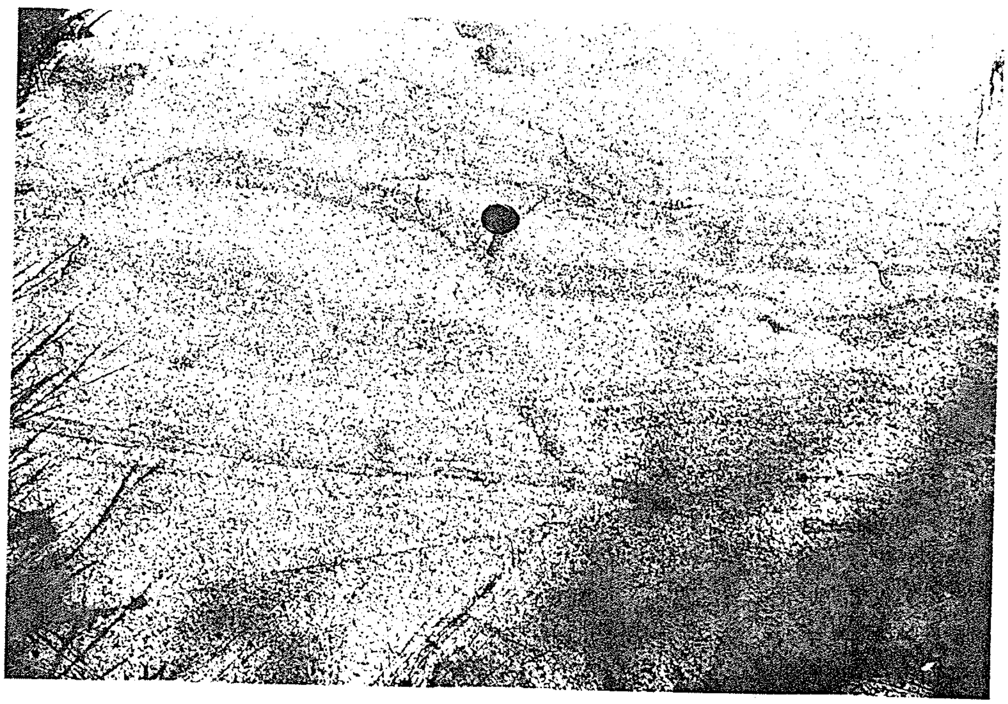


Figure 29. Part of a granodiorite outcrop with numerous modally graded layers that have been affected by several small faults with right-lateral or left-lateral apparent movements. Several faulting events apparently occured during layer formation as many of the faults affect only 2 or 3 layers, while others extend throughout the layer sequence.

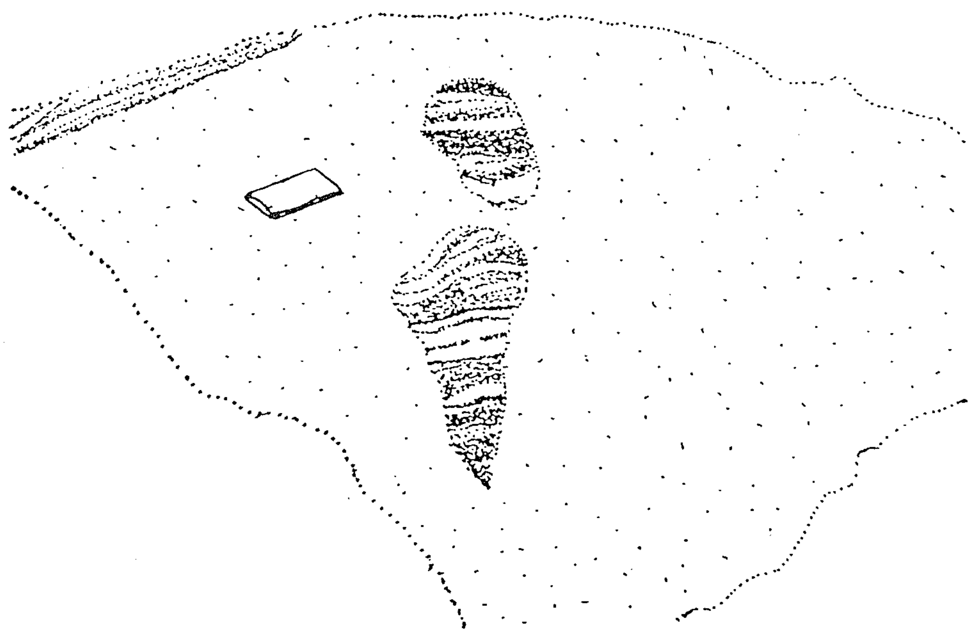


Figure 30. Layered inclusions of diorite within layered granodiorite in intrusion E. Width of book in illustration approximately 15cm.

MINERAL SEGREGATIONS

Segregations and clots of minerals occur most frequently in layered areas of the gabbroic rocks. Several different types occur, and their mode of occurrence provides insight into processes affecting the rocks. Interpretations of these structures will be discussed in more detail in later sections.

Mafic-mineral clots

These clots are most common. They commonly occur in groups or in trains several metres in length. They may be confined to a given stratigraphic interval in a layer sequence, in areas of disturbed layering, or near irregular contacts. Individual clots usually diplay sharp boundaries, and have irregular shapes, elongate forms, or ball-like forms (Figures 31 and 32). Sizes are variable, from centimetre size glomerocrysts to elongate forms several metres in horizontal and vertical dimensions. The maximum elongation directions are generally parallel to neighbouring mineral alignments and layering, however, most clots are found in wavy and swirl patterned rocks.

Cross-cutting mafic-mineral clots

There are several occurrences in intrusion D of mafic-mineral clots that crosscut the fabric in surrounding rocks (Figure 33). They usually have irregular shapes and sharp contacts with surrounding rocks. Dyke-like extensions can extend up to 3 metres from the main body of these clots.

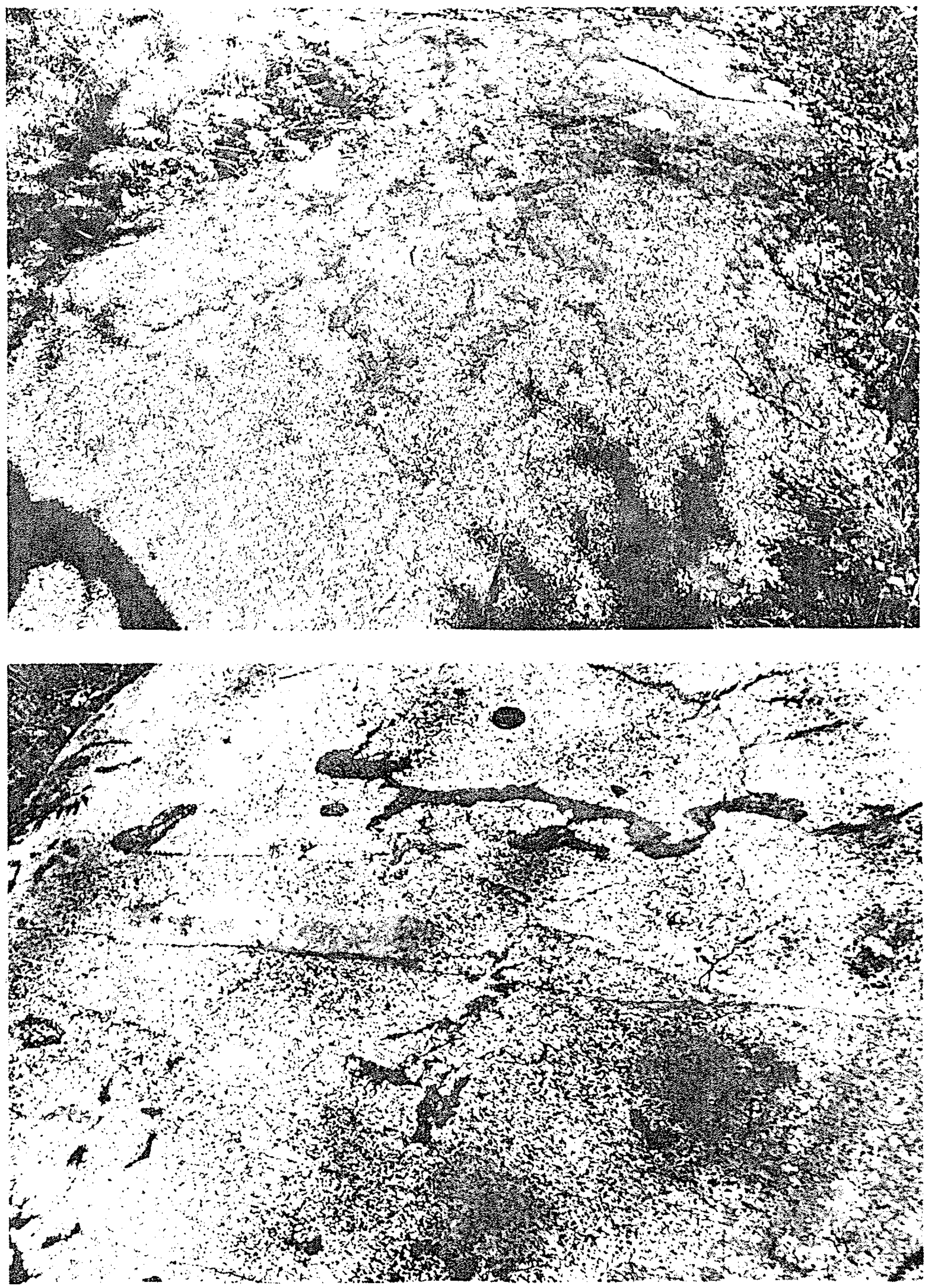
Feldspar-rich segregations

Only a small area in intrusion D contains feldspar-rich mineral segregations. The segregations usually have irregular forms, coarse grained to pegmatitic textures, and cross-cut the fabric of surrounding rocks (Figure 34).

Quartz-bearing segregations

Intrusion D also contains an area with mineral segregations of pegmatitic

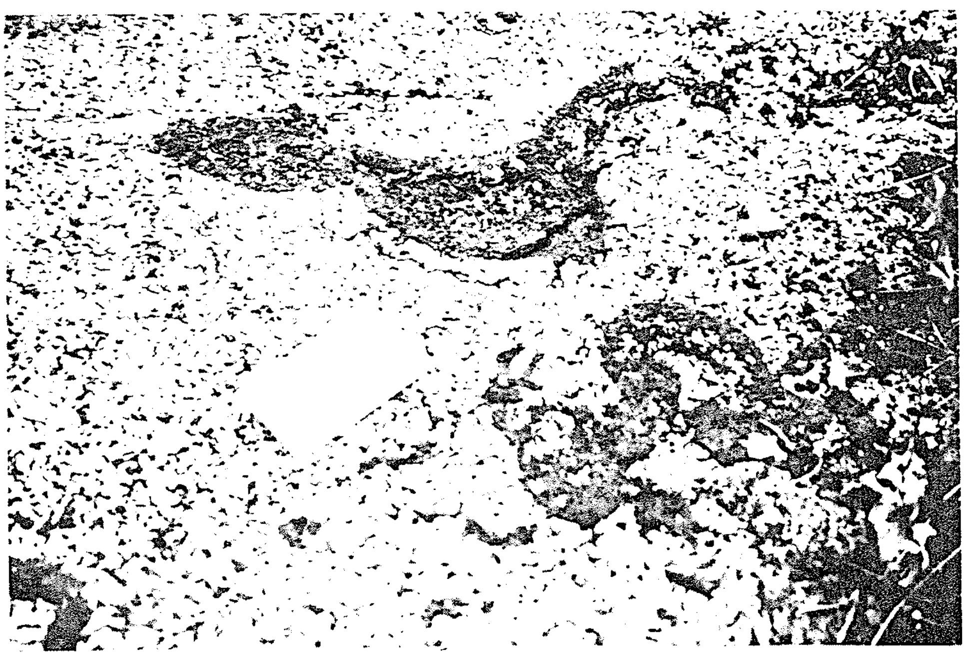
31a



31b

Figure 31. Examples of mafic-mineral clots: (31a) Irregular shaped clots ; (31b) Elongate shaped clots.

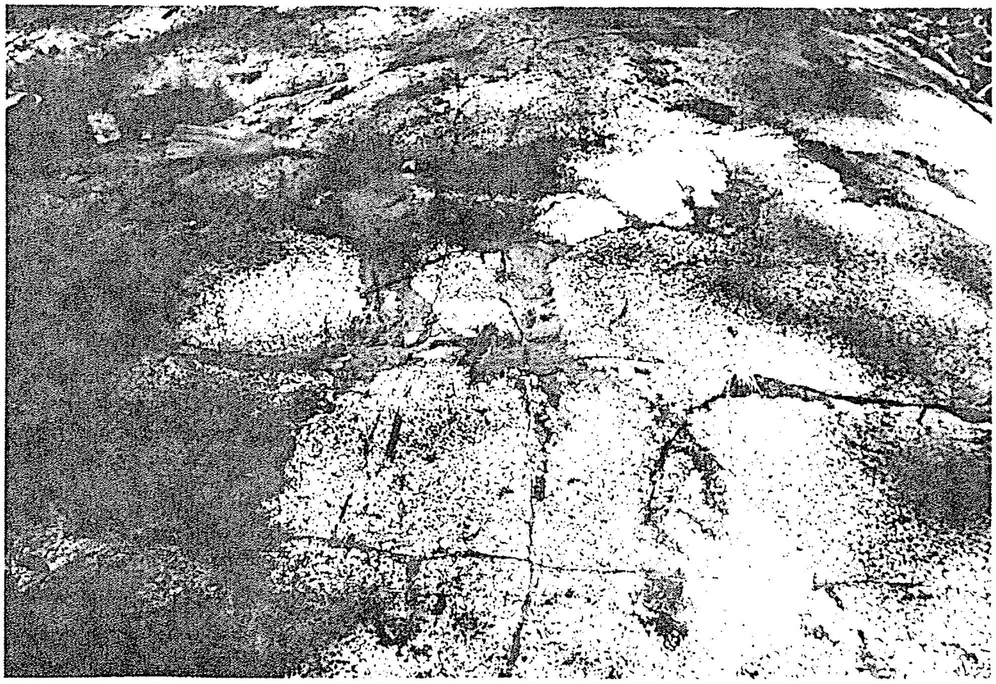
32a



32b

Figure 32. Examples of ball-like structures.

33a



33b

Figure 33. Examples of a mafic-mineral clots with dyke-like extensions that cross-cut the fabric in surrounding rocks.

Figure 34. Example of feldspar-rich clot.

feldspar, hornblende, and quartz. These segregations have sharply bounded, rounded forms, usually 5-10 cm in diameter (Figure 35).

Coarse gabbroic segregations

These segregations are also found only in intrusion D. They are gabbroic in composition, but of a much coarser grain size than the surrounding gabbro. Thay have irregular forms that are generally elongate parallel to the surrounding mineral alignments (Figure 36).

XENOLITHS AND COGNATE INCLUSIONS

Inclusions within the complex consist of xenoliths of surrounding country rocks, cognate inclusions derived from the component intrusions of the complex, and several of unknown origin that have not been correlated with any rocks observed around the complex. The inclusions range in size from a few centimetres up to approximately 5m by 15m. They usually have sharp boundaries, and angular to subrounded shapes. They may occur as isolated bodies, but more often are clustered near intrusive contacts or in scour structures. Xenoliths of host rock material have been found in all intrusions of the complex except intrusion B. The compositions of the cognate inclusions becomes more varied toward intrusion F, providing insight into the emplacement sequence of the intrusions (Table 1).

Table 1. Distribution of inclusions and dykes in the Falcon Lake complex

INTRUSIONS	INCLUSIONS	DYKES
A	host rocks	E,F, autointrusive
B	none found	F
C	host rocks, A,B, autoliths	E,F, autointrusive
D	host rocks, A,B,C, autoliths	E,F, autointrusive
E	host rocks, C,D, autoliths	F, autointrusive
F	host rocks, A,C,D,E, autoliths	autointrusive

The presence of inclusions points to the erosive capability of the magmas, and

Figure 35. Example of a quartz-bearing segregation.

Figure 36. Example of coarse grained gabbroic segregations.

suggests that stoping was likely an important emplacement process. In several layered areas autoliths have been found concentrated in scour structures or within specific stratigraphic intervals in a layer unit. The presence of autoliths indicates that the erosion and transport of previously consolidated material of individual intrusions occurred periodically.

DYKES

Dykes of material derived from member intrusions of the complex occur from place to place. They are steeply dipping, show evidence of dilation, and appear to radiate out from central parts of the complex. They usually have sharp contacts with little evidence of chilling.

Dykes of inner intrusion material are found in the outer intrusions, and along with the inclusions provide evidence for interpreting age relationships between the intrusions (Table 1).

There are also occurrences of autointrusive dykes in several of the intrusions. These dykes indicate that consolidation of rocks in certain portions of the individual intrusions had reached levels capable of supporting brittle or quasi-brittle deformation while other portions were still relatively fluid.

BRECCIA PIPES

Two breccia pipes are known to occur in the complex, both near the centre of the body. These structures are characterized by breccia zones with milled-rock matrix, sheet fracturing, alteration and mineralization. The Sunbeam-Kirkland structure in intrusion F has been developed as a gold mine (presently not operating), the Moonbeam structure along the northern contact of intrusions E and F is presently undeveloped. Independant studies of these structures (Halwas,1984; Barc,1985; Fingler,1986) have led to the interpretation that the structures likely represent late-stage, volatile-rich periods in the development of the complex.

CHAPTER 4

PRIMARY STRUCTURES AND THEIR RELATIONSHIPS IN THREE DETAILED-STUDY AREAS

INTRODUCTION

The relationships between primary structures have been studied in detail in three areas where exposure is exceptionally good. Each area was mapped at a scale of 1:100 and results are presented on Maps # 2 and # 3 (in attached pocket). The results of the mapping formed the basis of the observations and interpretations presented in the following sections.

SOUTHWEST DETAILED-STUDY AREA

This area includes a portion of the contact between host metavolcanic rocks and rocks of intrusion C along the southwestern edge of the complex (Map # 2). The layered rocks are exposed on two ridges separated by a topographically-low area occupied by a beaver-pond. To the north and east of these outcrop ridges the layering disappears into relatively uniform, sporadically layered gabbro. To the south of this area are rocks of intrusion B of the complex. Pyroxenite and melagabbro of intrusion B also occupy a large outcrop in the area of the beaver-dam,however, it is not known whether this outcrop is a large inclusion or an *in situ* remnant of the previous intrusion.

The layering in this area consists of modally graded layers, ungraded layers of uniform gabbro, and unimodal mafic layers and laminae. The layers are of various sizes, shapes and orientations, and usually occur as alternating sequences of several types. Both planar and curviplanar forms are common. Well developed planar laminations are prevalent throughout this area, and regularly have orientations parallel to the layering. Lineate laminations and wavy and swirl patterned horizons are uncommon.

The area can be subdivided into discrete units on the basis of characteristic layering and layering structures. Numerous structures such as unconformity-like and scour-like truncations are present on scales of less than a metre to features tens of metres in extent. The individual units are usually bounded by large-scale structures similar to unconformities, several of which have been traced across most of the detailed-study area (Figure 37 and Figure 38). A vertical outcrop exposure (Figure 39 and Figure 40) has permitted extrapolation of features observed on horizontal outcrop surfaces into the third dimension.

The northern outcrop ridge in this detailed-study area forms the basis of an interpretive three-dimensional block diagram (Figure 41). In this diagram the rocks are subdivided into six layer units, each possessing characteristic features. Table 2 presents a summary of the dominant characteristics of the units.

The rocks of this northern outcrop-ridge have also been cut by dykes of younger material that originated from more central parts of intrusion C (autointrusive dykes of gabbro), and from intrusive activity in later more central parts of the complex (aplitic diorite and quartz monzonite dykes). One quartz monzonite dyke displays a small area of layering.

The arrangement of the layer units and their structural relationships in this detailed-study area have provided evidence critical to understanding the emplacement of intrusion C. These include:

a) The overall shape of the outer intrusive contact of intrusion C in this area, as well as the arrangement of structures in this area, suggest that the entire layered area is part of a large-scale scour and trough-banded structure.

Table 2. Dominant characteristics of layering units, S.W. Detailed-Study Area

UNITS	CHARACTER
Unit 1	Concordant curviplanar layering generally parallel to outer contacts. Uniform gabbro layers alternating with modally graded layers and mafic laminae. Discordant lenses of pegmatitic gabbro (crescumulate ?). Local concentrations of host rock xenoliths along contact.
Unit 2	Curviplanar layering with several small-scale unconformities between subunits. Buttress configuration of layering against unconformities (see Figures 28a and 29a). Alternating modally graded layers, uniform gabbro layers, and mafic laminae.
Unit 3	Concordant planar layering parallel to unconformity between Units 3 and 2. Alternating mafic-rich layers and uniform gabbro layers. Layer horizon rich in xenoliths and inclusions, and associated disturbed layers.
Unit 4	Alternating curviplanar and planar layers. Discordant contacts between subunits. Local trough structures (see Figure 17a). Well exposed vertical cliff-face with up to 10m relief (see Figures 39 and 40). Alternating sequences of modally graded layers, uniform gabbro layers, and mafic laminae.
Unit 5	Single massive layer of coarse grained, leucocratic to anorthositic gabbro. Contacts with adjacent units not exposed.
Unit6	Concordant planar layer sequence. Interlayered modally graded layers, uniform gabbro layers, and mafic laminae, a clot-rich horizon of flow textured rocks, and an inclusion-rich horizon with associated disturbed layering.

b) Relationships between structures in this detailed-study area suggest a developmental sequence; from oldest on the outside to younger toward the centre of the intrusion.

c) The form and arrangement of the structures suggest that flow conditions alternated between periods of erosion and periods of layer formation and consolidation.

d) The varied orientations of the structures suggest that flow directions , as well as flow energies, were occasionally variable.

e) A general trend in the detailed-study area, from outer discordant structures to inner concordant structures, suggests an overall decrease in intrusive energy during emplacement of this intrusion.

NORTHEAST DETAILED-STUDY AREA

This area encompasses parts of intrusions C,D, and E in the northeastern part of the complex, and is displayed in the eastern portion of Map # 3. Figure 43 is an interpretive block diagram illustrating features of this area.

Rocks of intrusion C in this area are relatively uniform unlayered gabbro. They usually display a weakly defined planar lamination. The contact with intrusion D is highly irregular and marked by local concentrations of host rock xenoliths and inclusions of intrusions A and C in intrusion D. Intrusion C rocks are locally altered near this contact (see Figures 3a,and 4).

Intrusion D rocks in this area are mostly hornblende-magnetite gabbro. Mapping has revealed two large layered units in the detailed-study area. Unit 1 is characterized by well developed layers, generally oriented parallel to the intrusive contact with intrusion C. The layers are usually planar and dip steeply. Layer types include modally graded layers, mafic laminae, layers of uniform gabbro, and wavy and swirl patterned horizons rich in mafic-mineral clots, mineral segregations of various types, and inclusions. There is also evidence of a thick pyroxenite layer approximately 10 metres wide. Layer thicknesses range from 1cm to several tens of metres. Layering of Unit 1 has been truncated at a relatively high angle and the layering of Unit 2 has formed parallel to this unconformity-like angular discordant contact (see Figure 27). A 5 to 10cm thick mafic layer sequence containing laminae of cumulus magnetite and apatite has been found along most of the exposed unconformity surface. Layering in Unit 2 includes alternating modally graded layers, uniform gabbro layers, and mafic laminae within several metres of the unconformity, and thicker modally graded layers containing numer-

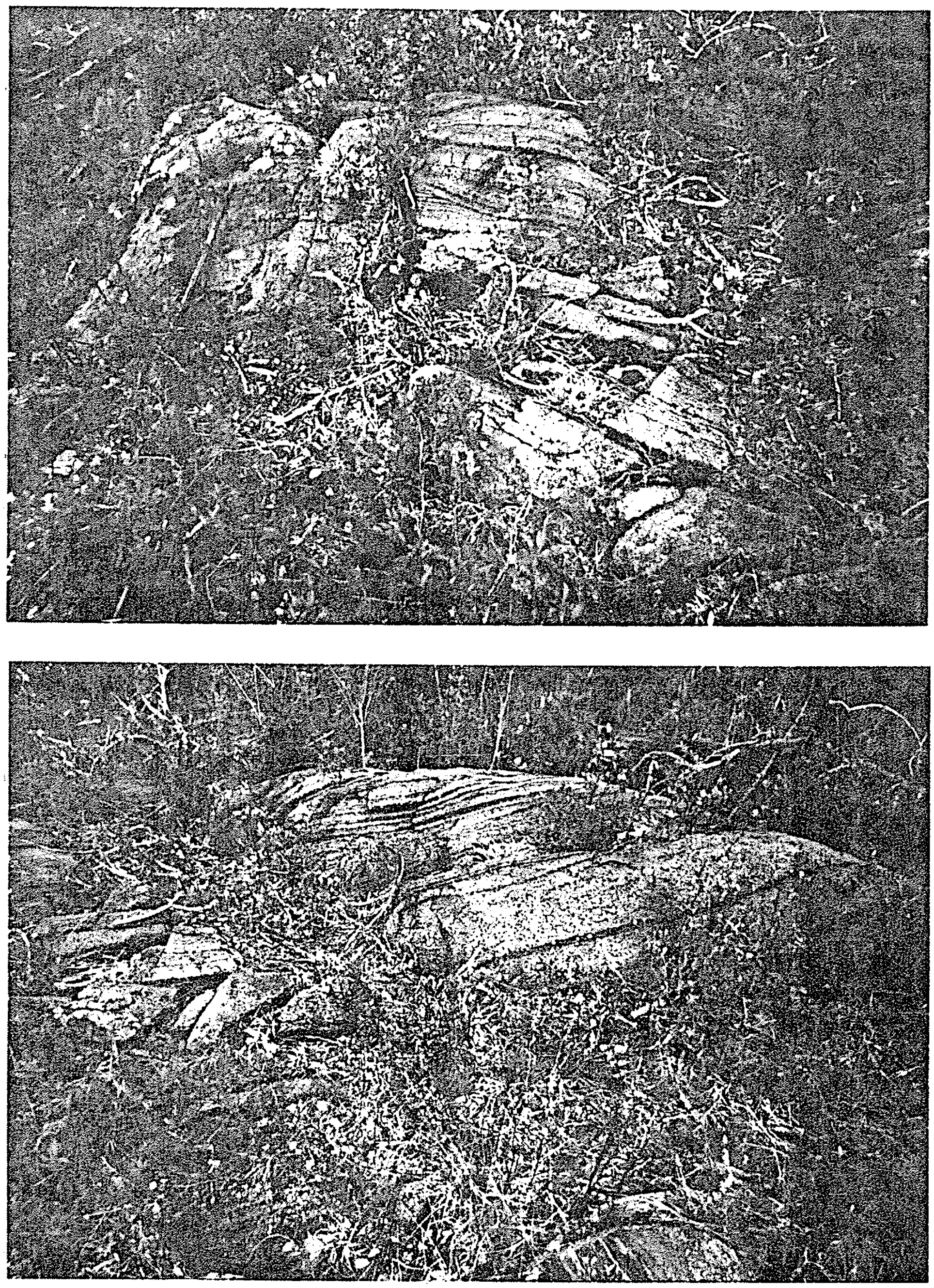


Figure 37. Two meter thick sequence of fine scale layering similar to sedimentary cross-bedding. This area is in Unit 2 above the contact between Units 1 and 2, and approximately 50m south of the area in Figures 25 and 26a.

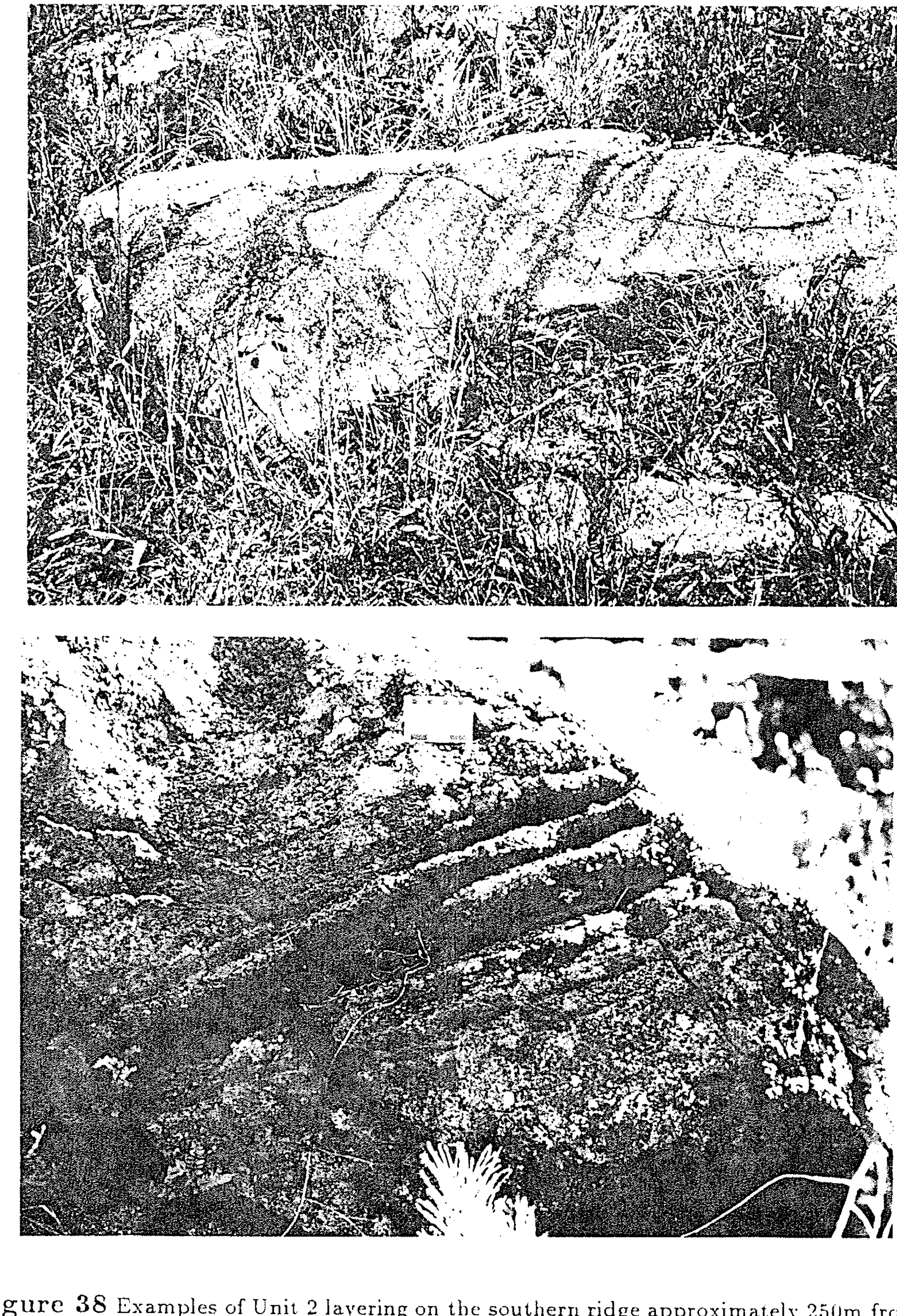


Figure 38 Examples of Unit 2 layering on the southern ridge approximately 250m from area of Figure 37. Unit 2 here is composed of several subunits that contain variably oriented layering including near horizontal layers.

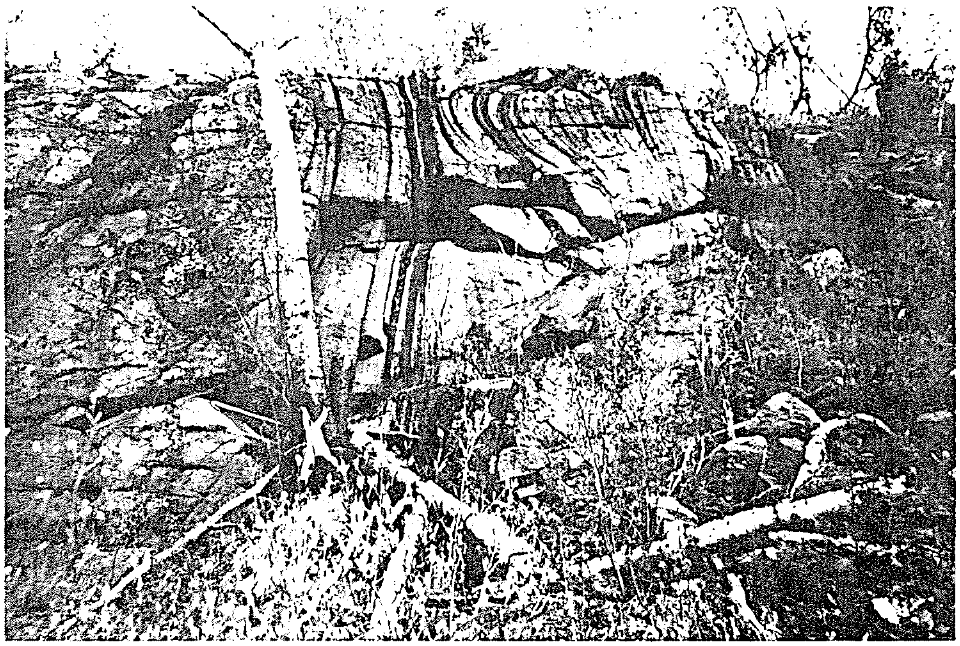


Figure 39. Cliff-face exposure of Unit 4 layering. This layering can be correlated with sequences on horizontal outcrops 75m to the north. Maximun height of the cliff-face is approximately 10m.

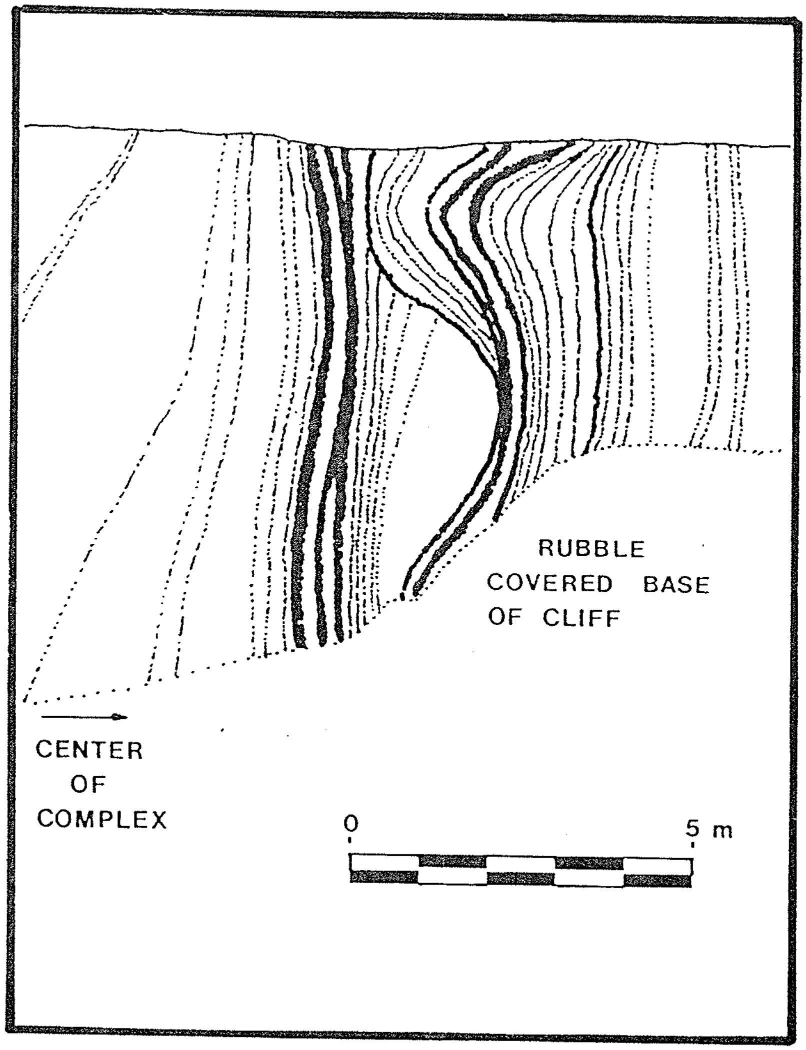


Figure 40 Illustration of major features of the cliff-face exposure (see Figure 39).

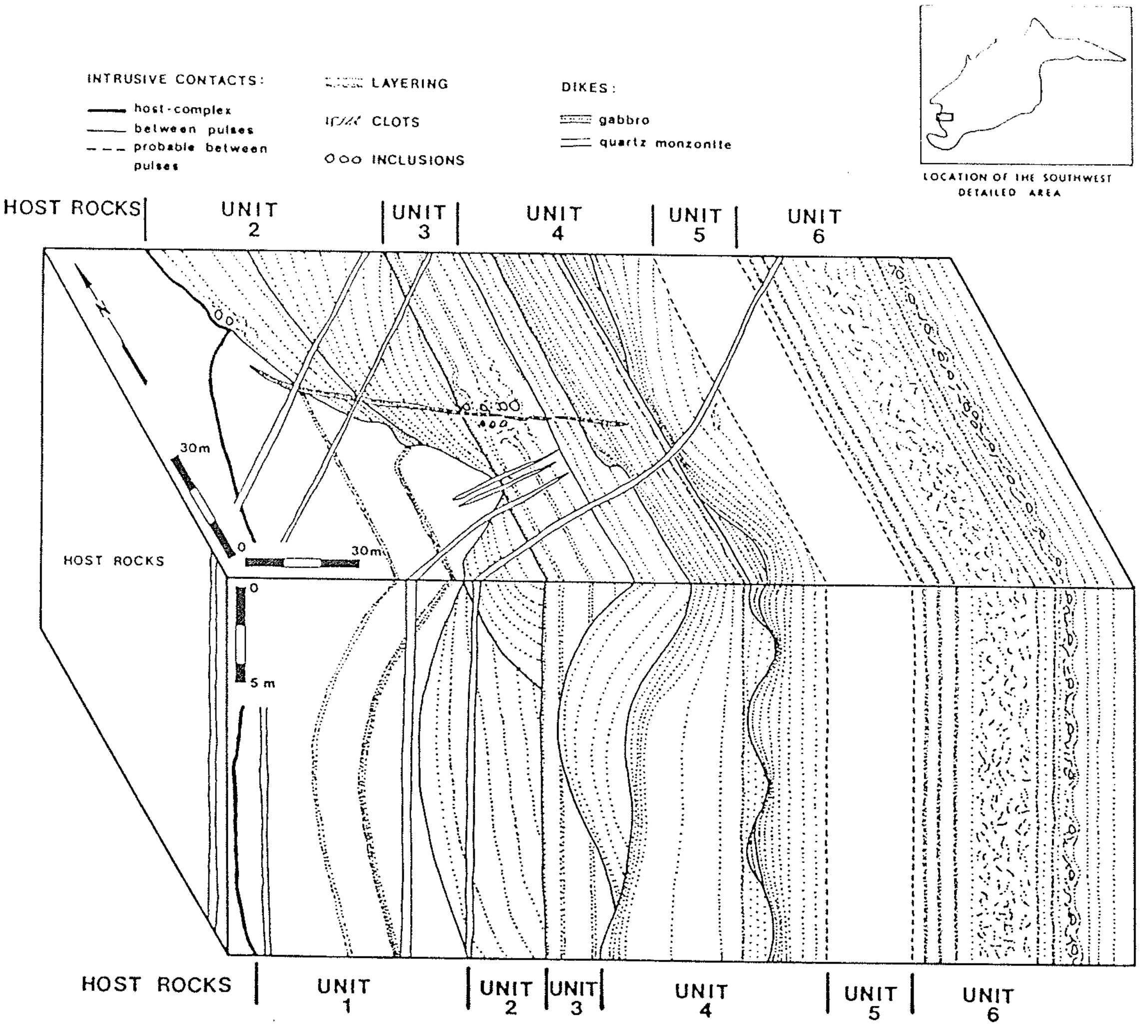


Figure 41. Interpretive block diagram of the northern outcrop ridge area, Southwestern Detailed-Study Area.

Figure 42 Inclusion-rich horizon in Unit 6. The inclusions have apparently disturbed the surrounding layer sequence.

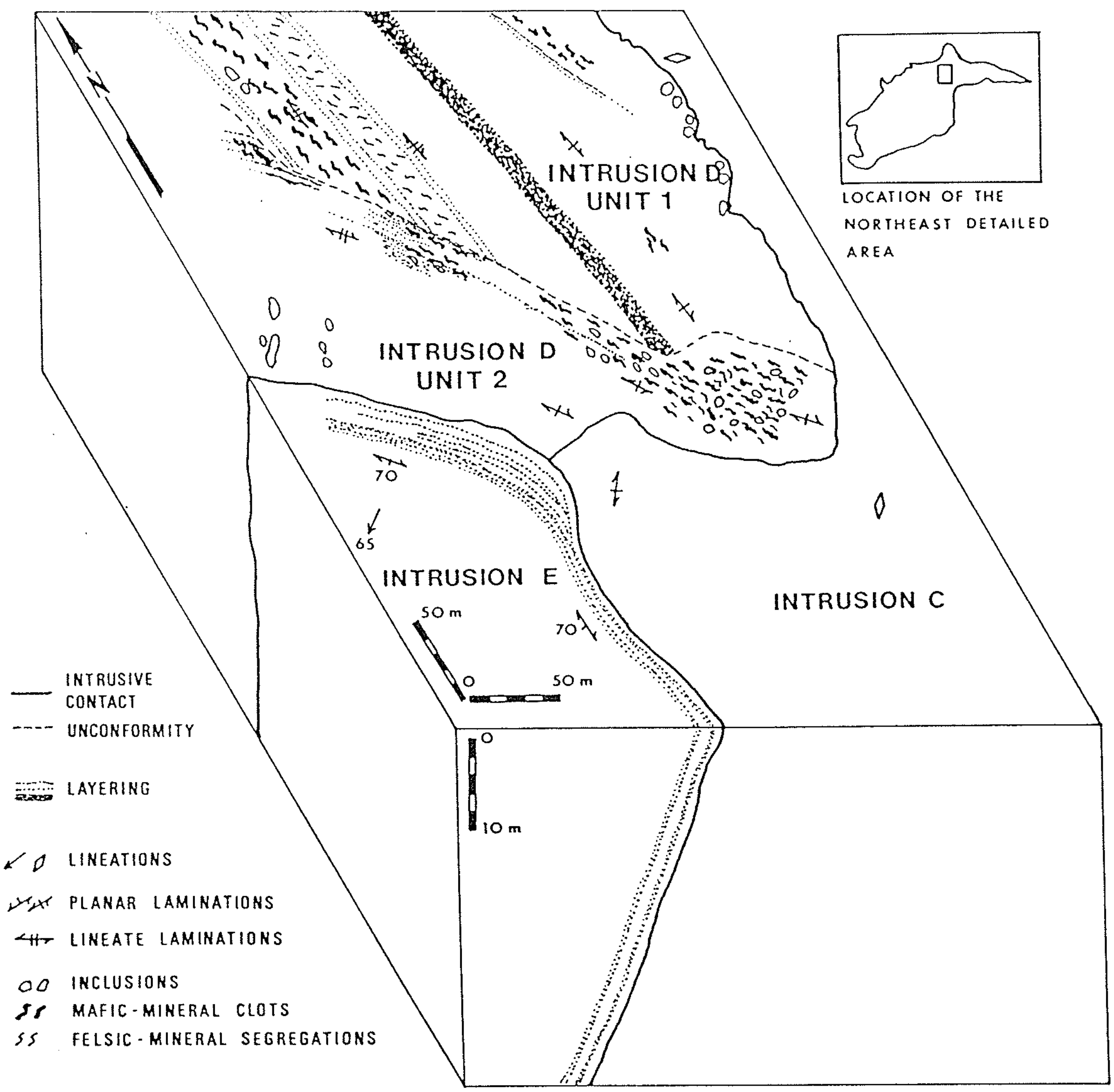


Figure 43 Interpretive block diagram of the Northeastern Detailed-Study Area.

ous clots and segregations further away. These thick layers generally have sharp but wavy contacts. In the southern portion of Unit 2, the layered rocks grade into a disturbed zone. The fabric of the rocks in this disturbed zone becomes wavy, swirled, and streaky (Figure 44), however the rocks retain an overall fabric orientation parallel to the unconformity. This disturbed zone also contains dismembered segments of mafic layers, inclusions of host rocks and intrusion A rocks (Figure 45), and pyroxenitic inclusions that are similar to rocks of intrusion B, but may have come from the thick pyroxenite layer in Unit 1 (Figure 46). Another unusual feature of this area is the local occurrence of quartz-bearing mineral segregations.

There are only a few scattered outcrops of intrusion D rocks near the contact with dioritic rocks of intrusion E in the western portion of this detailed study area. The rocks are generally uniform hornblende-gabbro, and contain several large inclusions of host metasedimentary and metavolcanic rocks.

Intrusion E rocks in this detailed-study area are dioritic. Along the contact with intrusion C gabbro, the dioritic rocks display well developed modally graded layering (Figure 47) and a planar lamination. One area of layering along the contact contains several low-angle layer truncations and buttress layering that suggests the presence of a large-scale scour. Well developed layering has been found within 50 metres of the contact. The layered diorite grades into relatively uniform rocks with only sporadic occurrences of modally graded layers and mafic laminae, and that usually display only a mineral lineation.

The configuration of contacts, and the structural relationships of layering and other primary features in this detailed-study area have led to the following observations and interpretations:

a) Intrusive contact relationships in this area suggest that the intrusions

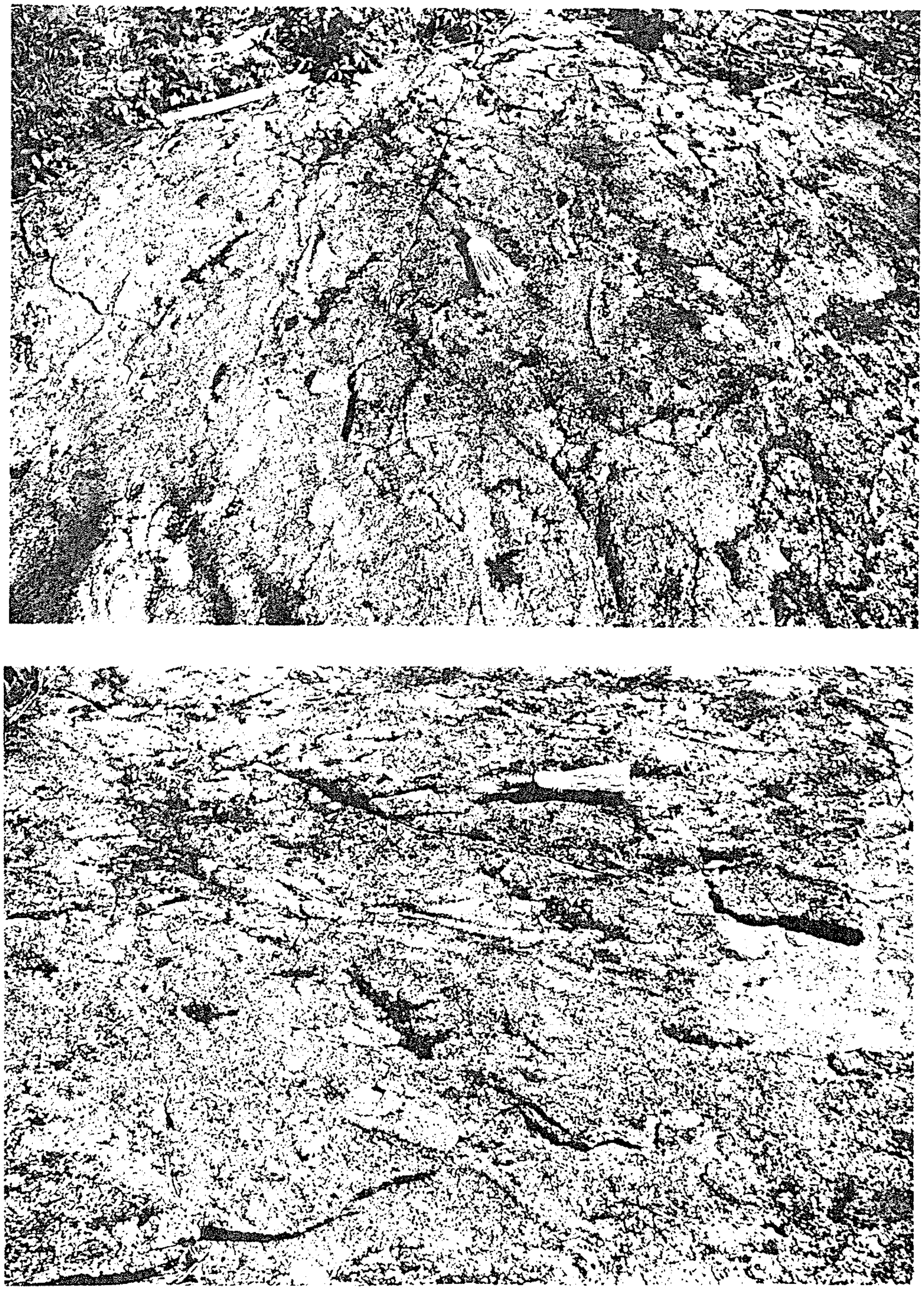
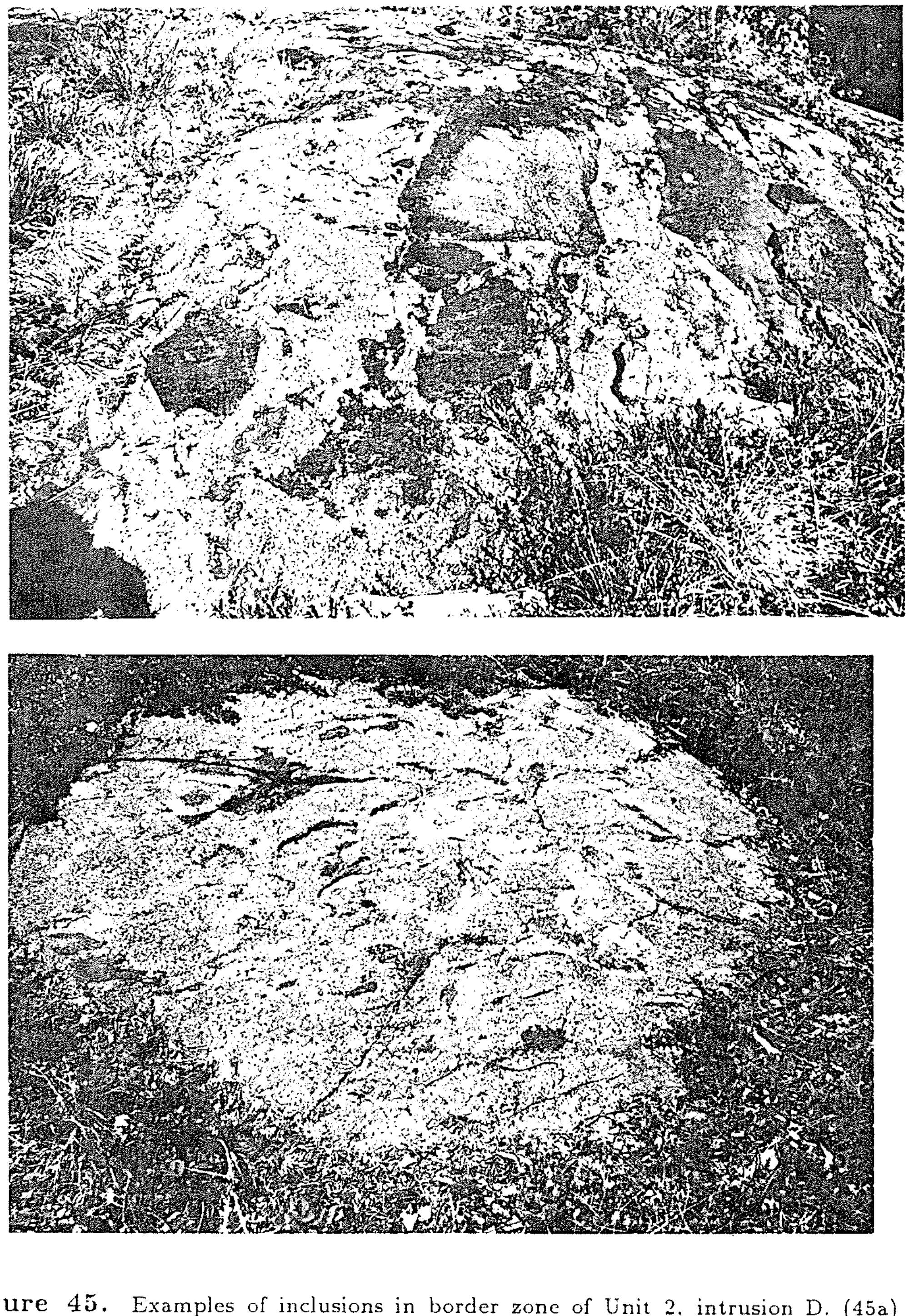


Figure 44. Two views of part of the disturbed zone in Unit 2 , intrusion D. This area is a confusing mixture of irregular mafic clots and gabbroic segregations, elongate and streaky anorthositic areas, angular melagabbro inclusions, rounded anorthositic inclusions, and rare angular pyroxenitic inclusions. The rocks usually display wavy and swirl patterned mineral alignments but retain an overall fabric orientation parallel to the contact between Units 1 and 2.

45a



45b

Figure 45. Examples of inclusions in border zone of Unit 2, intrusion D. (45a) Inclusions of host metavolcanic rocks and intrusion A gabbro (right of broom). (45b) Inclusions of anorthositic gabbro that may be cognate (Unit 1 of intrusion D) or from nearby intrusion C.

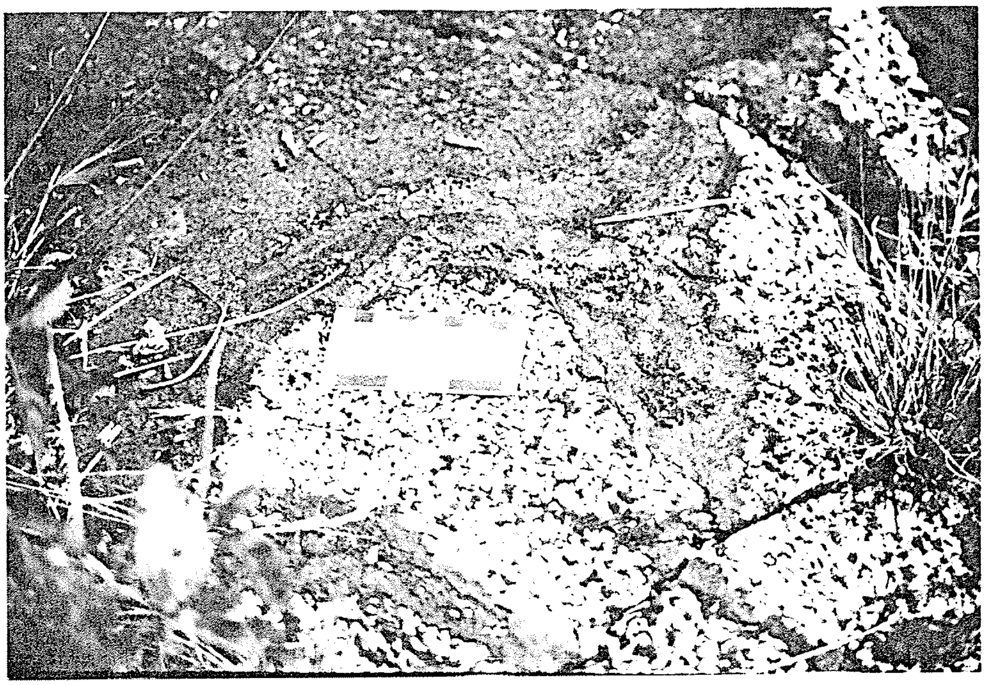


Figure 46. Border of a 1m by 1m inclusion of feldspar-bearing pyroxenite in the border zone of Unit 2. The inclusion is similar to intrusion B material, however it may also have come from a thick but poorly defined pyroxenite layer in Unit 1 of intrusion D. The border of the inclusion has apparently been remelted and contains several thin laminae of magnetite.

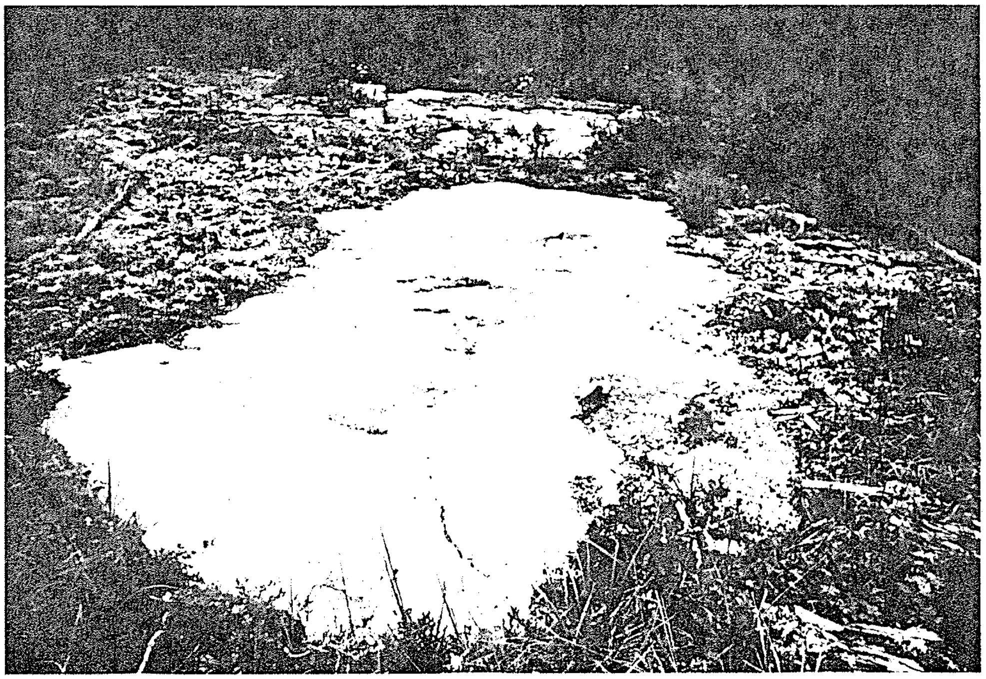


Figure 47. Modally graded layers in diorite near the outer contact of intrusion E with intrusion C.

become younger toward the centre of the complex.

b) The shape of the intrusive contacts in several areas, and the arrangement of structures within these areas, are similar to unconformities and large-scale scour and trough structures. These structures suggest that magmatic flow conditions in these areas alternated between periods of erosion and periods of layer formation and consolidation.

c) There are general trends in the younger two intrusions in this area, from layered rocks near outer intrusive contacts to unlayered rocks away from the contacts, and discordant structures in outer areas to generally concordant structures in inner areas, that suggest an overall decrease in intrusive energy during emplacement of each body.

CENTRAL DETAILED-STUDY AREA

The Central Detailed-Study Area is displayed in the western portion of Map # 3. It encompasses part of the contact between intrusions E and F in the north-central part of the complex. Figure 48 is an interpretive block diagram of the area.

In this area intrusion E is predominantly granodiorite in composition, and contains several thin, well developed modally graded layers and mafic laminae alternating with thick layers of uniform granodiorite. The layering is generally planar and steeply dipping, with a parallel, but weakly developed planar lamination. Wide areas of unlayered granodiorite contain steeply plunging mineral lineations only.

Intrusion F is quartz monzonite, and makes a sharp, discordant, and steep intrusive contact with intrusion E (see Figure 3b). In the detailed-study area the contact is relatively irregular, and the quartz monzonite occupies an embay-

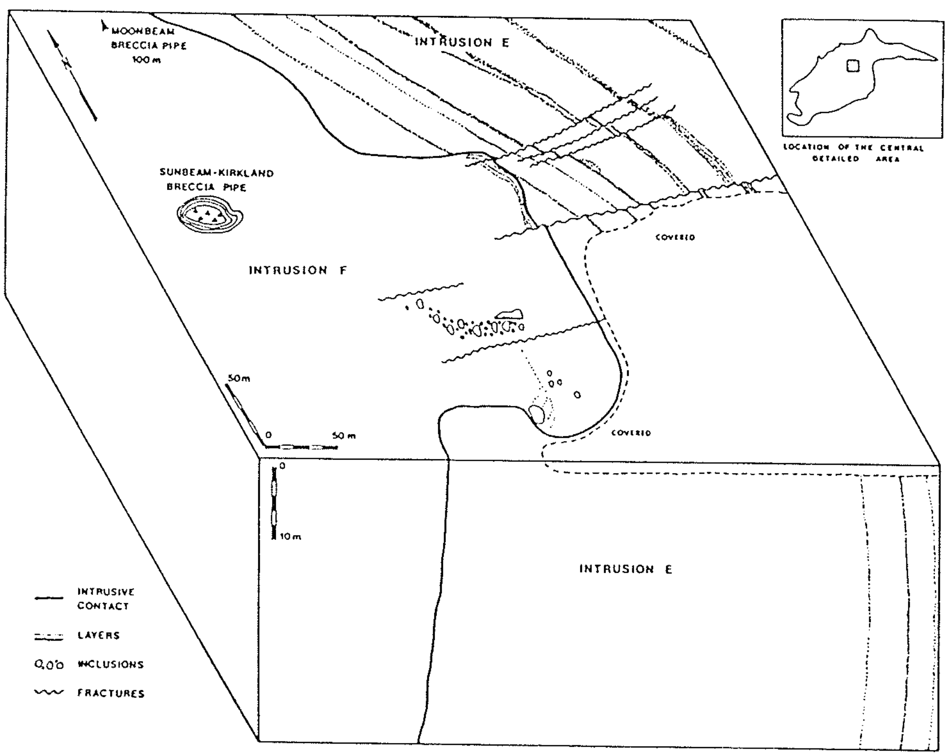


Figure 48. Interpretive block diagram of the Central Detailed-Study Area.

ment extending several hundred metres into the granodiorite. Layering in the quartz monzonite has been found in close association with the contact in this embayment. The layers are generally parallel to the intrusive contact. Layering is usually expressed as grain size gradations over several centimetres; from finer grained material near the intrusive contact, to inner medium and coarse grained porphyritic quartz monzonite. Two trough-like structures have been found within the embayment area. The embayment area also contains one of the largest concentrations of inclusions observed in the complex, including xenoliths of host rocks and inclusions of previous intrusions of the complex (Figure 49), and several of unknown origin (Figure 50). Just outside the embayment area is the Sunbeam-Kirkland breccia pipe.

The arrangement of structures, and their relationships in this detailed-study area, have led to the following observations and interpretations:

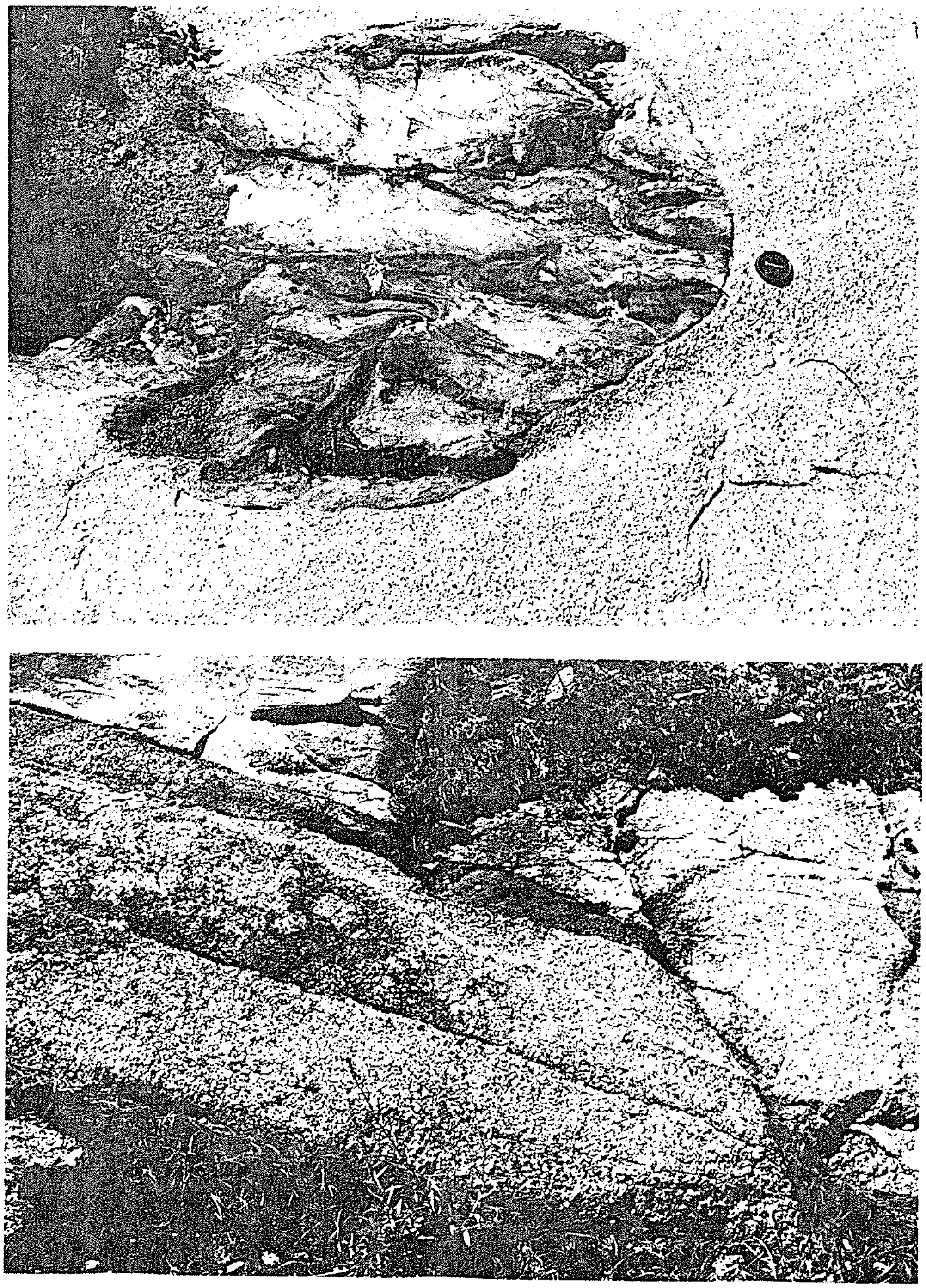
a) Contact relationships indicate that intrusion F is the younger of the two bodies in this detailed area; it is also the youngest in the complex.

b) The large embayment of intrusion F into intrusion E has the overall form of a large-scale scour structure, pointing to a localized episode of magmatic erosion during the emplacement of the last intrusion of the complex.

c) Relationships between structures in this detailed-study area suggest that the area was characterized by periods of erosion and periods of layer formation and consolidation.

d) In intrusion F, layering-related structures are found only near the outer intrusive contact. This suggests an overall decrease in energy after the initial intrusive event of intrusion F.

49a



49b

Figure 49. Examples of inclusions in the embayment area of intrusion F; (49a) Xenolith of metavolcanic host rock; (49b) Inclusion of layered diorite in the quartz monzonite. The broom sits on a nearby xenolith of host rock.

Figure 50. Example of a xenolith of unknown origin. The rock was apparently a conglomerate (note rounded fragments), however host metasedimentary rocks of similar composition have not been observed near the complex.

CHAPTER 5

DISCUSSION

INTRODUCTION

The objectives of this chapter are to summarize the major points interpreted in previous sections, and to provide further discussion that may be significant to understanding the overall emplacement and consolidation history of the complex. The major interpretations are as follows:

1.) Textural trends, and the relationship between textures and structures suggest that crystallization occurred in several stages, before and after emplacement.

2.) Magmatic flow was apparently the major process affecting the intrusive material during emplacement and consolidation. Flow was also responsible for the development of the majority of the primary fabric structures.

3.) Each intrusion of the complex exhibits its own composition or range in compositions, and is characterized by its own set of primary fabric elements. The arrangement and relationship of these structures in each intrusion indicate that the individual intrusions had complex and generally dynamic emplacement and consolidation histories.

4.) The Falcon Lake Intrusive Complex is a composite body composed of six individual intrusions. Relationships between the intrusions suggest a sequential emplacement history; from older-outer intrusions to younger-inner intrusions. The spatial distribution of the intrusions, from mafic rock types in outer areas to felsic rock types in inner areas, give the complex a concentrically zoned appearence.

The following sections provide discussion of the above points.

DEVELOPMENT OF PRIMARY TEXTURES AND STRUCTURES

Magmatic flow appears to have been the dominant process affecting the intrusions during emplacement, and appears to have been responsible for the development of most of the primary fabric structures in the complex. In the following sections, interpretations of possible processes that led to the development of the primary fabric structures, and their importance to understanding the emplacement and crystallization history of the complex are discussed.

Textural Trends

The cumulate and porphyritic textures observed throughout the rocks of the complex have significance in understanding the emplacement and crystallization history of the Falcon Lake complex in the following ways:

1.) The intruding magmas were apparently crystal-liquid mixtures. The ubiquitous presence of coarse grained cumulus and phenocryst crystals, especially in the rare examples of chilled rocks at outer intrusive contacts, suggest that some proportion of crystals was present in the magmas before intrusion to the present site. The cumulus crystals and phenocrysts were likely inherited from the source area of the magmas (Huppert and Sparks, 1985; Blake, 1987), although it is possible that growth of some of the primocrysts occurred during ascent and emplacement (Kouchi et al, 1986).

2.) Crystallization apparently occurred in several stages; a primary or cumulus crystallization stage in which the cumulus crystals and phenocrysts were formed, and a secondary or postcumulus crystallization stage which involved the solidification of the intercumulus and groundmass material (Irvine, 1982). The preferred orientation structures in the rocks involve only the primary stage crystals and suggest that the crystal-liquid mixtures underwent a mechanical orientation process before complete consolidation of the magmas; the secondary stage materials display only isotropic fabrics, and suggest that crystallization and solidification of this material may have occurred in a static magma.

Mineral Orientation Structures

Anisotropic fabrics in igneous rocks are usually interpreted to have formed in one of several possible ways; by gravity induced crystal settling on a depositional surface, by *in situ* directional growth in a crystallization front, or by flow of magmatic material containing inequant crystals (McBirney, 1984).

A gravity induced crystal settling process producing a preferred orientation of primary minerals is inconsistent with observations in the Falcon Lake complex. In the complex the preferred orientations are mostly steep or near vertical. The concentricity of the fabric structures within each intrusion, as well as the steep orientations, make post-intrusion tilting unlikely.

Oriented fabrics produced by *in situ* directional growth of crystals in a crystallization front have been studied in several layered intrusions. The rocks containing these types of oriented fabrics have been termed crescumulates (Irvine, 1982), and examples include the harrisitic rocks of the Rhum Ultramafic Complex (Brown, 1956; Wadsworth, 1961), the perpendicular-feldspar rocks of the Skaergard Intrusion (Wager and Brown, 1968), and Willow Lake layering or comb layering in several different bodies (Poldervaart and Taubeneck, 1959, 1960; Moore and Lockwood, 1973). In a more recent study, Petersen (1985) concluded that these fabrics likely formed by complex processes that include some degree of supercooling and continuous magma replenishment to the crystallization site. The constituent crystals, however, grow normal to solidification isotherms, which are usually parallel to nearby intrusive contacts. In the Falcon Lake complex only one minor occurrence of what may be crescumulate rocks have been found; the mineral orientation structures throughout the complex are usually parallel to the intrusive contacts. Consequently , this mechanism is not applicable for the majority of rocks in the complex.

Inequant crystals will show a preferred orientation in a flowing magma system, with the longest crystallographic axis or elongate faces of crystals oriented parallel to the direction of flow (Shaw, 1965; Jackson, 1967,1971; Best, 1982). The mineral alignments reflect the different hydraulic properties of a crystal-bearing magma flowing under laminar conditions (Shaw, 1965; Smith, 1974). This explanation for the development of mineral alignments appears to be applicable to the rocks of the Falcon Lake complex. In the complex the mineral lineations reflect streamline laminar flow, the planar laminations reflect a more sheet-like laminar flow, and the lineate laminations reflect local lamellar flow conditions. The wavy and swirl patterned structures likely reflect mixed flow conditions; partly laminar and partly turbulent.

Instantaneous freezing would be required to retain the isotropic fabrics expected from turbulent flow; a gradual cooling and consolidation process would cause reduction of turbulent flow to laminar flow (Shaw, 1965). Completely isotropic fabrics that would suggest turbulent flow conditions do not appear to occur in the complex. Turbulently flowing magmas in the complex were apparently erosive, and were likely responsible for the angular discordant contacts and scour structures observed in the layered rocks.

Field mapping of the mineral orientation structures can provide insight into the overall patterns and directions of flow, as well as any local variations. In the Falcon Lake complex, however, the true directions of flow remain uncertain.

Layering and Associated Structures

The layering throughout the Falcon Lake Intrusive Complex contains elements and structures that suggest that magmatic flow, most likely laminar flow, was the major process responsible for their development. The features that suggest magmatic flow include; (a) the preferred orientation structures, (b) grain size and compositional grading of layers, (c) and evidence that the layering was affected by obstructions in the path of flow, or by changes in flow conditions (Shaw, 1965; McBirney and Noyes, 1979).

The preferred orientation structures, that were discussed in a previous section of this paper, contained features that suggested that they were developed under laminar flow conditions. The close association of well developed mineral alignments and layering suggest concurrent development under similar flow conditions. Under laminar flow conditions, especially in a magma containing suspended crystals, velocity or viscosity gradients could lead to shear flow and dispersive shear stresses between crystals (Bhattacharji and Smith, 1964; Bhattacharji, 1967; Ryerson et al, 1988). Flow sorting of magma constituents, controlled by repeated variations in shear stresses and grain size variations of crystals in suspension, appears to offer the best explanation for modally graded and grain-size graded layers (Wilshire, 1968; Smith, 1975). In the Falcon Lake complex the grain-size gradations also reflect the compositions of the primary minerals in suspension; from finer grained mafic crystals to coarser-grained plagioclase crystals. The shapes of crystals, and the proportion of crystals to liquid, could also affect the distribution and arrangement of the layering elements (Marsh and Maxey, 1985; Ryerson et al, 1988).

Although the modally graded and grain-size graded layers apparently reflect well developed shear flow and mechanical segregation of crystalline and liquid material, there are several other types of layers in the complex. The ungraded layers that alternate with the graded layers likely reflect simple streamlined laminar flow conditions where shear flow conditions were not developed. The wavy and swirl patterned layer horizons appear to reflect mixed flow conditions; partly laminar and partly turbulent.

The disruption of layering associated with inclusions points to the disturbance of local flow patterns. Around inclusions the preferred orientation structures and layers become somewhat irregular, the layers may be truncated, and in some areas, later layering may be deflected in the area of the inclusion. These effects appear to be similar to those in clastic sedimentary environments.

The development of the layering in the Falcon Lake complex appears to be related to magmatic flow and a progessive consolidation of magma in solidification fronts. Figure 51 is an illustration of the conditions in a solidification front near an intrusive contact in the Falcon Lake complex. Inherent to this interpretation is the presence of conditions similar to those in a boundary layer as discussed by McBirney and Noyes (1979). Major differences between their idea and that presented here include the fact that the boundaries are usually near vertical or vertical in the Falcon Lake complex, and that the original magmas are considered to have been crystal-rich in the Falcon Lake complex.

Within the solidification front, temperature, viscosity, velocity, as well as compositions, likely changed along gradients that were functions of the rate of heat-loss through the side-walls and the hydraulic properties of the magmas (McBirney and Noyes, 1979). The solidification front likely graded from an outer static zone in which crystallization of the intercumulus and groundmass material was proceeding to form solid rock, to an inner zone of flowing magma. This inner zone was likely characterized by laminar flow conditions in which velocity and

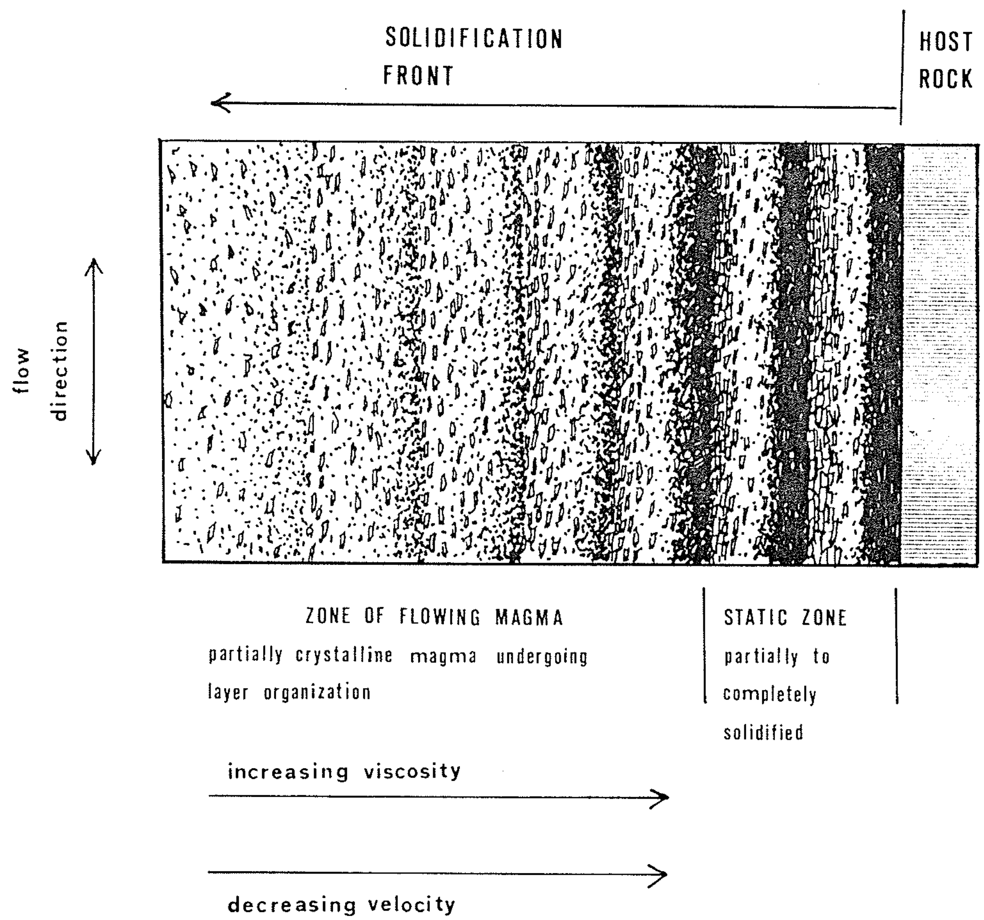


Figure 51. Diagrammatic illustration of conditions in a solidification front near an intrusive contact in the Falcon Lake Intrusive Complex. The solidification front can be divided into two main parts; a outer static zone in which crystallization of the intercumulus and groundmass material proceeds to eventually form solid rock, and an inner zone of flow, usually characterized by laminar flow conditions. At times the two zones may overlap, and the partially consolidated or consolidated material may be scoured by the flowing magmas. Within this solidification front as a whole, are gradients of viscosity and velocity controlled by the properties of the magma and its crystalline phases.

viscosity gradients would produce shear flow conditions and flow sorting of constituents ultimately responsible for the layering. Fluctuations in the laminar flow conditions, from streamline flow to lamellar flow would produce the variations in layer element arrangements. The flow in the inner zone was also likely subject to periodically turbulent flow conditions that would cause the magmas to erode the outer partly or completely consolidated zone. Periodicly turbulent flow events account for the scour and unconformity structures within the layered areas of the complex.

The thickness of the solidification front is a function of the inertial forces of the magmas and the rate at which energy is dissipated by viscosity and conduction (McBirney and Noyes, 1979). It was estimated by Shaw (1974), that basaltic magma boundary layers (or solidification fronts) can be less than a metre in thickness, and up to 50 metres in more viscous magmas such as granite. These estimates, however, neglected several aspects such as the negative temperature dependence of viscosity and the positive dependence of viscosity on the concentration of crystals (McBirney and Noyes, 1979), as well as the non-Newtonian properties of certain magmas (Komar, 1972a,b). The width of the solidification fronts in the Falcon Lake complex are unknown, however, the large variations in sizes of layers and the extent of layering point to variable and fluctuating conditions in the boundary layers. The best examples of layering structures in the Falcon Lake complex occur near outer intrusive contacts, however, there are also several layered areas well within individual intrusions. What appears to be required for the development of layering anywhere in the complex is magmatic flow near any solidification front where velocity and viscosity gradients could be produced.

The presence of sedimentary-like structures such as angular discordant contacts and the scour and trough structures have been interpreted by others to have formed by the action of magmatic currents in a magma chamber convection system (Harry and Emeleus, 1960; Goode, 1975; Mukherjee and Haldar, 1975; Barriere, 1981; Parsons and Butterfield, 1981; Irvine, 1981). They are usually small-scale features and have been taken to represent only local perturbations in the system. In the Falcon Lake complex however, these structures range from less than a metre to hundreds of metres, suggesting both large and small scale fluctuations in flow conditions, raising the possibility of forceful intrusive action rather than a magma convection system as being responsible for the magmatic flow.

Mineral Segregations

The different types of mineral segregations and clots point to several different processes that may have been responsible for their development. The mafic-mineral clots that are usually found within specific horizons in layer sequences likely reflect the magmatic segregation of mafic crystal or mafic-rich magmatic material under mixed flow conditions. The partly turbulent and partly laminar character of this type of flow would not allow the development of laterally continuous sheet-like or shear flow conditions that were likely responsible for the well developed modally graded and grain-size graded layers. The presence of these types of clots in local areas where the preferred orientation structures and layering have been disrupted by the presence of inclusions or irregularities along contacts indicate a more local disturbance of laminar flow patterns.

The mafic-rich and feldspar-rich segregations that cross-cut the surrounding fabrics inicate the activity of residual, volatile-rich, late-magmatic material. Their cross-cutting nature indicates that the surrounding material was at least partially consolidated, and reacted in a brittle fashion to the invasion of this material. The process of injection was likely similar to that of a filter-pressing system.

The large amounts of quartz in one type of mineral segregation suggests that these structures represent xenoliths of quartz-rich host rocks that were melted and recrystallized, but did not mix with the surrounding gabbroic material. The coarse grained gabbroic segregations were likely partially remelted cognate inclusions derived from earlier components of the complex.

EMPLACEMENT AND CONSOLIDATION HISTORIES OF COMPONENT INTRUSIONS

Each intrusion of the Falcon Lake Intrusive Complex apparently had its own complex emplacement and consolidation history. The location, form, and arrangement of primary structures in each intrusion, as well as contact relationships between intrusions, provide insight into processes operating during intrusion and consolidation. In this regard the three detailed-study areas provide the best data in the complex. The features of these areas have led to the following observations and interpretations:

a). The structures within each intrusion suggest that magmatic flow was the major process responsible for their development, that flow conditions alternated between periods of erosive flow and periods of layer formation and consolidation, and that flow directions as well as flow energies were occationally variable.

b). The arrangement of structures within each intrusion suggest a general developmental sequence; from older in the outer portions to younger toward the centre of each intrusion.

c). Two general trends occur in each intrusion: (1) from outer layered rocks to inner unlayered rocks; (2) from a large number of discordant structures in outer portions, to a fewer number, and generally concordant structures in inner portions of intrusions. These features suggest an overall decrease in intrusive energy during emplacement of each intrusion. Another general trend, from a large number of structures in outer intrusions to fewer structures in inner intrusions, suggests and overall decrease in intrusive energy during the emplacement history of the entire complex.

Hydraulic parameters of magmatic flow during emplacement were likely similar to fluid flow in a conduit. Changes in in flow rates, flow directions, and flow mechanisms during ascent could be a product of irregularities in the conduit walls and/or changes in intrusive forces. For low flow rates movement would likely be laminar and the magmas would tend to gradually solidify against the conduit walls; high flow rates would likely be turbulent and result in erosion of the conduit walls (Huppert and Sparks, 1985). Contact relationships and structures at intrusive contacts throughout the complex suggest that conditions during initial intrusion of each pulse of magma were turbulent and led to erosion and removal of material from host rocks and previous intrusions. The scour structures along the intrusive contacts represent local expressions of this turbulent flow. The mineral orientation structures and layering in each intrusion represent the reduction of flow rates from turbulent to laminar conditions. A reduction in flow velocity can be explained by either an overall decrease in the driving forces of emplacement, or to an increase in the viscosity of the magmas by heat-loss through the sidewalls of the conduit (Delaney and Pollard, 1982; Marsh, 1982). Further reduction of flow energies and continued heat-loss would lead to the progressive consolidation of the magmas against the conduit walls. The progessive consolidation against the walls would cause constriction of the conduit, with still-fluid magmas occupying the inner portions of the conduit (Delaney and Pollard, 1982;

McBirney, 1984). The complex interaction of periodic erosion and consolidation in the component intrusions of the complex is reflected by structures such as local scours along intrusive contacts, layering interupted by unconformities and scour structures, and the local occurrence of autoliths and autointrusive dykes. The arrangement of these structures within individual intrusions suggest that flow conditions were not constant throughout the conduit, and that while certain areas were undergoing erosion by turbulent flow, other areas may have been undergoing progressive consolidation. The arrangement of the structures within each body, however, support an overall progressive consolidation from older in the outer areas to younger toward the centre.

Several trends in the intrusions suggest that flow rates generally declined during each intrusive episode. There is also an overall trend throughout the complex, from a large number of structures in the outer-mafic intrusions to fewer structures in the inner-felsic intrsuions, that may be related to the composition of the intruding magmas; erosional capabilities are usually greatest for primitive magmas and least for cooler fractionated magmas (Huppert and Sparks, 1985).

The orientations of most of the structures within each intrusion of the complex are near vertical and suggest either upward or downward directions of movement during emplacement. The true direction, however, remains unclear. Several structures with other than steep orientations point to the local variability of flow directions. The direction of flow may have been influenced by local irregularities along conduit walls such as protuberences of host rocks or previously consolidated magma, by local areas of erosion, or by the presence of inclusions. These irregularities could influence flow patterns causing deflections and eddying, or the local transition to turbulent flow conditions (Shaw, 1965; Kille et al, 1986).

The general absence of chilled material at contacts between the component intrusions suggests the movement of large amounts of magma past the contacts, and thermal equilibrium between intruding and intruded material (Delaney and Pollard, 1982; Kille et al, 1986). The general absence of thermally metamorphosed rocks at these contacts, however, is problematic. Their absence can be explained if the emplacement of the successive intrusions was into still-fluid or partially consolidated, and still high temperature, areas of previous intrusions. The one area where contact metamorphosed rocks occur between intrusions (at the contact between older intrusion C and younger intrusion D in the northeast of the complex), suggests that the erosive emplacement of intrusion D magma extended into a previously consolidated and cooler area of intrusion C. It was suggested by McBirney (1984), that thinner areas of intrusions would move slower and freeze sooner than the conduit centres. The area where the metamorphosed rocks occur is at the entrance of a dyke-like extension of intrusion C in the northeastern portion of the complex that was likely cool and consolidated at the time of the younger intrusion.

EMPLACEMENT HISTORY OF THE COMPLEX

The Falcon Lake Intrusive Complex displays an overall concentric zonation; from outer mafic rocks, to inner felsic rocks. This concentric zonation cannot have been inherited directly from a compositionally zoned magma as density differences of liquids having these compositions preclude their having been horizontally zoned in the liquid state (McBirney, 1984). Possible origins of steeply dipping zoning include contamination by host rocks, inward crystallization, and multiple intrusions of magma (Figure 52). The Falcon Lake complex is a composite body containing several sharply bounded zones representing at least six separate intrusions of magma. The boundaries are intrusive contacts between rocks of different compositions which contain their own sets of fabric elements. Contact relationships between the intrusions suggest a sequential emplacement history; from outer-oldest intrusion A, to inner-youngest intrusion F. This interpretation is supported by the distribution of inclusions and dykes. Inclusions of outer-intrusion material are found in inner intrusions, and dykes of inner intrusion material

The compositional trend of the successive intrusions of the complex, from outer mafic rocks to inner felsic rocks, suggests a common source area for the magmas; possibly a deeper, progressively differentiating magma chamber. The sharp contacts between intrusions of different composition suggest that the source area was subject to periodic rather than continuous tapping. The overall form of the complex represents successive intrusions of progessively more differentiated magma, each intruded more or less in the centre of its less differentiated predecessor. The first intrusion was dyke-like, succeeding intrusions gave the complex a more equant shape, and the final intrusion occupied the centre of the complex (Figure 53). This intrusive sequence gives the complex an overall conduit-like form.

The form and arrangement of the successive intrusions in the complex are likely related to ascent mechanisms, and several are possible. These include: a dyke-like ascent (Delaney and Pollard, 1982; Maaloe, 1987); the periodic ascent of magma diapirs (Marsh, 1982); or a mechanism transitional between the previous two (Maaloe, 1987). The dyke-like ascent mechanism can explain the dyke-like form of the initial intrusion in the complex, however, it does not adequately account for the later cylindrical forms and the sharp intrusive contacts between intrusions of different composition. The periodic ascent of magma diapirs mechanism can explain the sharp intrusive contacts between intrusions of different

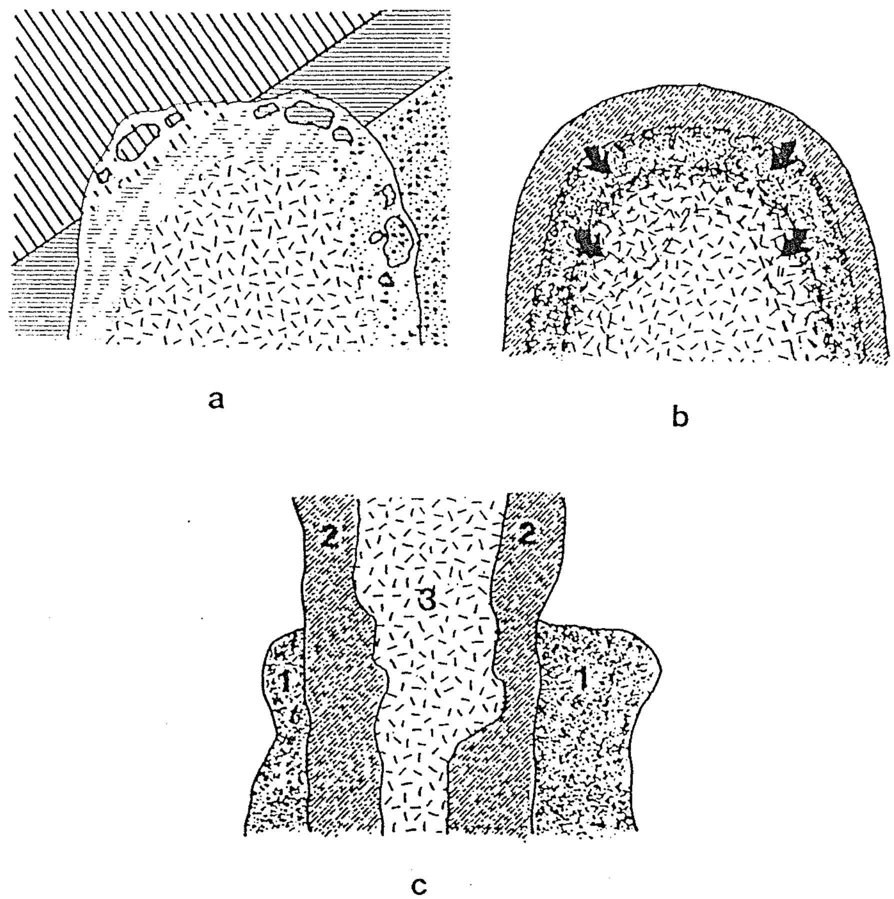


Figure 52. Origins of steeply dipping zonation in intrusive bodies (modified after McBirney, 1984), a) contamination by host rocks; b) inward crystallization; c) multiple intrusions.

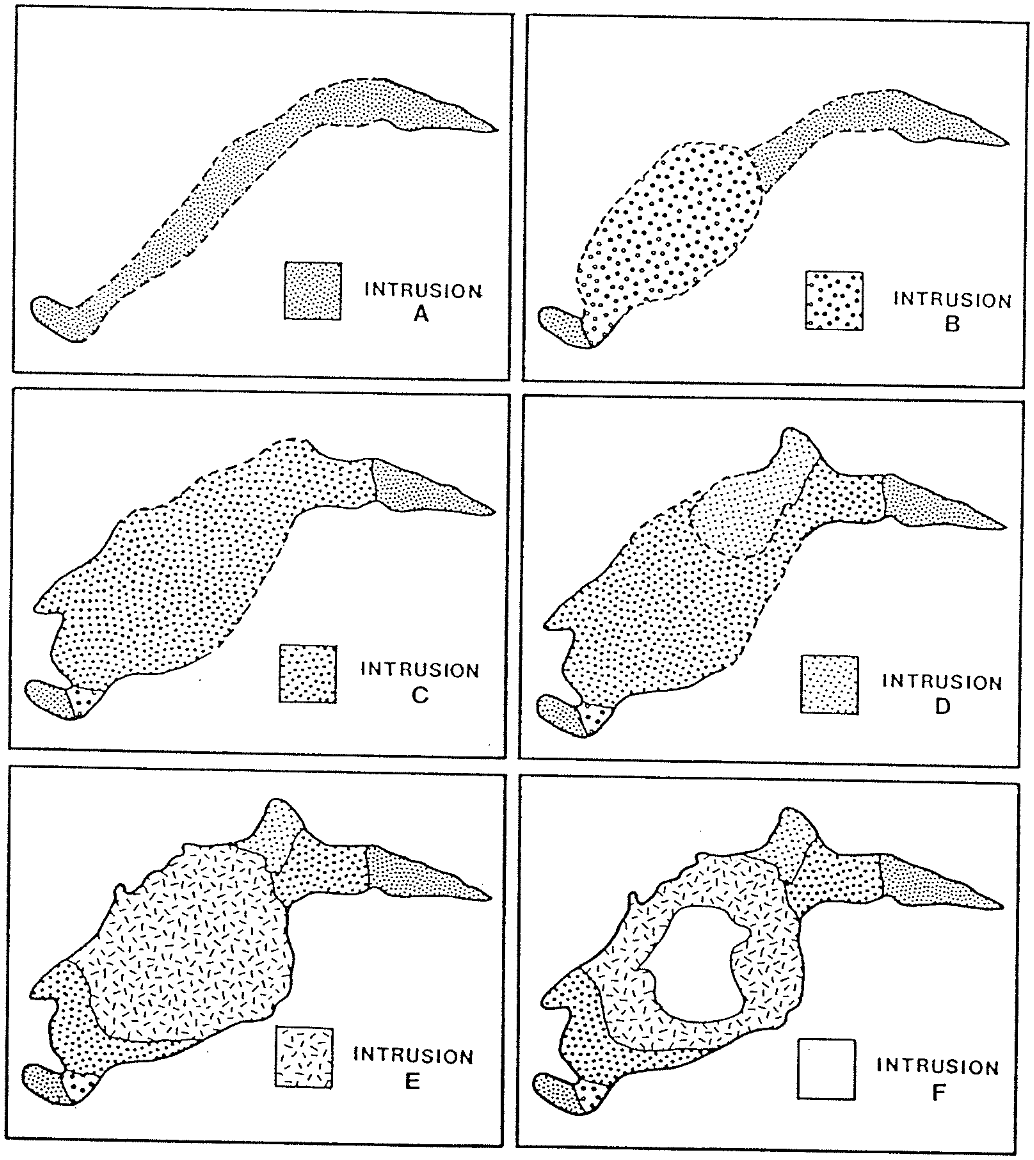


Figure 53. Emplacement sequence of the Falcon Lake Intrusive Complex.

compositions, the cylindrical forms of the later intrusions and their spatial distribution, however, it does not adequately explain the initial dyke-like intrusion. A combination of these two types of ascent mechanisms; an initial dyke-like mechanism, and later, periodic diapir-like ascent in a common magma conduit, is more consistent with features of the Falcon Lake complex.

Large amounts of magma moving through a conduit can produce a wide area of thermally metamorphosed host rocks around the conduit, and raise the temperature of host rocks to a level where no chilling would occur (Delaney and Pollard, 1982; Kille et al, 1986). Coarse grained intrusive rocks are found near the outer intrusive contacts of the Falcon Lake complex , as well as a wide thermal metamorphic aureole in host rocks around the complex. This suggests that larger amounts of magma than are now observed in place moved through the complex, and supports the interpretation that the Falcon Lake Intrusive Complex, at the present erosional level, represents a cross-section through a magma conduit.

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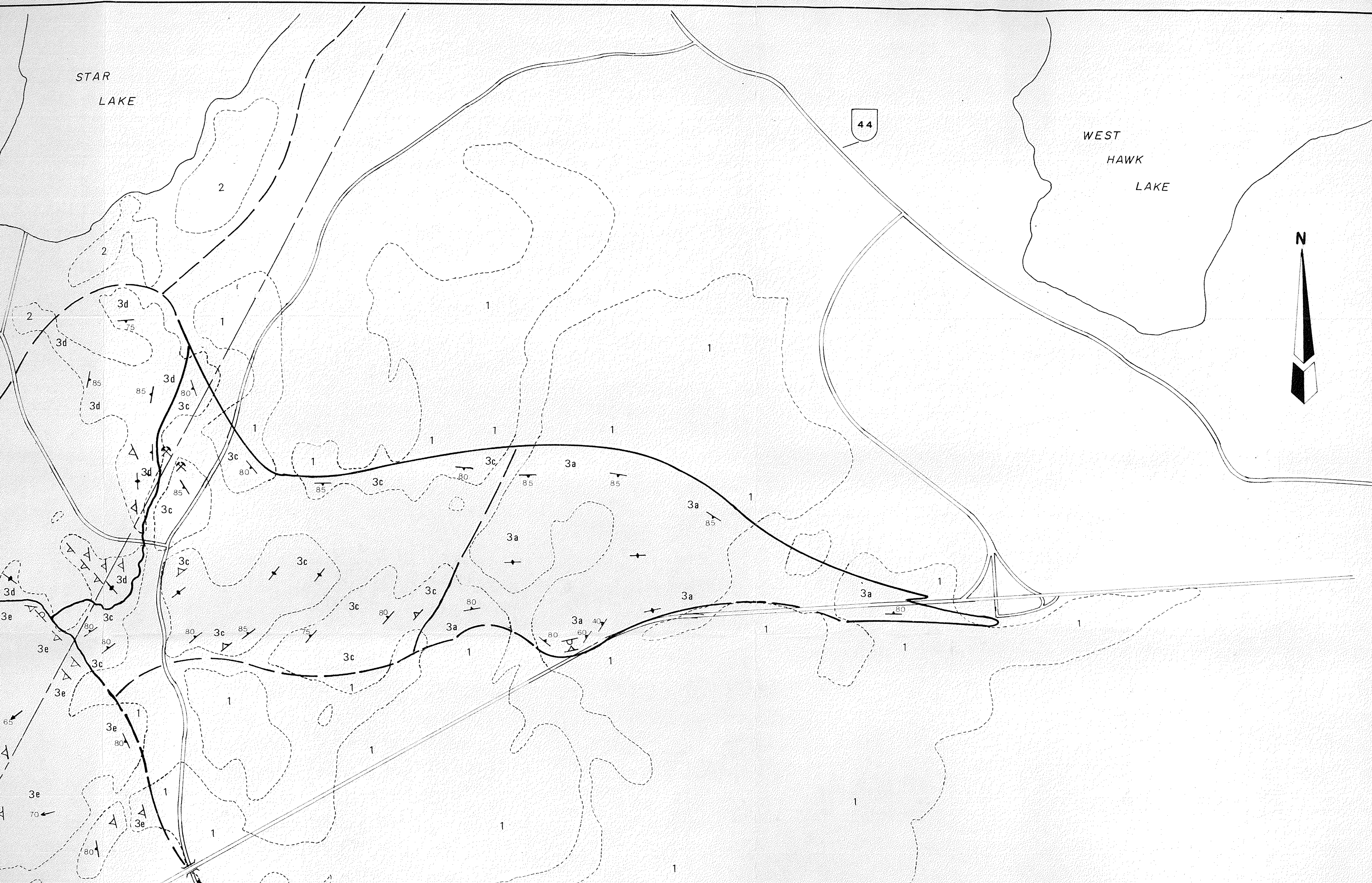

STAR LAKE
WEST HAWK LAKE
44
N
1
2
3a
3c
3d
3e

MANITOBA
WPG
FLIC
NORTH
60
55
49
102
50
92
R 16 E
R 17 E
STAR
LAKE

LEGEND

FALCON LAKE INTRUSIVE COMPLEX

- **3f** Intrusion F : quartz monzonite
- **3e** Intrusion E : diorite, granodiorite
- **3d** Intrusion D : gabbro, hornblende-magnetite gabbro
- **3c** Intrusion C : gabbro, hornblende gabbro
- **3b** Intrusion B : pyroxenite, melagabbro
- **3a** Intrusion A : gabbro

SUPRACRUSTAL HOST ROCKS

- **2** Metasedimentary rocks
- **1** Metavolcanic rocks

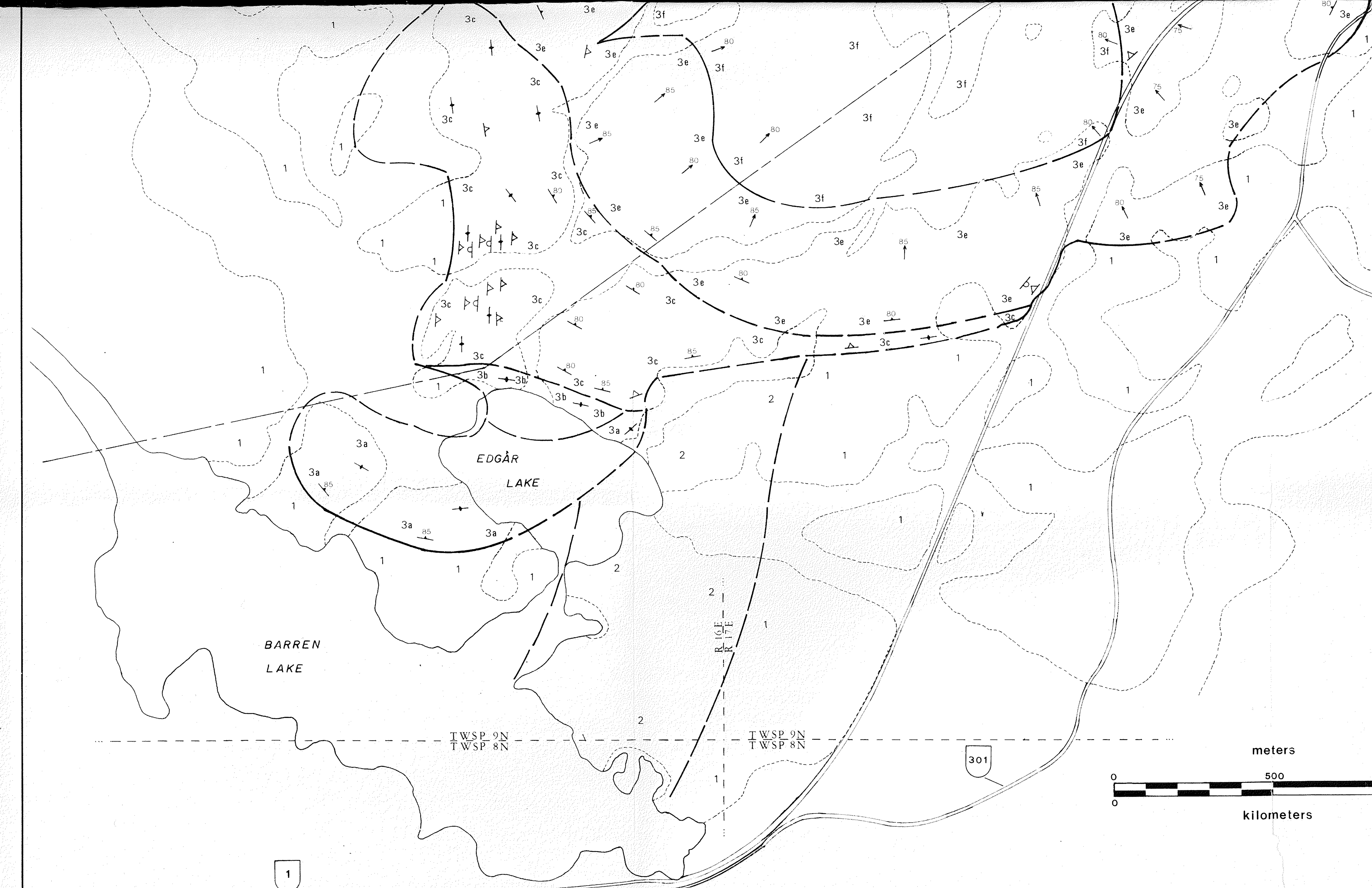
SYMBOLS

- area of outcrop
- geological boundary (defined, approximate)
- mineral lineation
- mineral lamination (inclined, vertical)
- layering, trough banding
- mine shaft, trench or quarry
- hydro-electric power line
- roads
- highway designation

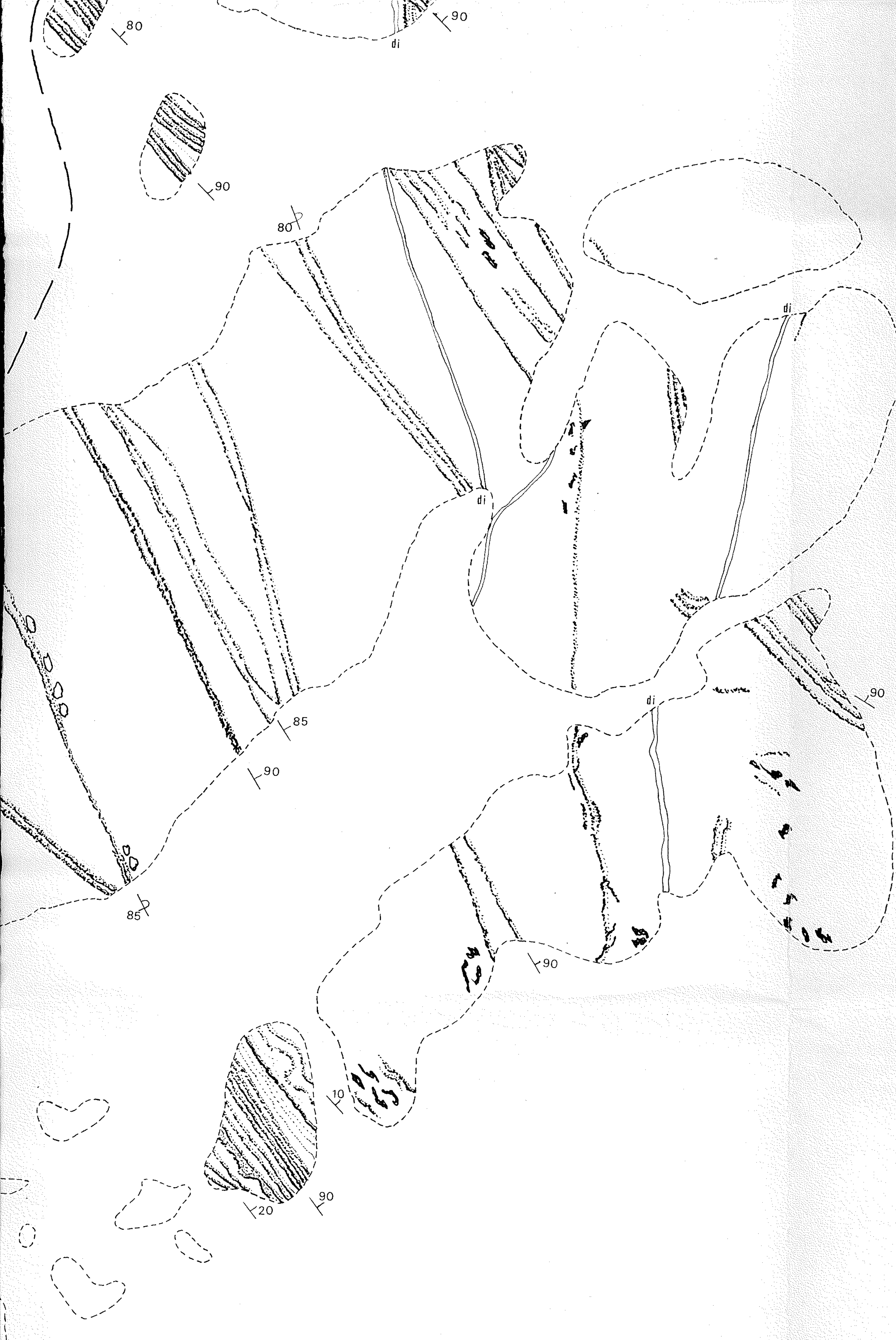
MAP 1
GEOLOGY OF THE FALCON LAKE INTRUSIVE COMPLEX

GEOLOGY BY W.S. MANDZIUK

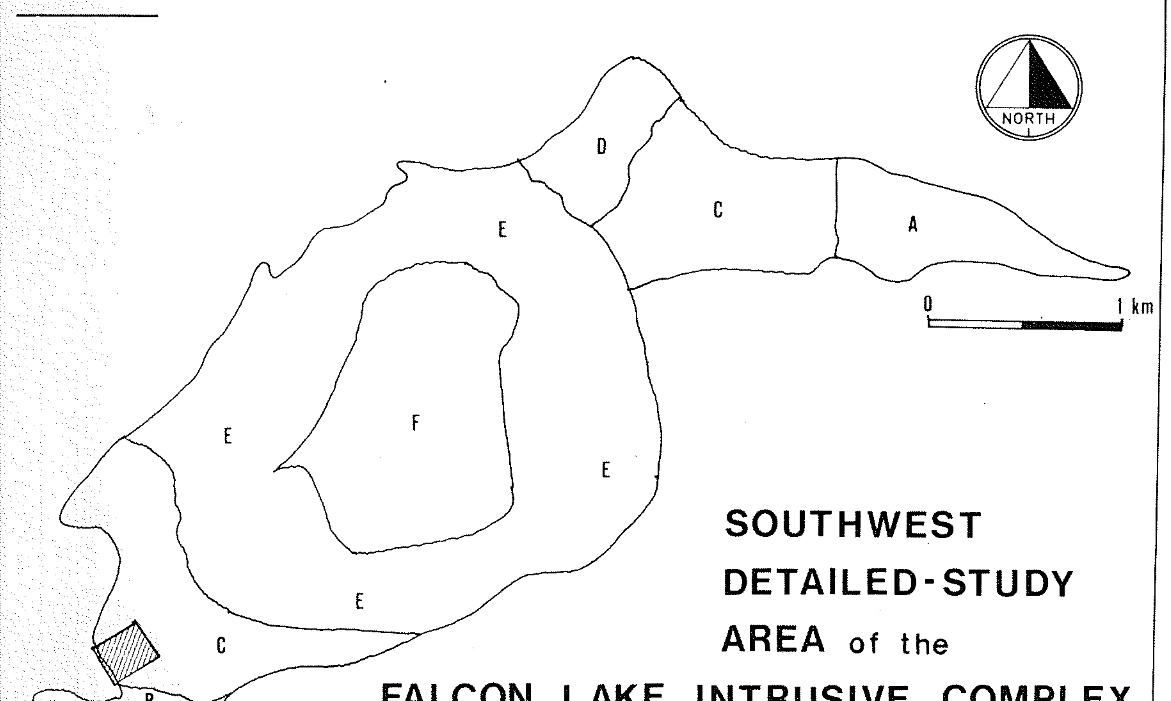
DRAFTED BY W.S. MANDZIUK.


EDGAR
LAKE
BARREN
LAKE
R 16 E
R 17 E
TWSP 9N
TWSP 8N
TWSP 9N
TWSP 8N
301
1
meters
0
500
0
kilometers


N
80
90
80
90
90
90
90
65
90
90
85
85
90
90
65
ga
qm
qm
qm



KEY MAP



SOUTHWEST
DETAILED-STUDY
AREA of the
FALCON LAKE INTRUSIVE COMPLEX

LEGEND

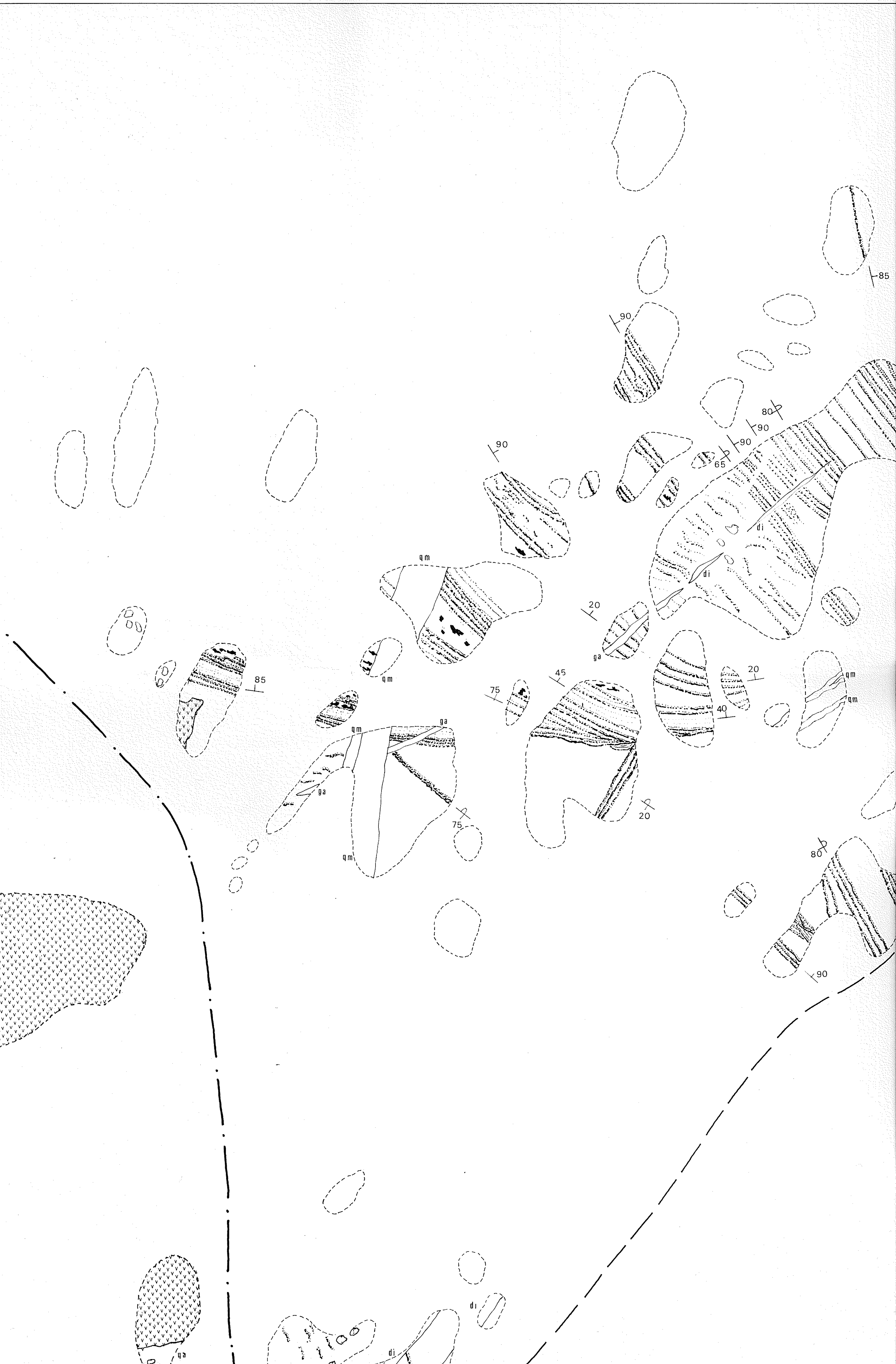
INTRUSION C		FALCON LAKE INTRUSIVE COMPLEX
INTRUSION B		
METAVOLCANIC ROCKS		

SYM

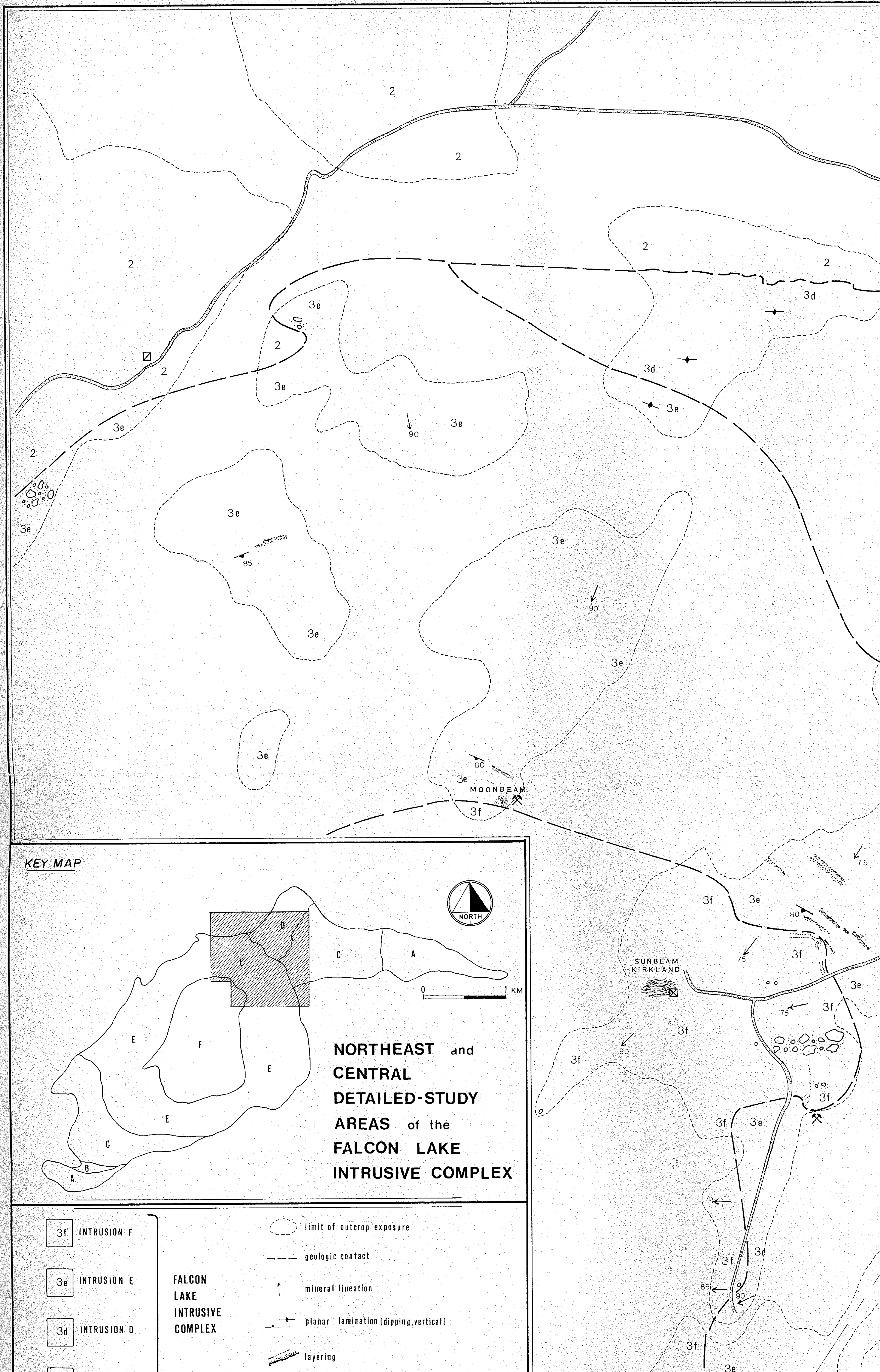
MAP 2

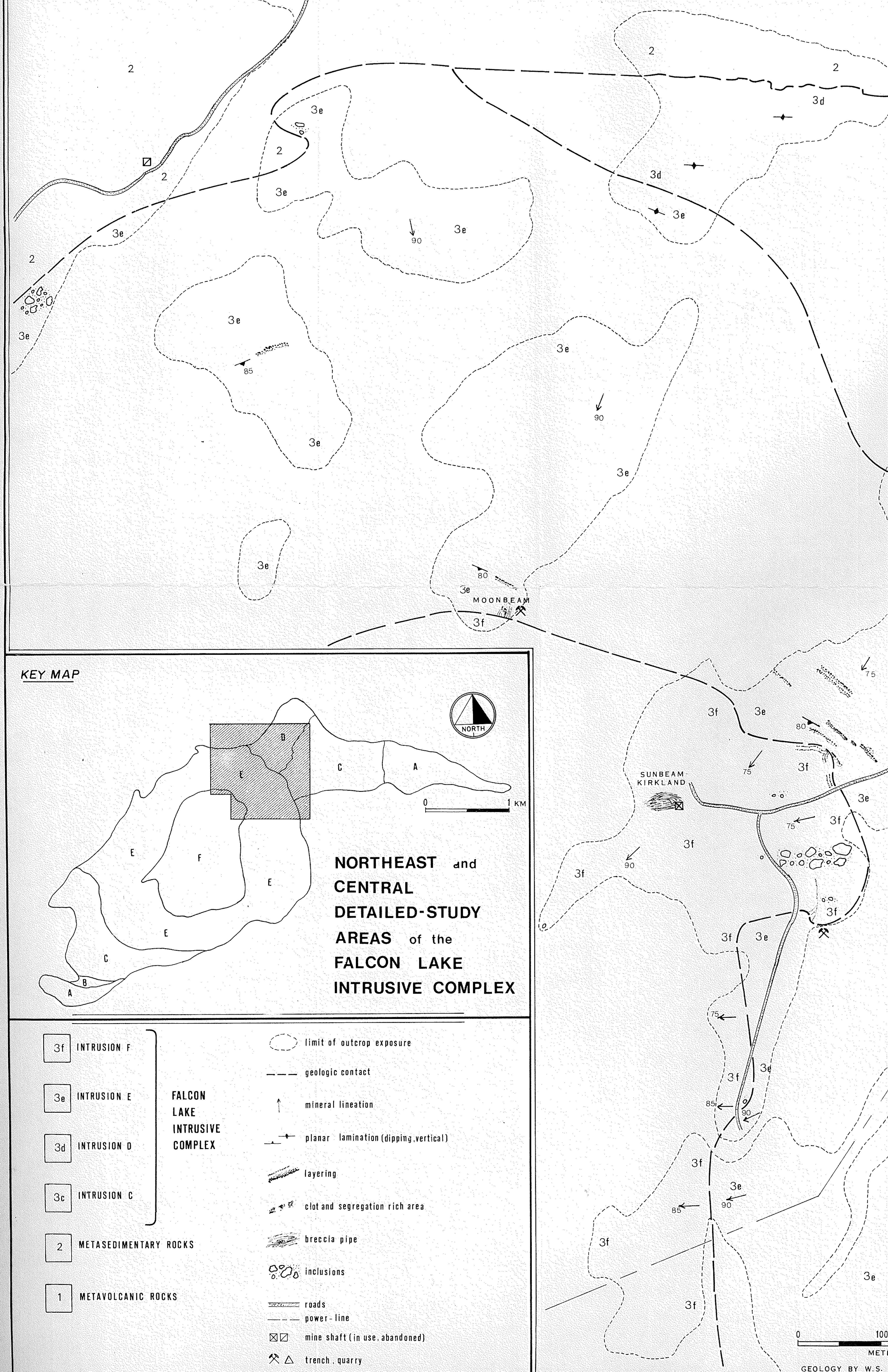
SOUTHWEST DETAILED-STU

65
80
75
0
metres
25



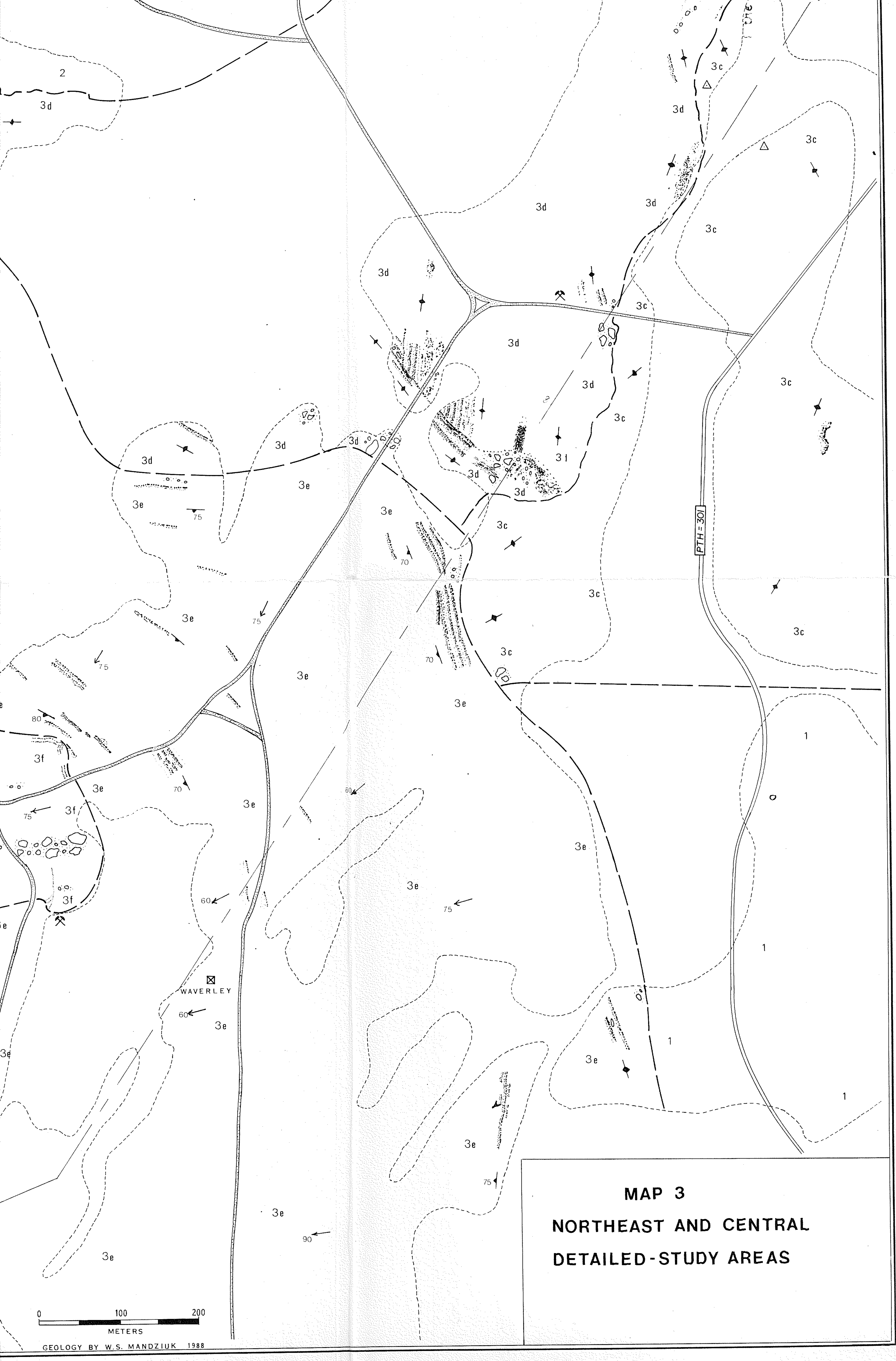
85
90
80
90
90
65
di
di
20
20
40
qm
qm
45
75
ga
qm
85
qm
ga
qm
ga
75
20
qm
80
90
di
di
ga


KEY MAP
NORTH
0
1 KM
A
B
C
D
E
F
NORTHEAST and
CENTRAL
DETAILED-STUDY
AREAS of the
FALCON LAKE
INTRUSIVE COMPLEX
3f INTRUSION F
3e INTRUSION E
3d INTRUSION D
FALCON
LAKE
INTRUSIVE
COMPLEX
limit of outcrop exposure
geologic contact
mineral lineation
planar lamination (dipping, vertical)
layering
MOONBEAM
SUNBEAM-
KIRKLAND
2
3d
3e
3f
90
85
80
75



KEY MAP
NORTH
0
1 KM
NORTHEAST and
CENTRAL
DETAILED-STUDY
AREAS of the
FALCON LAKE
INTRUSIVE COMPLEX
3f INTRUSION F
3e INTRUSION E
3d INTRUSION D
3c INTRUSION C
FALCON
LAKE
INTRUSIVE
COMPLEX
2 METASEDIMENTARY ROCKS
1 METAVOLCANIC ROCKS
limit of outcrop exposure
geologic contact
mineral lineation
planar lamination (dipping, vertical)
layering
clot and segregation rich area
breccia pipe
inclusions
roads
power-line
mine shaft (in use, abandoned)
trench, quarry
MOONBEAM
SUNBEAM-
KIRKLAND
GEOLOGY BY W.S.


N
2
3d
3c
3e
3f
3l
1
PTH=301
WAVERLEY
75
70
80
60


MAP 3
NORTHEAST AND CENTRAL
DETAILED-STUDY AREAS
PTH 301
WAVERLEY
0 100 200
METERS
GEOLOGY BY W.S. MANDZIUK 1988
2
3d
3c
3e
3f
1