STRUCTURE AND RHEOLOGY OF THE MIDDLE ALLOCHTHON AT 68° N, SCANDINAVIAN CALEDONIDES

by

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B.S.E. Princeton University
(1986)

Submitted to the Department of
Earth, Atmospheric and Planetary Sciences
in Partial Fulfillment of the
Requirements for the Degree of

MASTER OF SCIENCE
in Earth and Planetary Science

at the

Massachusetts Institute of Technology

June 1991

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ABSTRACT

At the latitude of the study, the contact between the Baltic basement and the overthrust Caledonian Allochthon is well exposed across the width of the orogen. The higher parts of the allochthon consist of largely oceanic rocks derived from west of the Baltic continental margin. A complex zone of imbricated basement slices (Middle Allochthon) is developed between these higher nappes and the underlying basement. This study involved compiling a 1:100,000 scale map from published and unpublished sources which traces the basal thrust of the upper nappes and the underlying Middle Allochthon, Lower Allochthon and tectonized basement from the Caledonian Thrust Front in Sweden to the Norwegian Coast. Samples of the granite thrust slices and the foliated granitic basement from across the map transect were examined in thin section.

Compilation of the map shows that the Middle Allochthon is not continuous across the transect. North of the Efjord culmination, where the Middle Allochthon is cut out, the upper nappes rest directly on foliated parautochthonous granite basement and its thin sedimentary cover sequence. The lithologic character of the Middle Allochthon varies from east to west. In Sweden, Precambrian granite slices dominate the section with only minor amounts of thin original sedimentary cover overlying individual granite sheets. West of the Norwegian border the proportion of sediment increases, becoming the dominant around the Efjord culmination near where the Middle Allochthon is cut out. In the Akkajaure region where exposure is most extensive, significant variations in the thickness and number of thrust sheets are observed in the orogen-parallel direction. Folds with vergence parallel to the trend of the orogen are observed in the Efjord region. Lateral structural variations and orogen parallel transport may be important in the overall structural development of the Middle Allochthon.

Crystal-plastic mylonitic deformation microstructures are developed in the Swedish part of the section. West of the Norwegian border, annealing microstructures dominate. The annealed rocks retain a foliation proportional to the degree of strain, and possibly weak crystallographic preferred orientations.

ACKNOWLEDGEMENTS

I would like to thank Clark Burchfiel for providing financial support for my two summers of Norwegian fieldwork, and for supporting me in my ultimate decision to pursue a different path. I especially thank him for not allowing me to quit before turning in this pile of papers. I also owe special thanks to Bo Lawler for enduring horseflies and fog-outs during the summer of 1990, and for providing humor and perspective when things got bleak. By and large I have enjoyed my two years at MIT; for the friendships I have gained it was well worth it. I am glad to have been able to be part of the group geologists, geochemists and geophysicists who have, against the odds, managed to partially destratify the Green Building. Finally I would like to thank Kerry Kelly who has borne the brunt of my temporary insanity during this tumultuous year, and managed to make my life more pleasant through it all.

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INTRODUCTION

The Scandinavian Caledonides at the latitude of 68° north offer an excellent opportunity to directly observe the deep structural levels of an orogenic belt. Deep erosion has removed most of the shallow levels of the orogen, leaving at the surface allochthonous units previously at depths as great as 30 km (Hodges, 1982). A fortuitous combination of deeply incised glacial valleys and broad late-Caledonian warping of the Baltic margin provides extensive exposure of the contact zone between the autochthonous or parautochthonous basement and the overlying nappes. Thus it is possible to study in detail the kinematic and mechanical aspects of nappe emplacement and the response of the basement.

At the latitude of the transect, a complex shear zone which is developed between the basement and geosynclinal nappes can be traced continuously from the Caledonian front in Sweden northwestward to the Norwegian coast. Deformation of granitic and quartzose rocks within the shear zone is dominated by crystal plastic processes, and the metamorphic grade generally increases westward within this zone. Potentially, changes in the rheological behavior of the mid-crustal level of an orogenic belt with increasing temperature and pressure can be traced across the transect.

This paper is intended to provide the foundation for a more detailed study of the kinematics and mechanics of the Middle Allochthon across the transect. The primary objective here is to assess the structural variations and continuity of the shear zone across a transect from the Caledonian front in Sweden, westward to the coast of Norway. A 1:100,000 scale map of the tectonized zone between the parautochthonous crystalline basement and the Upper and Uppermost Allochthons has been compiled from published and unpublished sources. In addition, sample suites from several localities across the transect were examined in thin section to provide a reconnaissance of microstructural variations. The results of published and unpublished work on various segments of the shear zone are summarized in order to assess the first order structural development across the entire transect. The paper concludes by identifying major problems which need to be resolved through more detailed field and laboratory study.

GEOLOGY AND TECTONICS OF THE SCANDINAVIAN CALEDONIDES

Regional Tectonic Setting

The Scandinavian Caledonides are part of the major Caledonian-Appalachian mountain chain which flanks the northern Atlantic Ocean (Figure 1). This mountain chain extends from the Gulf of Mexico along the eastern margin of North America to Greenland, and from the northern tip of Scandinavia to the British Isles. The Caledonides of Scandinavia and East Greenland are the result of the closing of the Iapetus Ocean during the early to middle Paleozoic. Subduction of the Iapetus appears to have been westward beneath Greenland. Significant Caledonian age granitic magmatism and west-verging Caledonian nappes of oceanic affinity found on East Greenland suggest that it was the site of a magmatic arc and accretionary wedge complex

In Scandinavia, many of the allochthonous units have a strong miogeosynclinal character and Caledonian magmatism within the Baltic margin is almost completely absent (Stephens et al., 1985). The Baltic margin appears to have been the site of passive sediment accumulation until it was overrun by the Greenland-Laurentian continent. With complete subduction of the Iapetus, the western margin of the Baltic continent was thrust beneath Laurentia. Miogeosynclinal rocks of the Baltic margin and oceanic rocks accumulated within the ocean basin and along the Laurentian subduction zone were strongly deformed and thrust eastward over the Baltic craton producing the Caledonian mountains of Scandinavia.

Structure and Timing of Deformation

The Scandinavian Caledonides consist of a sequence of thin, areally extensive thrust nappes emplaced eastward onto the Baltic continent. The incision of glacial valleys transverse to the trend of the orogen and late cross-folding of the Caledonian allochthons has exposed a series of tectonic windows along the length of the orogen. Everywhere the basal contact is exposed, from the thrust front westward to the Norwegian coast, allochthonous Caledonian rocks are found resting on Precambrian gneisses of the Baltic shield. Although it is often uncertain whether the Baltic gneisses exposed in the windows have been displaced during orogenesis, it is clear that they were originally part of the Baltic continent (Gorbatschev, 1985). The Baltic-Laurentian continental suture must therefore lie west of the present Norwegian coast. In many places the thin sedimentary cover of the basement gneiss is preserved beneath the overriding nappes. Nappe emplacement appears to have been a thin-skinned process with major structures developed parallel to the surface of the ancient Baltic platform.

Three major phases of Caledonian deformation have been recognized in Scandinavia (Roberts and Gee, 1985). The main phase, generally termed the Scandian (Gee, 1975), began in the Mid or Early Silurian and continued to as late as Early Devonian. It is during this period that the Caledonian nappes were emplaced onto the Baltic platform. Extensive metamorphism and deformation during the Scandian has obscured much of the evidence for earlier deformation. In northern Norway, however, an earlier orogenic phase (the Finnmarkian) has been recognized which spans the late Cambrian to the early Ordovician (Sturt et al., 1978; Roberts and Gale, 1978). In part, this early Caledonian phase included the obduction of ophiolites onto the Baltic margin (Roberts and Gee, 1985). Late Caledonian deformation is recorded in southern Norway in the folding, thrusting and weak metamorphism of the latest Silurian to middle Devonian Old Red Sandstone (Roberts and Gee, 1985).

Tectonostratigraphy

The Scandinavian Caledonides can be subdivided into five major tectonostratigraphic units which extend the length of the orogen (see Figure 2, after the Tectonostratigraphic Map of the Scandinavian Caledonides, Gee et al., 1985). These units include the autochthonous or parautochthonous Baltic basement and four allochthonous units - the Lower, Middle, Upper, and Uppermost Allochthons.

The character of these units, particularly as they occur at the latitude of the transect, is described below. Only brief treatment is given the Lower and Middle Allochthons as their structure is described in detail in subsequent sections.

Autochthon/Parautochthon

Pre-Caledonian rocks of the Baltic Shield are exposed beneath and eastward of the frontal thrust in Sweden, in tectonic windows and culminations within the orogen, and along the Norwegian coast (Figures 2 and 3). The basement can only be considered strictly autochthonous where it occurs beneath the thrust front. In more western exposures, the basement exhibits a Caledonian foliation related to emplacement of the overlying allochthons, and has been disrupted by late Caledonian folding which produced the windows and culminations. Because of uncertainty in the degree of lateral transport experienced by the basement west of the thrust front, these rocks are referred to as parautochthonous (cf. Gee and Zachrisson, 1979).

The Autochthon/Parautochthon in this area consists of Proterozoic and lesser Archean basement overlain by a thin platformal sedimentary sequence of Vendian to Cambrian age. The basement exposed across the orogen is dominated by coarse grained perthitic granitic intrusions of the post-Svecokarelian Trans-Scandinavian Granite-Porphyry Belt (Gorbatschev, 1985). U-Pb and Rb-Sr age determinations bracket the age of these granites between 1.6 and 1.8 Ga (Bjorklund, 1989, and references therein). East of the thrust front the Baltic basement consists of low grade Proterozoic supracrustal sedimentary rocks and granitic porphyries intruded by granites of the 1.91 to 1.86 Ga Perthitic Monzonite Suite (Bjorklund, 1989, and references therein). Precambrian supracrustal rocks (other than the platformal cover) are only rarely found in basement exposures within the orogen at this latitude. The Precambrian basement of the Lofoten Islands is somewhat more complex than that further east. Here the basement consists of Archean migmatitic gneiss and early Proterozoic supracrustal rocks, 1.8 Ga Svecofennian intrusions primarily of mangerite, and 1.38 Ga Lodingen granite (Griffin et al., 1978). These crystalline rocks are overlain by supracrustal sequences of the Leknes Group on the westernmost Lofoten Islands (Tull, 1972, 1977) and the Austerfjord Group on central Hinnoy (Hakkinen, 1977). Both the Austerfjord Group and the Leknes Group are at least middle Proterozoic in age.

A thin platformal cover sequence referred to as the Dividal Group (Kulling, 1964; Foyn, 1967; Thelander, 1982) is found unconformably overlying the basement beneath the frontal thrust. This sequence consists of a locally developed basal conglomerate overlain by a thin sandstone, sandy to shaley siltstones, and black, graphitic shale. The Caledonian frontal thrust truncates the Dividal Group just above the base of the black shale unit, leaving a total stratigraphic thickness of typically only 10 to 20 m (Bjorklund, 1989). Dividal Group equivalent rocks can be traced across the orogen via tectonic windows and culminations where they are commonly preserved in parautochthonous contact with the basement. On the island of Hinnoy, Bartley (1981a) described a sequence called the Strovann Group, part of which may be correlative with the Dividal Group (Bjorklund, 1987). Across the transect, the sequence and lithologic character of the Dividal Group equivalent rocks is very similar and distinctive. This cover sequence is also found in association with Precambrian basement slivers within the Lower and Middle Allochthons, giving strong evidence that these tectonic units are derived from the Baltic margin.

Lower Allochthon

The Lower Allochthon is best developed on the eastern side of the orogen where it consists primarily of quartzites, psammites and shales similar (but not identical) to the Dividal Group, and minor basement slivers. In this area the inclusion of basement slivers appears to be related to pre-existing basin topography at the time of thrusting (Roberts and Gee, 1985). The Lower Allochthon can be followed westward where it is exposed around the edges of tectonic windows. Toward the west the Lower Allochthon contains increasing amounts of crystalline basement, indicating that the basal thrust must cut down into the basement further west. Typically the structure of the Lower Allochthon is characterized by the local development of duplexes which interleave and thicken the stratigraphic sequence.

Metamorphic facies increases westward within the Lower Allochthon from low greenschist at the thrust front up to amphibolite in the westernmost exposures. The westward increase in metamorphic grade combined with attenuation of the section and increased folding and ductile deformation make differentiation of the Lower Allochthon from the Middle Allochthon difficult in the Norwegian part of the transect.

Middle Allochthon

The Middle Allochthon is dominated by areally extensive slices of Precambrian basement rocks which locally retain their sedimentary cover sequence of basal quartzite, psammitic and pelitic schists. These rocks are generally metamorphosed to greenschist facies, but reach amphibolite facies in their westernmost exposures (Roberts and Gee, 1985). Everywhere across the study section, the Middle Allochthon contrasts markedly with the higher grade Upper Allochthon above. The structure of the Middle Allochthon is characterized by large-scale imbrication along ductile thrusts. Strain in the Precambrian basement slices is most intense near the thrusts, generally evidenced by development of an intense mylonitic foliation. The metasediments typically exhibit a high degree of ductile strain characterized by penetrative mylonitic foliations, intense isoclinal recumbent folding, and rotation of fold axes into parallel with the stretching lineation (Roberts and Sturt, 1980).

The Middle Allochthon basement slices are interpreted to have been derived from the western edge of the Baltic continent (Gorbatschev, 1985). In the Finnmark region of northernmost Norway, Middle Allochthon Precambrian rocks record early Caledonian (Finnmarkian) deformation (Sturt et al., 1978; Roberts and Gale, 1978). At the latitude of this transect and further south, evidence of Finnmarkian deformation is absent from the Middle Allochthon. This may in part be due to strong overprinting during the main (Scandian) phase of thrusting.

Upper and Uppermost Allochthons

The Upper and Uppermost Allochthons comprise a wide range of lithologies from diverse tectonic environments. Rifted margin, island arc, ocean floor, accretionary wedge, and stable continental shelf sequences are assembled into several complex nappes. The deformation and metamorphism recorded by these rocks is generally early Caledonian. Translation eastward across the Baltic Shield during the Scandian appears to have only deformed the lowest structural levels.

The Upper Allochthon can be subdivided into two major nappe units - the Seve and Koli Nappes. The structurally lower Seve Nappe consists of schists, gneisses, amphibolites, and migmatites generally metamorphosed to amphibolite facies or higher. The overlying Koli Nappes consist of greenschist facies volcanosedimentary rocks representing an eastward transported island arc. The Seve and Koli Nappes are commonly but not always separated by a thrust. All units of the Upper Allochthon thin and wedge out to the west. The Uppermost Allochthon primarily comprises migmatitic gneisses and lesser schists and psammites metamorphosed to amphibolite facies. In the western half of the transect, the Upper Allochthon pinches out completely and the Middle Allochthon is overlain by the Uppermost Allochthon. In this area, however, the Uppermost Allochthon may be correlative with the Koli Nappe. Despite this uncertainty, it is clear that the Upper and Uppermost Allochthons were assembled prior to final emplacement onto the Baltic Shield. On the main map (Plates 1 and 2), the Upper and Uppermost Allochthons are represented together as "UPPER ALLOCHTHON".

MAP-SCALE STRUCTURE OF THE EMPLACEMENT ZONE

Explanation of the Map (Plates 1 and 2)

A nearly continuous map of the sheared rocks between the Autochthon/Parautochthon and the Upper and Uppermost Allochthons at about 68° North has been compiled at 1:100,000 scale from published and unpublished sources (Plates 1 and 2; references therein). The structural and lithological character of this shear zone varies significantly across the transect. In the eastern half of the transect the Middle and Lower Allochthons can be identified and distinguished, however, further west they become indistinguishable and in places the Lower and Middle Allochthons are missing entirely. In order to avoid confusion, the sheared rocks lying structurally between the undeformed basement and the basal thrust of the Upper or Uppermost Allochthons will be broadly referred to in this paper as the 'emplacement zone'.

The complexity of the emplacement zone at this latitude generally precludes more detailed tectonostratigraphic subdivision. As such, the compilation map shows the locations of key lithologies within the emplacement zone along with major structures. The lithologies represented are granite and its sheared equivalents, quartzite, undifferentiated sediments other than quartzite, and amphibolite.

In addition, rhyolitic porphyries and Precambrian sediments associated with the basement have been represented where they occur in the eastern portion of the transect. In the eastern part of the section, true mylonitic textures (S-C fabrics, dislocation glide and creep, dynamic recrystallization) are developed in the granites. Further west the granites show annealed textures. Where the granites are annealed, they are subdivide into unfoliated basement, foliated and strongly foliated.

The granites and quartzites are traced due to their structural/tectonic significance and their lithologic similarity across the transect. Granite slivers within the emplacement zone are presumably derived from the Baltic basement. The quartzite corresponds to the basal unit of the Baltic platformal sequence; its presence on granite slivers indicates the level of the original basement cover contact.

The remainder of the emplacement zone rocks consist primarily of meta-psammitic schists and gneisses, with lesser meta-arkoses, calcareous schists and marbles. The lithologic variability and structural complexity of these rocks make correlations on the scale of the transect difficult. They are therefore grouped together as undifferentiated Baltic platform sediments. The locations of amphibolites and hornblende granodiorites are presented because of their potential importance for radiometric dating.

Except in the northwestern-most area of the transect, alluvial cover is not a significant problem. Alluvium is only explicitly represented on the portion of the map north of Ofotfjord. On the remainder of the map, solid lines are used to represent exposed and mappable lithologic and tectonic contacts, and dashed lines are used for contacts which are less certain. Specific distinction was not made between 'uncertain', 'concealed' and 'inferred' contacts since these are not consistently defined among the various source maps used as a basis for the compilation.

Structural Variation Across the Transect

The nature of the emplacement zone changes significantly between the thrust front in Sweden and the westernmost exposures on the island of Hinnoy, Norway. In the Swedish portion of the transect distinct Middle and Lower Allochthons are developed between the basement and the nappes of the Upper Allochthon. The Middle Allochthon in this area (the Akkajaure Nappe Complex) consists of an approximately one kilometer thick stack of flat-lying, imbricate granite sheets, each with a thin veneer of cover sediment (Bjorklund, 1985 and 1989). The granite slivers are areally extensive and can be traced continuously for over eighty km from the thrust front to the Norwegian border. The metamorphic grade increases slightly (muscovite to biotite - Bjorklund, 1989) from the thrust front to the national border but remains within the greenschist facies.

At about the Swedish-Norwegian border the Middle Allochthon thins to several hundred meters in structural thickness and the lithologic character changes dramatically. Several of the granite sheets pinch out in this area and the Middle Allochthon just west of the national border is dominated by meta-sediments rather than granite. Some of the sedimentary units in this region are metamorphosed to garnet grade, and the Lower and Middle Allochthons cannot be readily distinguished. As in the Akkajaure Nappe Complex, the overall structural style is characterized by thin, continuous sheets of granite and sediment imbricated along ductile thrusts parallel to the basement. Foliation is poorly developed in the basement and dies out immediately away from the basal thrust.

The Lower/Middle Allochthon complex can be traced northwest through several isoclinal folds to the Efjord culmination, although there is a gap in the available detailed mapping. Around the Efjord culmination the granite slivers are discontinuous, and folding is an important structural feature in addition to imbricate thrusting. The section here is also dominated by meta-sediments, some containing garnets. On the northern limb of the Efjord culmination, the Lower/Middle Allochthon complex is tectonically cut out and the Upper and Uppermost Allochthons rest directly on massive foliated granite. The granite foliation is concordant with the thrust contact of the overlying nappes, and dies out with structural distance from the thrust.

A highly disrupted sedimentary package is found between the basement and the Upper Allochthon at the village of Forsa. North of Forså, around the west side of the mountain Hafjell, a sequence of thin, continuous sedimentary layers is preserved between the foliated basement and the Uppermost Allochthon. These sediments do not exhibit the complicated imbrication of the Forså complex or Middle Allochthon, but appear to be the parauthochthonous cover of the foliated basement granite. The exact nature of the transition from the Forså complex to the less deformed sediments around Hafjell is obscured by vegetation. The nature of the foliated granites below the sediments is similar to that described along the north shore of Efjord, though the foliation persists for over a kilometer structurally below the thrust.

On the north shore of Ofotfjord, at the village of Skar, the emplacement zone consists of foliated basement overlain by strongly sheared sediments and an imbricated sliver of granite. The section of sediments and imbricate granite has a structural thickness of only about 100 m. Metamorphism in these rocks reaches amphibolite grade. North of Skar alluvial cover becomes substantial and the thrust structures are complicated by late Caledonian folding and post-Caledonian high angle faulting. There is substantial disagreement over the tectonic interpretation of rocks in this area, particularly on eastern Hinnøy (Bartley, 1981a; Tull et al., 1985; Bjorklund, 1987). The nature of the emplacement zone in this area is uncertain and will be discussed subsequently. Bartley's mapping of the area north of Skar (Bartley, 1981a) is presented on the compilation map since it shows the actual extent of observable outcrop.

For the purpose of detailed description, the transect is divided into five segments:

- Akkajuare region
- National border to Mannfjord
- Efjord Culmination
- Forså to Ofotfjord
- Skar to East Hinnoy

Detailed descriptions of several of these areas are presented elsewhere (see for example Bartley, 1981a; Bjorklund, 1989; Bjorklund, 1987; Hodges, 1982; Tull et. al.;1985) . The purpose here is not to merely reiterate previous work but to present key observations which shed light on the nature of the Middle Allochthon, and the broader emplacement zone, across the transect.

Akkajaure Region

The broad, northwest trending valley which contains the lake Akkajaure provides a deep cut across the trend of the orogen, from the thrust front to the Swedish-Norwegian border. This valley exposes a broad expanse of the Middle Allochthon including long segments of its thrust contact with the overlying Upper Allochthon, and several tectonic windows into the underlying Lower Allochthon and Parautochthon. Bjorklund (1985, 1989) has recently completed a detailed study of the northern half of the Akkajaure valley from which much of the following has been summarized.

The Middle Allochthon in this area is referred to as the Akkajaure Nappe Complex and consists of Precambrian granite sheets which have been tectonically stacked along ductile thrusts. Individual thrust sheets are capped by a thin sequence of quartzite and phyllites commonly only a few meters thick. These cover sediments are considered to be equivalent to the autochthonous Dividal Group which rests depositionally on the Baltic crystalline basement east of the thrust front. The Akkajaure granite sheets are generally interpreted to be slices of the Baltic continent which form a schuppen zone between the Upper Allochthon and the Lower Allochthon and Autochthon.

The Akkajaure Nappe Complex is bounded below by the Akkajaure Thrust and above by the Seve-Koli Thrust. The Seve-Koli Thrust and the overlying Seve and Koli Nappes of the Upper Allochthon are well exposed along the north wall of the valley and on two high peaks in the central part of the area. The rocks of the Seve Nappe are predominately garnet-amphibolites and garnet schists while the Koli Nappe consists of schists with or without garnets and lesser calcareous schists, marbles and amphibolites (Bjorklund, 1985). The lithologies of the Upper Allochthon contrast markedly with the granites and lower grade metasediments of the Akkajaure Nappe making the Seve-Koli Thrust a prominent and easily identified feature in the field.

The lithologies of the Lower Allochthon are very similar to those of the Middle Allochthon. The Lower Allochthon is distinguished from the Middle Allochthon by its lower degree of metamorphism, lower level of strain, and minor proportion of granite slivers relative to sediments. The Lower Allochthon outcrops at the thrust front at the southeastern end of Akkajaure and in two tectonic windows north of the center of Akkajaure. In each of these areas the Akkajaure Thrust can be readily identified due to the highly mylonitized Akkajaure Nappe granite directly above the thrust which forms a steep scarp. Six distinct thrust sheets have been identified within the Akkajaure Nappe Complex, the lower three of which extend the full length of the Akkajuare valley (Bjorklund, 1985 and 1989). The most conspicuous feature of the thrust sheets is their extreme thinness relative to areal extent. The lowest sheets extend to the northwest for over 80 km yet have thicknesses on the order of only 200 to 400 meters. The thrust sheets are approximately horizontal and parallel to one another, and the lower bounding thrust of each granite sheet is parallel to the overlying sedimentary veneer. Assuming that the parallel geometry of the thrusts is not the result of rotation due to high strain, these relationships indicate that the original basement detachments of the granite slivers were parallel to the basement-cover contact and restricted to a shallow depth beneath it (Bjorklund, 1985).

The internal thrusts of the Akkajaure Nappe Complex are defined by narrow zones of intense mylonitization (Bjorklund, 1989). Augen-gneiss to protomylonitic textures are developed in the interior of the granite sheets indicating much less intense deformation than near the thrusts. Foliations developed in the granite gneisses and mylonites are sub-horizontal and parallel to the thrust planes. Mineral stretching lineations trend generally WNW to ESE and assymetric augen and mylonitic textures consistently record top-to-the-ESE sense of shear (Bjorklund, 1985 & 1989). The intensity of internal deformation within granite sheets varies through the nappe stack, with the upper three thrust sheets generally exhibiting higher strain than the lower three sheets (Bjorklund, 1985). In all sheets the degree of internal strain increases toward the west. This is accompanied by a general westward thinning of the entire complex and a slight increase in metamorphic grade (white mica to biotite).

The Akkajaure Nappes are also attenuated laterally, toward the NNE. This is particularly evident in the area of Autajaure where the thrusts bounding the upper two granite sheets merge with the Sevi-Koli Thrust. The Akkajaure Complex is quite thin around the tectonic window surrounding Autajaure, and is completely absent between the Upper and Lower Allochthons along the southeast side of this window. Due to the low angles at which the Akkajaure Nappe thrusts merge with the Seve-Koli Thrust, they do not provide clear evidence of tectonic cut-out of the Akkajaure Nappes by the overlying thrusts. Bjorklund (1989), however, has noted that the cover sediments of the Akkajaure granite slices are preferentially absent where the slices are directly overrun by the Seve-Koli Thrust. He concludes that the lack of sedimentary cover rocks in the footwall of the Seve-Koli Thrust appears to be directly related to the thrust, but notes that given the ductile nature of the thrusting, it is difficult to envision the complete stripping away of the cover rocks over a transport-parallel distance of more than 100 km.

In addition to the large-scale imbricate thrusts, several smaller scale duplex structures are identified within the Lower Allochthon and along the internal thrusts of the Akkajaure Nappe Complex. The duplexes locally thicken the sedimentary package up to 200 meters and involve only minor interleaving of the underlying granites. In each of the duplexes Bjorklund (1989) reports WNW-dipping thrust planes, consistent with a top-to-the-ESE transport direction. These structures are too fine to show at a scale of 1:100,000, and are marked on Plate 2 as undifferentiated Middle and Lower Allochthon where they occur in the two tectonic windows and on the high peaks in the center of the Akkajaure region.

Three generations of folding have been identified in the Akkajaure region (Bjorklund, 1989). The earliest are rare syn-thrust sheath folds related to shear in the vicinity of the thrust planes. The most common folds in the area trend transverse to the structural grain of the orogen and fold the Akkajaure thrusts and syn-thrust fabrics. These folds are assymetric and inclined to recumbent in style and are observed on all scales. The largest transverse fold overturns the lowest and next lowest granite sheets along the southeast shore of Akkajaure. It should be noted that this fold does not appear to involve higher nappes in the section. Thus the development of transverse folds may post-date some but not all Akkajaure Nappe Complex thrusting. The latest-phase folds trend NNE and have upright open geometry in the eastern part of the region which becomes tighter in folds further west.

National Border to Mannfjord

A late-Caledonian basement upwarp near the Swedish-Norwegian border tilts the Caledonian allochthons to the northeast, providing a structural cross-section of the rocks between the crystalline basement and the Upper Allochthon. In this area, the Lower and Middle Allochthons of the Akkajaure region thin markedly, attaining a combined structural thickness of only a few hundred meters just west of the national border. The attenuation of the section is due to the pinch-out of two of the upper Akkajaure thrust sheets as well as a general westward thinning of individual thrust sheets.

As in the Akkajaure region, the section is composed of sheets of granite gneiss and metamorphosed sediments, presumably the original cover of the granite. A quartzite horizon is commonly found directly overlying the granite gneiss, but is also found in lenses within the granite sheets. Reddish-weathering schisty zones of retrograded granite mylonite occur within the granite sheets, parallel to the bounding thrusts. These zones sometimes contain quartzite lenses, indicating that the granite units may be compound thrust sheets (Burchfiel, unpublished field notes).

Garnets are found in the schists and occasionally in the granite gneiss, particularly in the structurally higher units. Unlike the Akkajaure nappes the proportion of meta-sediments in the section is equal to or greater than that of granite gneiss. It should be noted that the thrust sheets present west of the national border are not mapped continuously into the Akkajaure Nappe Complex. Where last mapped, they strike approximately north-south and project to the south side of Akkajaure which is not mapped in detail. Thus, it is uncertain whether the thrust sheets west of the national border are directly correlated with the Akkajaure Nappe Complex.

The structural development of the emplacement zone in the Tysfjord area involves significant folding as well as thrusting. Early thrusting which assembled the granite and sedimentary slices produced a penetrative foliation throughout the sequence. Within the Lower and Middle Allochthons this foliation parallels the thrust sheet contacts, however, the foliation in the parautochthonous granite merges with the foliation in the overlying quartzite with an angular discordance of about 10° to 15°. This original foliation is folded by isoclinal inclined to recumbent folds with axes trending N 30° E to N 60° E. This generation of folds internally deforms all of the sedimentary units. A second generation of open to tight, commonly kink or chevron geometry folds is also developed throughout the section. The axes of these folds trend N 60° W to N 30° W and the geometry of the kink folds generally indicates westward vergence. The second generation folding commonly transposes or crenulates the earlier foliation. A strong secondary axial planar foliation is developed in the basement granite in the core of the large second generation antiform just east of Mannfjord.

Efjord Culmination

The emplacement zone can be traced northwest of Mannfjord, around several large orogen-parallel folds, to the Efjord culmination. On the south limb of the culmination, the emplacement zone consists of a thick sequence (up to 1½ km) of tectonically interleaved meta-sediments with less abundant, discontinuous slivers of granite gneiss. The meta-sediment sequence comprises white quartzites, psammitic and graphitic schists, and biotite quartzo-feldspathic gneiss. Garnet is locally present in the schists and biotite quarzto-feldspathic gneiss. Thin, discontinuous quartzite layers are found within the sedimentary package that are not associated with granite gneiss slivers. Due to the high degree of recrystallization and the transposition of fabrics it is difficult to determine whether the biotite quartzo-feldspathic gneiss is derived from highly strained Precambrian basement lithologies or from the latest Precambrian to Cambrian Baltic platform sediments.

A strong S 60° E stretching lineation is developed throughout the Lower/Middle Allochthon complex. However, a weak north to northeast plunging foliation is developed in small ductile shear zones dipping 35° to 45° which cut down into the parautochthonous basement. As they near the Lower/Middle complex from the basement, they are rotated in to parallel with the dominant foliation and the N-NE lineation is overprinted by the S 60° E lineation. The dominant structures in the Efjord culmination are isoclinal folds with east-west trending fold axes. The presence of the isoclinal folds and the weak N to NE trending lineation suggests a significant component of tectonic transport parallel to the trend of the orogen.

The most striking feature in the Efjord area is the complete pinch-out of the thick meta-sedimentary package at the north side of the culmination. The sedimentary section pinches out abruptly where a portion of the basement granite appears to be recumbently folded back on itself. Northwest of this fold, along the north wall of Efjord, the Upper Allochthon rests directly on foliated, coarse-grained granite gneiss. No shear zones or sedimentary rocks are found within this granite along the north shore of the fjord.

Forså to Ofotfjord

At the village of Forså, a zone of tectonic slices is again found between the basement granite and the Upper Allochthon. Hodges (1982) divides this zone into upper and lower parts. In the lower part he identifies tectonic slices of Baltic platform sediments and minor Precambrian granite along with amphibolite and garnet-quartz-muscovite schist lithologies which he believes to be of Upper Allochthon affinity. If true, this would represent the only place across the transect where Upper Allochthon-affinity rocks are found below the basal thrust of the Upper Allochthon. The upper part of Hodges' Forså Complex consists of a coherent, isoclinally folded sequence of Baltic platform sediments.

The emplacement zone can be traced northwest to a ridge near the mountain Håfjell. However, Because of alluvial cover and vegetation northwest of Forså, individual units of the Forså Complex cannot be traced to the ridge near Hafjell where the lower thrust of the Upper Allochthon is next seen. At least the lower part of the Forså Complex does not appear to continue along this ridge. The emplacement zone in this area appears to be a coherent sequence of metamorphosed Baltic platform sediments with a white quartzite lying directly on the basement granite for over 10 km along strike. Foliations in the sedimentary section are transposed and isoclinal folds are common. Only one small sliver of granite is identified within the emplacement zone, just above the basement contact where the Ofoten Synform turns the section back to the northeast.

The underlying granitic basement is strongly foliated. The foliation is most intense at the basement/cover contact, where the granite takes on a schisty character. Structurally below this contact the granite becomes a medium to coarse-grained foliated augen-gneiss. The intensity of the foliation decreases with structural depth below the thrust, eventually dying out several kilometers away. Tull et. al. (1985) present evidence that indicates that the basement foliation is directly related to the emplacement of the Upper Allochthon and that there is no tectonic discontinuity between the foliated granite and the parautochthonous basement.

Skår to East Hinnoy

The emplacement zone is exposed on the north shore of Ofotfjord at the village of Skår. The zone here is only about 200 meters thick and consists of amphibolite-grade metamorphosed sediments and a relatively thick sliver of granite. No quartzite is found at this locality. The same relationships described for the parautochthonous granite west of Hafjell are observed here.

Directly north of Skar, emplacement zone exposure is lost in a marshy low-lying area, then reappears at the north side of Ramboheia in isolated outcrops. In the area around Tjeldsund, the Caledonian rocks are folded by northwest trending folds and dissected by post-Caledonian, northeast striking high angle faults. On Ramboheia and east Hinnoy, the detailed structure of the emplacement zone is not well constrained due to alluvial cover. A sequence of basal quartzite, overlain by marble, psammitic schists, and calcareous schists (Storvann Group, Bartley, 1981a) is found in contact with locally foliated basement gneiss. This sequence is truncated above by a thrust contact with the Upper Allochthon. The Storvann Group is considered to represent Baltic platform sediments similar in character to the Dividal Group (Bartley, 1981; Tull et. al., 1985; Bjorklund, 1987). The tectonic interpretation of these rocks is controversial, particularly where they outcrop along the eastern shore of Storvatn. Bartley (1981a) interprets the Storvann Group to be locally derived, while Bjorklund (1987) considers the same rocks to be part of an imbricate stack of far-travelled granite slices and cover sediment correlative with the Akkajaure Nappe Complex. Given the discontinuity of the western continuation of the Akkajaure nappe sheets previously demonstrated, the Storvann rocks cannot be directly correlated with the Akkajaure Nappe Complex.

The structural development of eastern Hinnoy presented by Bartley (1981) involves several important phases of thrusting and folding. The first deformational event is associated with the ESE-directed thrust emplacement of the Upper Allochthon onto the Baltic basement. This event is recorded by the development of a pervasive foliation in the Storvann Group and underlying basement parallel to the basal thrust of the Upper Allochthon. The foliation in the basement dies out with depth below the cover contact. The first deformational phase also produced isoclinal folds within the Storvann Group. A second thrusting phase locally transposed the original foliation and isoclinally folded the previous thrusts. These isoclines verge to the ESE. Two phases of large-scale folding followed, both generating upright to overturned assymetric folds (Steltenpohl and Bartley, 1988). The first set of folds has axial orientation WNW-ESE and shows SSW vergence. The second set of folds is oriented NE-SW and shows variable vergence. The high angle faults which dissect the Caledonian structures are of probable Mesozoic age (Bartley, 1981b).

MICROSTRUCTURAL VARIATION ALONG THE EMPLACEMENT ZONE

Approximately one hundred samples of granite and quartzite were examined in thin section in order to provide a first order assessment of microstructural variation across the transect. The purposes of the microstructural study are: 1) to determine to first order the rheological variations across the transect, and 2) to identify potential methods for measuring finite strain. Granite and quartzite lithologies were chosen for study because they are ubiquitous across the emplacement zone and because of their relatively homogeneous petrologic character. Emphasis is placed on the deformation structures developed in the granites since they record the mechanical response of the Baltic basement during emplacement of the higher nappes.

Petrographic work was performed on standard 30 micron thin sections cut parallel to the X-Z plane. The thin sections were stained to facilitate identification of quartz, plagioclase, and potassium feldspar. Representative photographs of samples from each of the areas discussed below are included in the appendix, along with sample locality maps. In the photos taken under parallel polars, quartz appears clear white, plagioclase light gray, and potassium feldspar dark gray.

The microstructures observed in the granites and quartzites can be divided into two broad classes: those that preserve primary ductile deformation structures (mylonites) and those that are annealed. The mylonitic textures, dominated by dislocation glide structures and dynamic recrystallization, are developed primarily in the Akkajaure region. West of the Swedish-Norwegian border static annealing has overprinted much of the original deformation fabric. The transition from rocks which record deformation to those that have been annealed appears to occur gradually over a distance of about 20 km west of the national border (Bjorklund, 1989).

Akkajaure to Tysfjord

Granites of the Akkajaure region show varying degrees of strain, ranging from ultramylonites along major thrusts to protomylonites and augen gneisses in the interior of thrust sheets (Photos A1 through A8). Banding of more and less intensely mylonitized zones occurs on scales ranging from centimeters to several meters and is most strongly developed near major thrusts. Contacts between bands tend to be sharp. The bands may be the result of strong strain localization, or the rotation of earlier deformation fabrics into parallel with the main mylonitic foliation (cf. Ramsay et al., 1985). Macroscopic quartz veins which cross-cut the mylonitic foliation near major thrust zones generally exhibit S-shaped geometries consistent with top-to-ESE shear sense. These veins are commonly rotated into parallel with the mylonitic foliation.

Type I S-C mylonitic fabrics (Lister and Snoke, 1984; Berthe et al., 1979) are developed within the granites and give consistent top-to-ESE shear sense (Bjorklund, 1989). The textures are characterized by the development of a very fine-grained matrix of recrystallized quartz, plagioclase, and potassium feldspar around large perthite and plagioclase porphyroclasts. Porphyroclasts are often assymetrical with fine-grained neoblastic tails. The neoblasts are typically of mixed sizes of order 10 to 100 microns and are slightly elongate to equant (Photo A9). They are generally strain free. Perthite and plagioclase porphyroclasts show evidence of deformation by dislocation glide in the form of undulose extinction, sub-grain development, and bent and kinked twins. Microfaulting of porphyroclasts is also common, often with "extensional normal fault" geometries (Photo A10). Microfractures are filled with fine grained neoblasts. Primary quartz grains, where preserved, show intense elongation and undulose extinction. Bent micas are common.

Quartzites of the Akkajaure region are typically very fine grained (<0.1 to 0.5 mm) completely recrystallized mylonites. The quartzites are generally impure, containing feldspar and mica which give the rocks a strongly laminated and banded appearance. Coarser vein quartz (c. 0.5 mm) is common within the quartzite mylonites, and exhibits deformation fabrics similar to but not as intensely developed as those in the surrounding quartzite (Photo A11). The coarser grained quartz retains a strong crystallographic preferred orientation evidenced by the extinction of large domains of grains under crossed polars. The finer grained quartzites generally show a more random crystallographic fabric, possibly indicating superplastic deformation (White, 1977; Schmid, 1982).

Norwegian Border to Skar

Toward the western end of the Akkajaure region and into Norway, Bjorklund (1989) has noted an overall increase in recrystallized grainsize (0.1 to 1.0 mm) and a tendency toward more equant grains with straight grain boundaries and low energy grain boundary intersections (Photo A12). Coarse grained, commonly polygonized biotite defines the foliation. Many perthitic porphyroclasts are partially or completely recrystallized as strain-free microcline and plagioclase polygrains. Undulose extinction, bending of twins, and subgraining is only minor west of the Norwegian border. These structures suggest a high degree of recovery and annealing within the deformed rocks. It should be noted that in outcrop the annealed granites are similar in appearance to the mylonitic granites at Akkajaure.

Westward through the Efjord, Hafjell, and Skar areas, the granite microstructure is dominated by annealing textures as described above (Photos A13 to A33). Only gross structural features related to deformation appear to be preserved. These include annealed microcline polygrains which appear to be remnant porphyroclasts, and recrystallized biotite foliation spacing and overall grainsize which appear to decrease with higher strain. The latter observations suggest that the textures may be primary deformation fabrics developed at high enough temperatures that recovery could keep pace with the strain. Locally the quartzites appear to preserve a weak crystallographic preferred orientation fabric (Photo A27).

The decrease in interfoliation spacing and overall grainsize reduction with increasing strain is most pronounced in the parautochthonous basement rocks in the Hafjell and Skar areas. At Hafjell a gradual decrease in grainsize is observed over a structural distance of about a kilometer toward the lowest Caledonian thrust (Photos A19 to A26). In the structurally deepest sample (TG-13) single feldspars within the granite exceed 5 mm (Photos A19 and A20). At the contact with the overlying quartzite, the granite has been well homogenized and has a grainsize of 0.1 to 0.5 mm (Photos A25 and A26). Note that the biotite in Photo A21 appears to define the S-surface (of an S-C mylonite).

A similar trend is observed in the parautochthonous basement at Skar (Photos A28 to A33). Over a distance of 30 m the grainsize is reduced from 0.5 to 1.0 mm to 0.1 to 0.3 mm. Pegmatite and quartz veins are developed in the granite slice which overlies the Parautochthon. The pegmatites are typically half meter long lenses of predominately coarse grained pink potassium feldspar. Some of the pegmatites are little deformed while others appear to have been sheared into continuous pink gneissic bands. Similar relations are observed for the quartz veins, suggesting that significant fluid volumes were mobile in the rocks during the main deformation.

Storvatn, East Hinnoy

Granite slices along the shore of Storvatn on eastern Hinnoy exhibit coarse grained protomylonitic textures in their interiors (Photos A34 to A37) and finer grained foliations along thrusts (Photos A38 to A40). Unlike other granite slices examined west of Akkajaure, the granites here contain perthitic porphyroclasts which exhibit undulose extinction and bent twins (Photo A35). These are surrounded by a matrix of recrystallized quartz, plagioclase, and potassium feldspar grains of order 0.2 mm. Near thrusts, the porphyroclasts are commonly absent, and the granite consists of moderately well homogenized recrystallized grains between 0.1 and 0.5 mm. The mineral grains within the Storvatn granites typically have more irregular grain boundary morphology and less equipartitioned grain boundary junctions than the annealed-looking rocks to the east. Quartzite mylonites overlie individual granite sheets. The quartzites generally have strong crystallographic preferred orientations. Overall the Storvatn rocks appear to be less deformed and preserve more of their original deformation fabrics than other sheared granites and quartzites examined west of the Norwegian border. This would appear consistent with Bartley's (1981a) interpretation of the Storvann Group as locally derived.

DISCUSSION

The most striking feature of the map transect is the discontinuity and lithotectonic variation within the Middle Allochthon as it is traced from the thrust front westward. The Middle Allochthon thins westward from a thickness of over one kilometer near the Caledonian front to a few hundred meters west of the Norwegian border. Structural duplexing appears to thicken the section at the Efjord culmination before it pinches out abruptly along the north shore of Efjord. Where the Middle and Lower Allochthons are absent northwest of Efjord, a strong foliation is developed in the underlying parautochthonous granites. This foliation gradually dies out with structural depth beneath the allochthons. On east Hinnoy, a sequence of granite slivers and their cover are present between the Parautochthon and the Upper Allochthon. The tectonic interpretation of these slivers is unclear, but they appear to have experienced a lesser degree of deformation and recrystallization than similarly placed granite slices further to the east.

Unravelling the kinematics and tectonic significance of the Middle Allochthon will require understanding the controls on the variable thickness of the unit and its pinching out. Significant lateral thickness variations are observed in the Akkajaure region where lateral exposure is most extensive. In the Efjord area evidence is found for orogen-parallel shortening along isoclinal transverse folds. This observations suggest a significant orogen-parallel component in the structural development of the Middle Allochthon. Palinspastic reconstruction of the Middle Allochthon along a NNW section (Bjorklund, 1985 and 1989) does not appear valid, especially given the elimination of the Middle Allochthon northwest of Efjord.

First order examination of microstructures across the transect shows that only the rocks of the Akkajaure and Storvatn areas retain primary deformation microstructures. It is unclear whether the intervening rocks in the transect experienced static annealing or were deformed at temperatures which allowed recovery processes to keep pace with strain. The quartzites appear to retain a weak crystallographic preferred orientation and may be useful in determining sense of shear, particularly in relation to transverse folds in the Efjord region. Recrystallized grainsize and foliation spacing in the annealed-looking granites decrease systematically with increasing strain. The grain morphology in these rocks, however, does not preserve evidence of crystal plastic strain processes. Thus grainsize and foliation spacing can only provide a crude relative scale of finite strain. The extreme shear and homogenation of the granites generally precludes the use of ribboned grains as strain indicators.

In summary, future study of the Middle Allochthon at this latitude should focus on determining the details of orogen-parallel transport. The prime locality for this work would be the Efjord culmination where transverse isoclinal folds are best preserved. The weak crystallographic preferred orientations locally preserved in the quartzites may provide useful sense of motion information. The use of microstructures to determine finite strain and to identify variations in rheologic behavior across the transect does not appear feasible. One aspect of the rheology that is yet to be addressed and may prove fruitful is the role of fluids in localizing the detachments of the granite slivers. Bartley (1981a) has argued that the shallow level of basement detachment is controlled by the infiltration of water from the overlying sediments. Significant vein formation across the transect in association with the major thrusting gives evidence for important fluid interaction. The application of oxygen isotope and fluid inclusion studies may yield important information bearing on this problem.

FIGURES

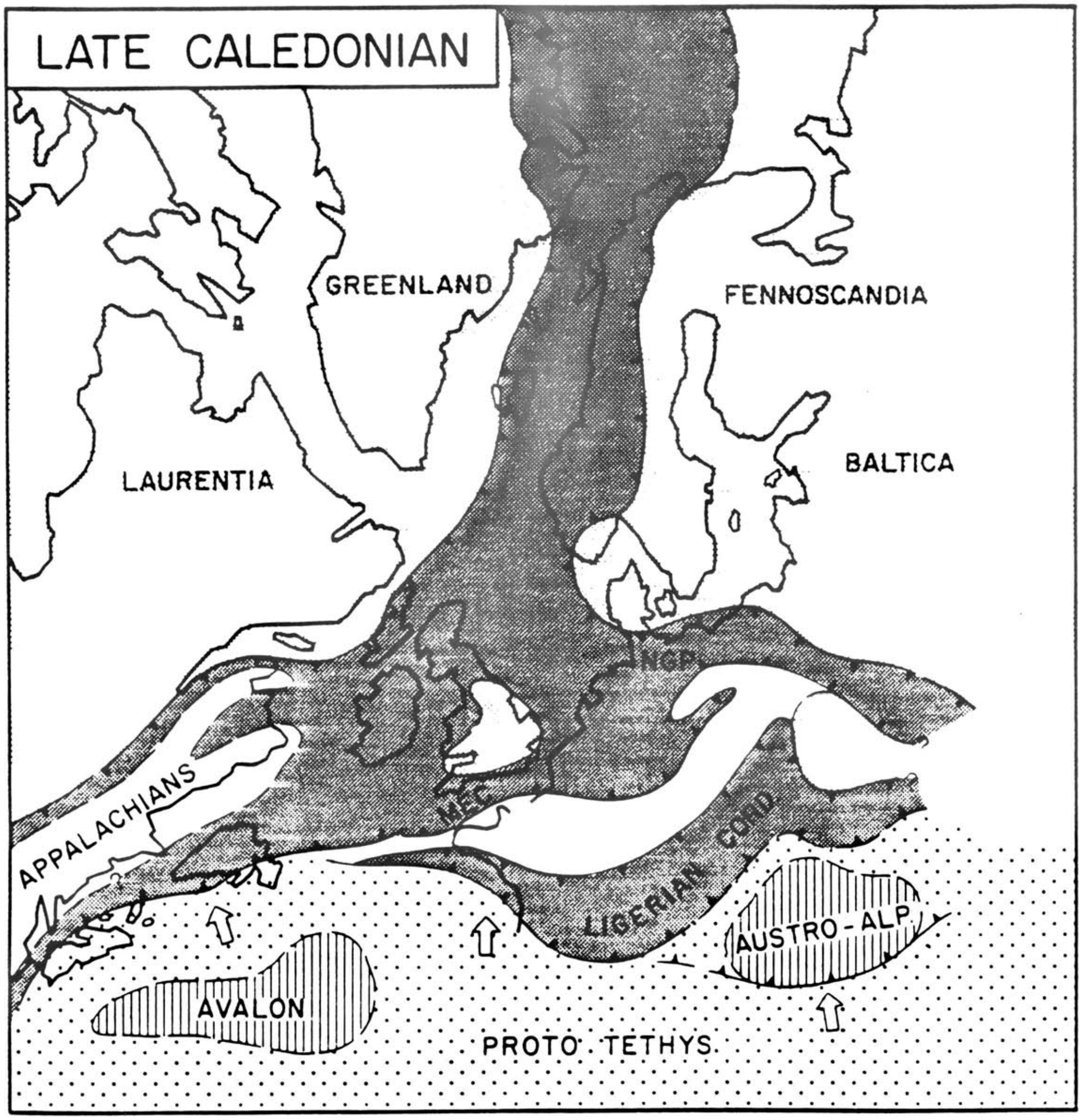

Figure 1: Extent of the Caledonian- Appalachian orogen (dark gray) during late Caledonian time. (figure from Ziegler, 1985)

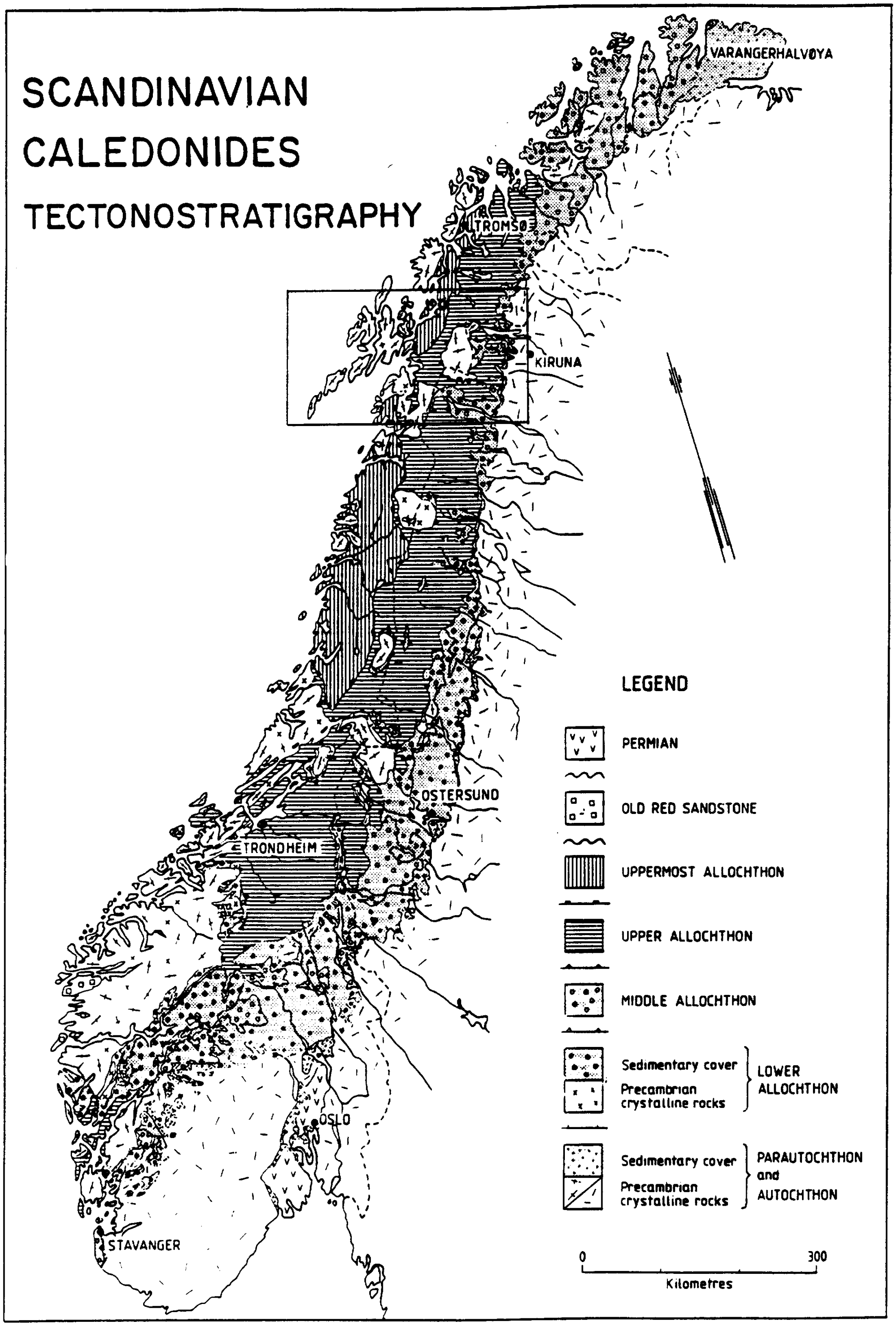

Figure 2: Tectonostratigraphy of the Scandinavian Caledonides (from Roberts and Gee, 1985; based on Gee et al., 1985). The box shows the location of the transect.

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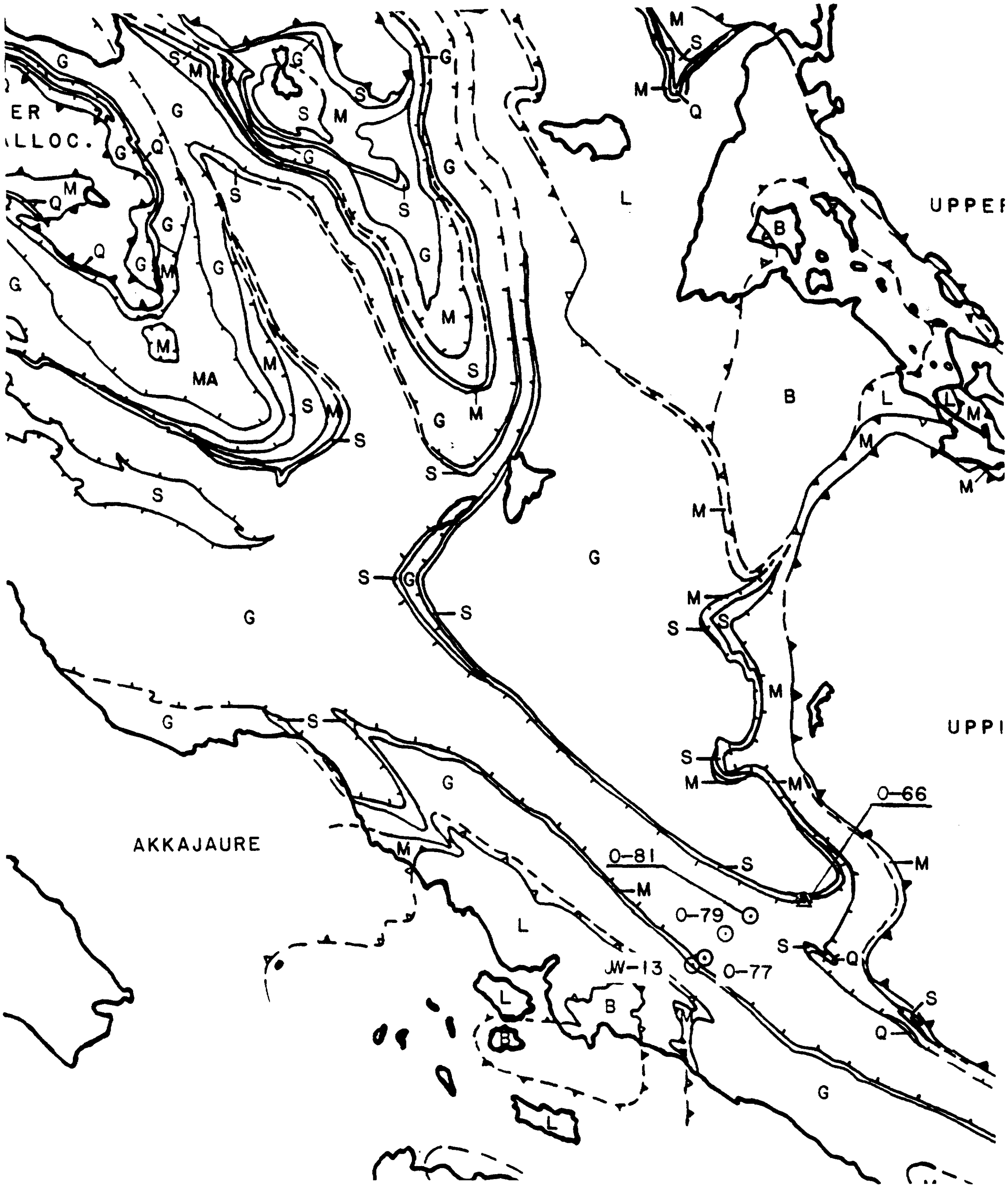
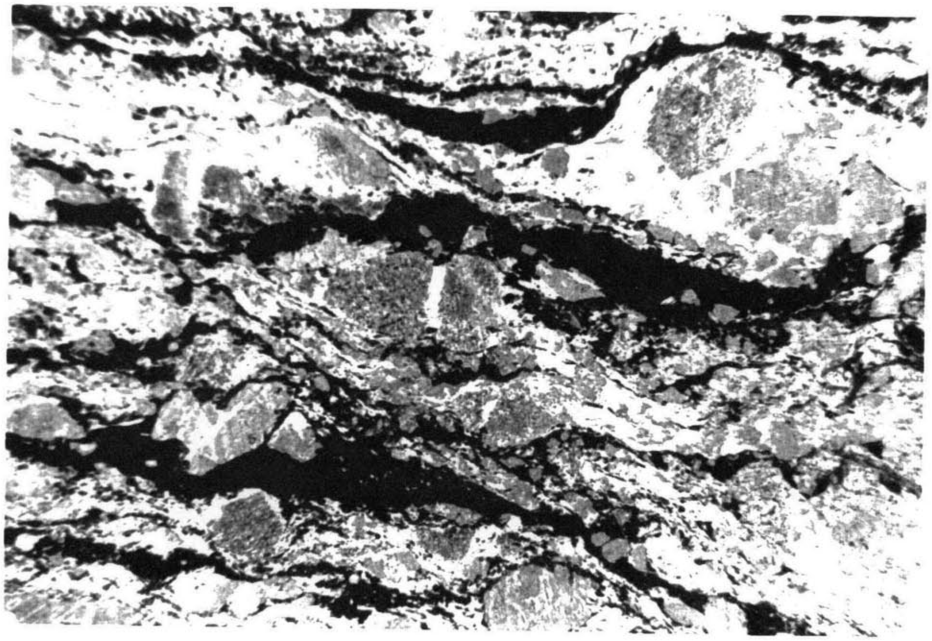
APPENDIX

PHOTOGRAPHS OF REPRESENTATIVE MICROSTURCTURES

NOTE: On sample locality maps, circles represent granite samples, and triangles represent quartzite samples.

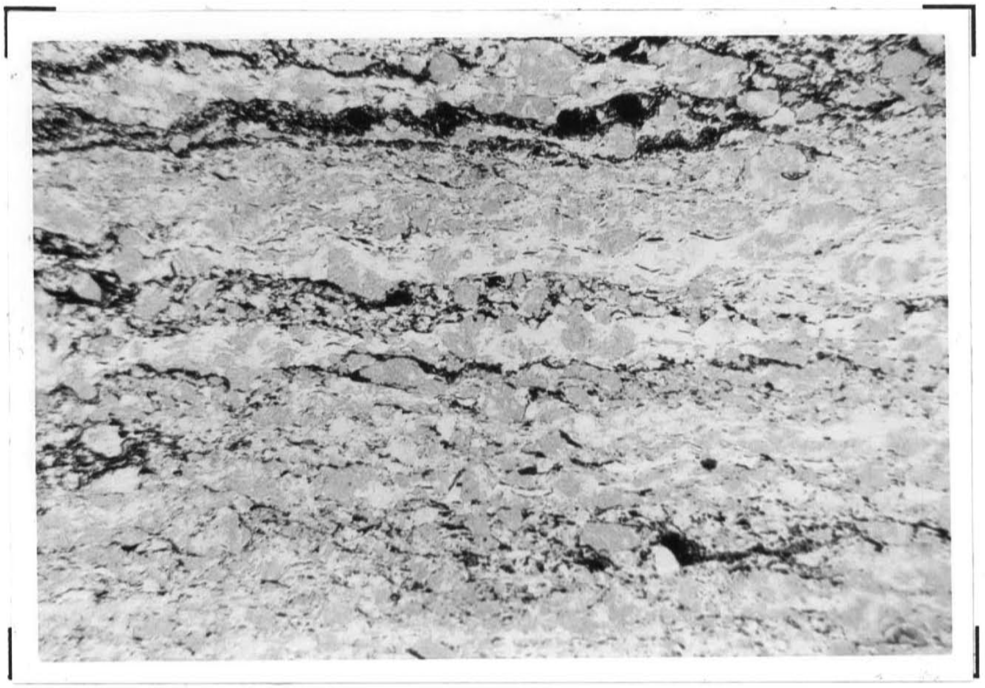
CENTRAL AKKAJAURE REGION



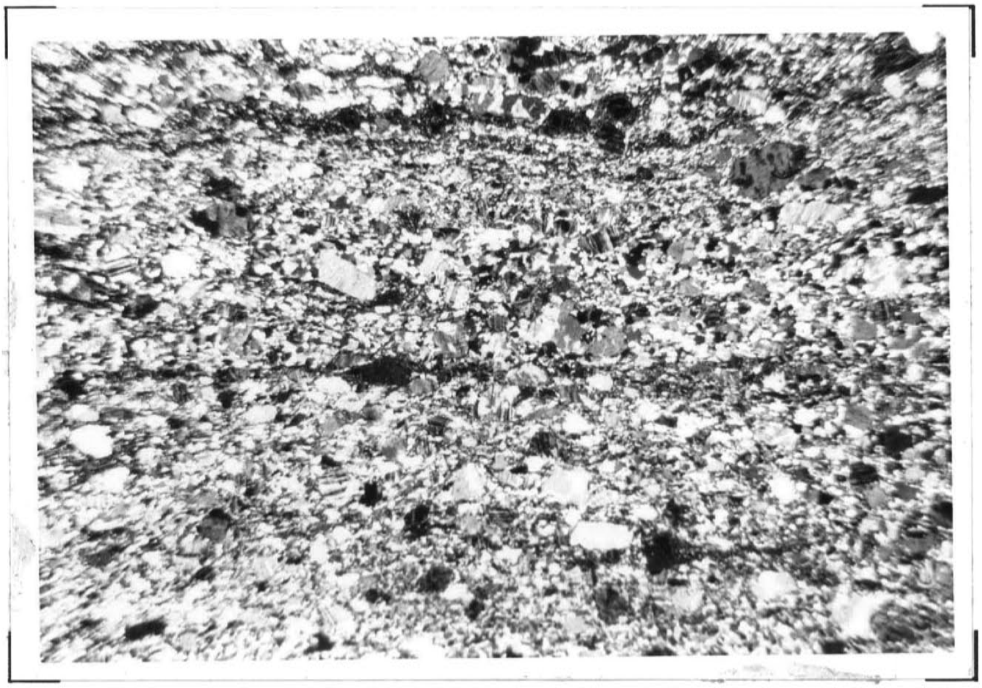


Photograph A1: Granite sample 0-77
(|| polars; field is 13.3 mm wide)

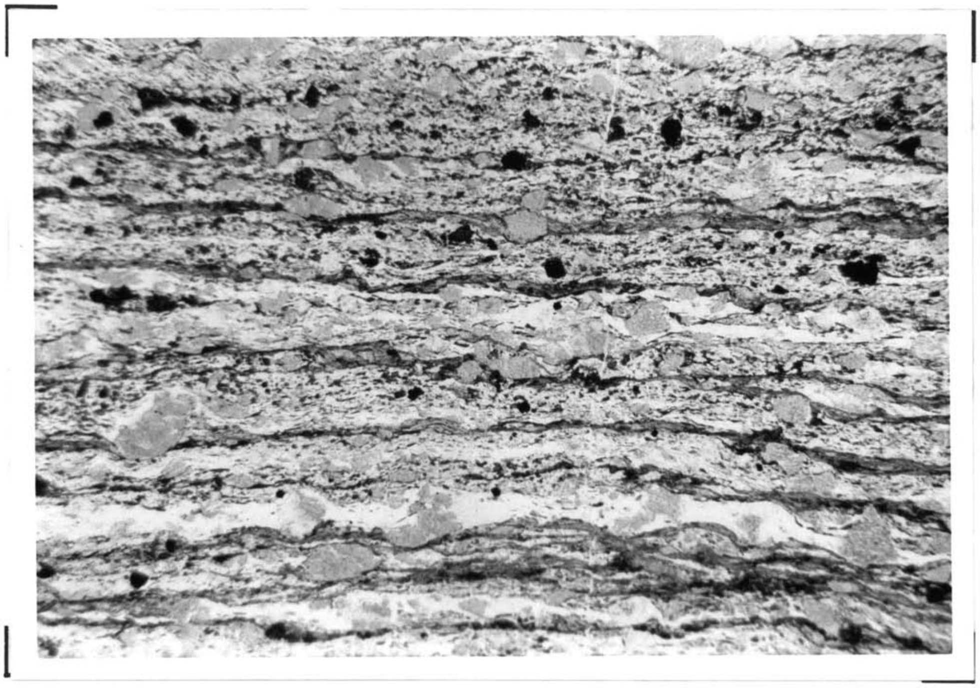
Photograph A2: Granite sample 0-77
(X polars; field is 13.3 mm wide)



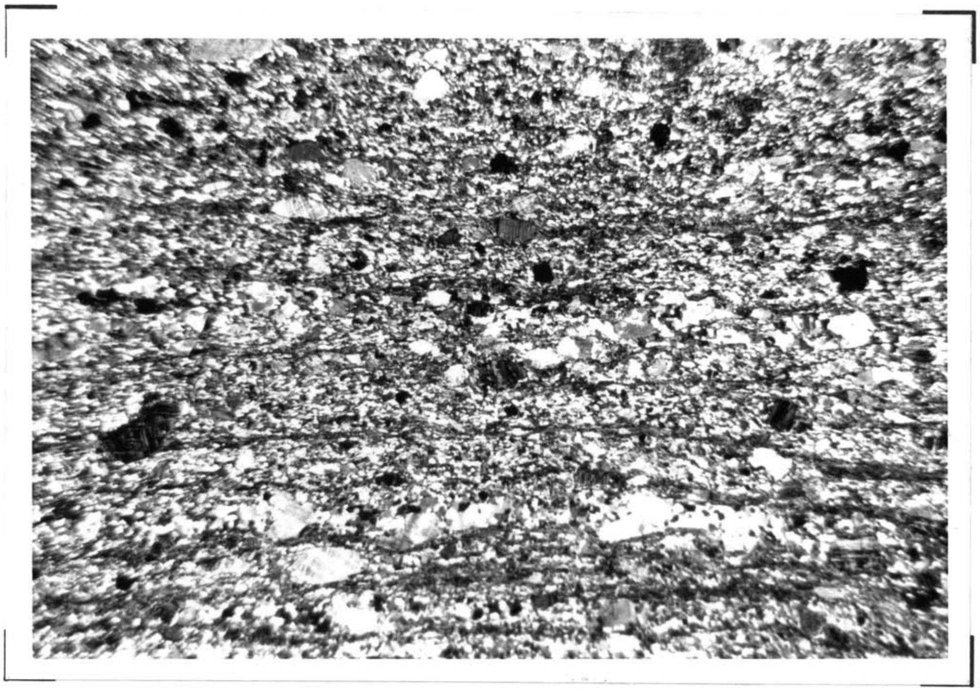
Photograph A3: Granite sample 0-79
(‖ polars; field is 13.3 mm wide)



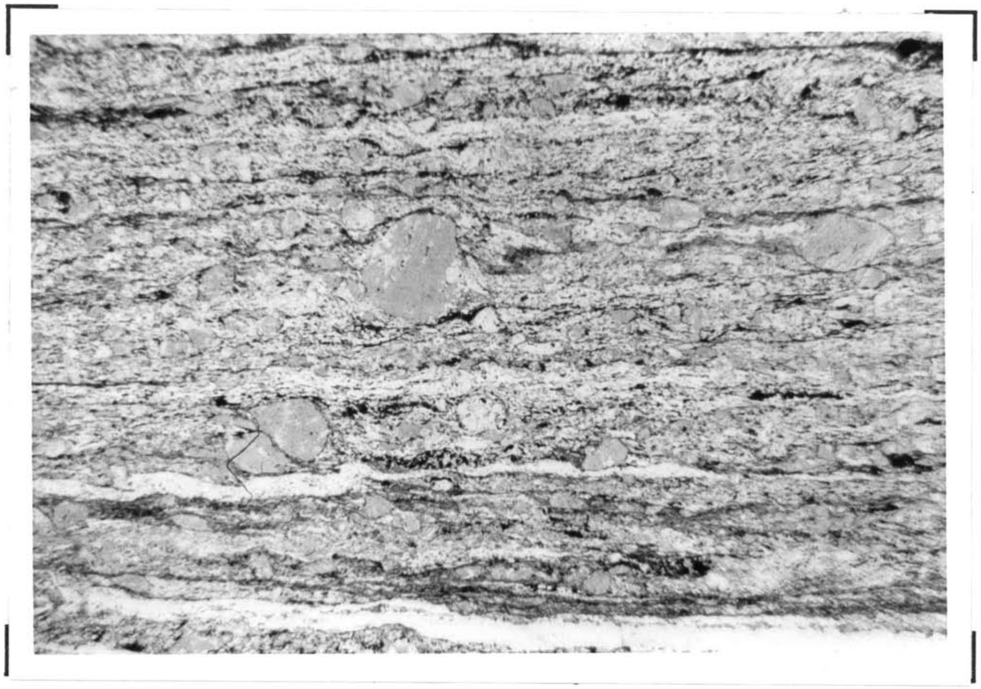
Photograph A4: Granite sample 0-79
(X polars; field is 13.3 mm wide)



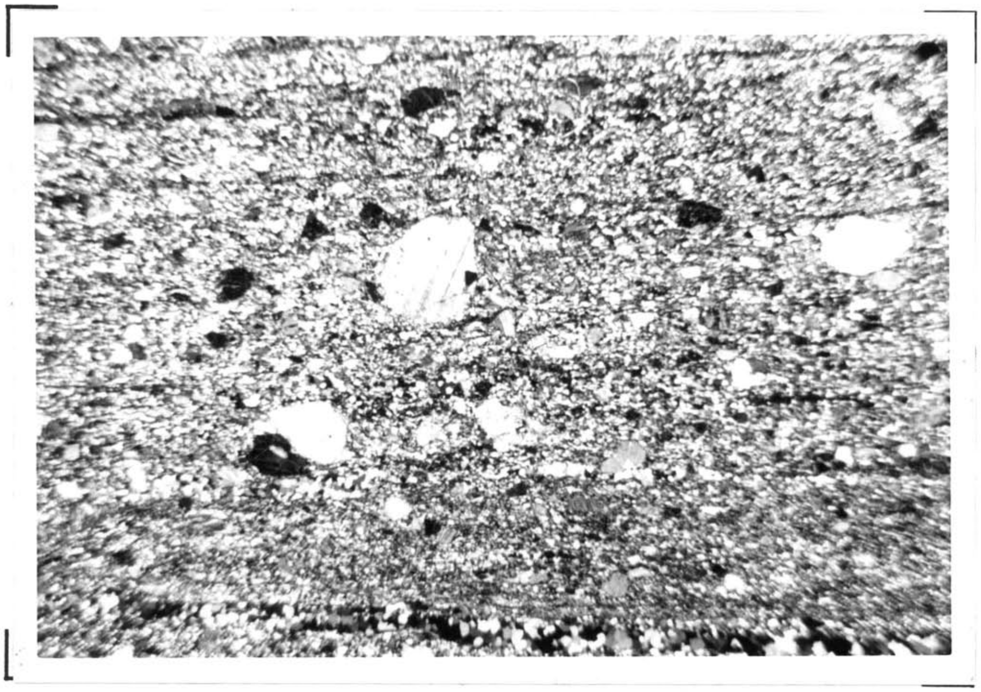
Photograph A5: Granite sample 0-81
(ll polars; field is 13.3 mm wide)



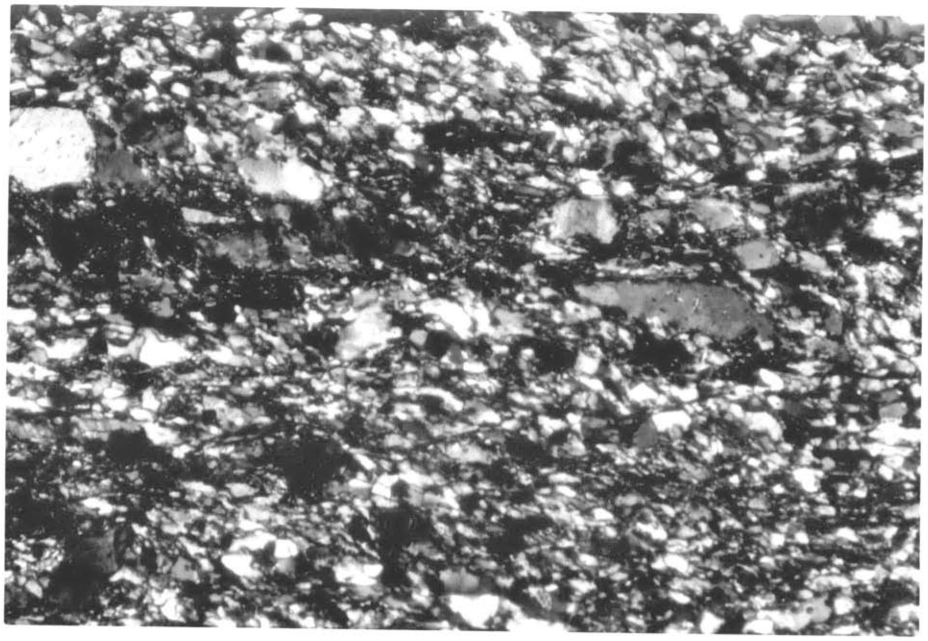
Photograph A6: Granite sample 0-81
(X polars; field is 13.3 mm wide)



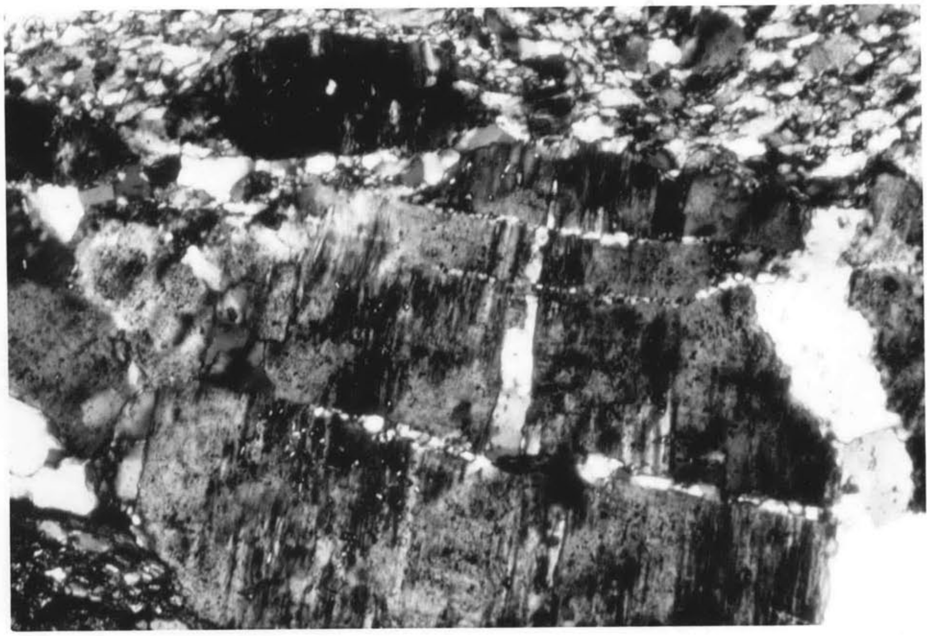
Photograph A7: Granite sample JW-13
(ll polars; field is 13.3 mm wide)



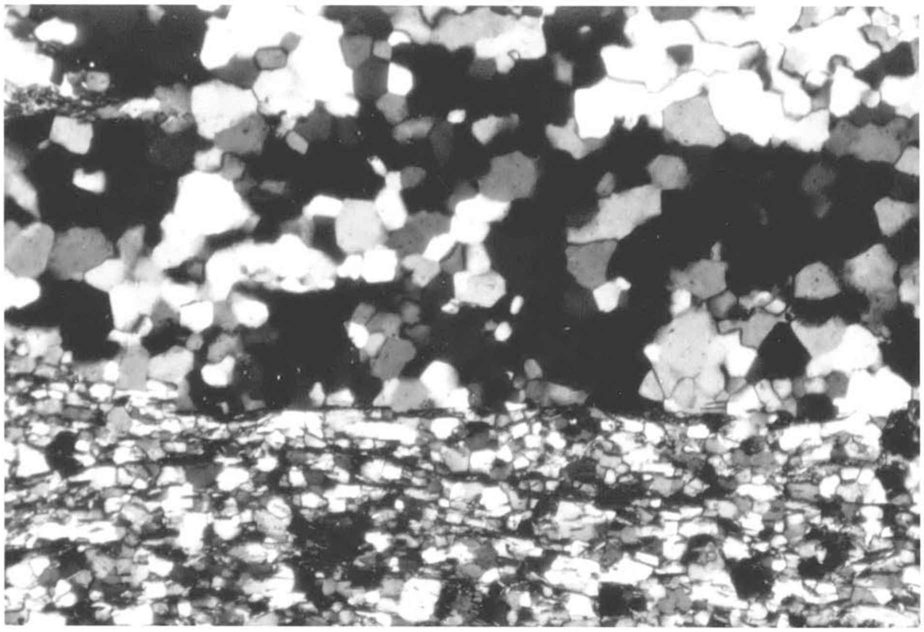
Photograph A8: Granite sample JW-13
(X polars; field is 13.3 mm wide)



Photograph A9: Granite sample JW-13
(X polars; field is 1.8 mm wide)

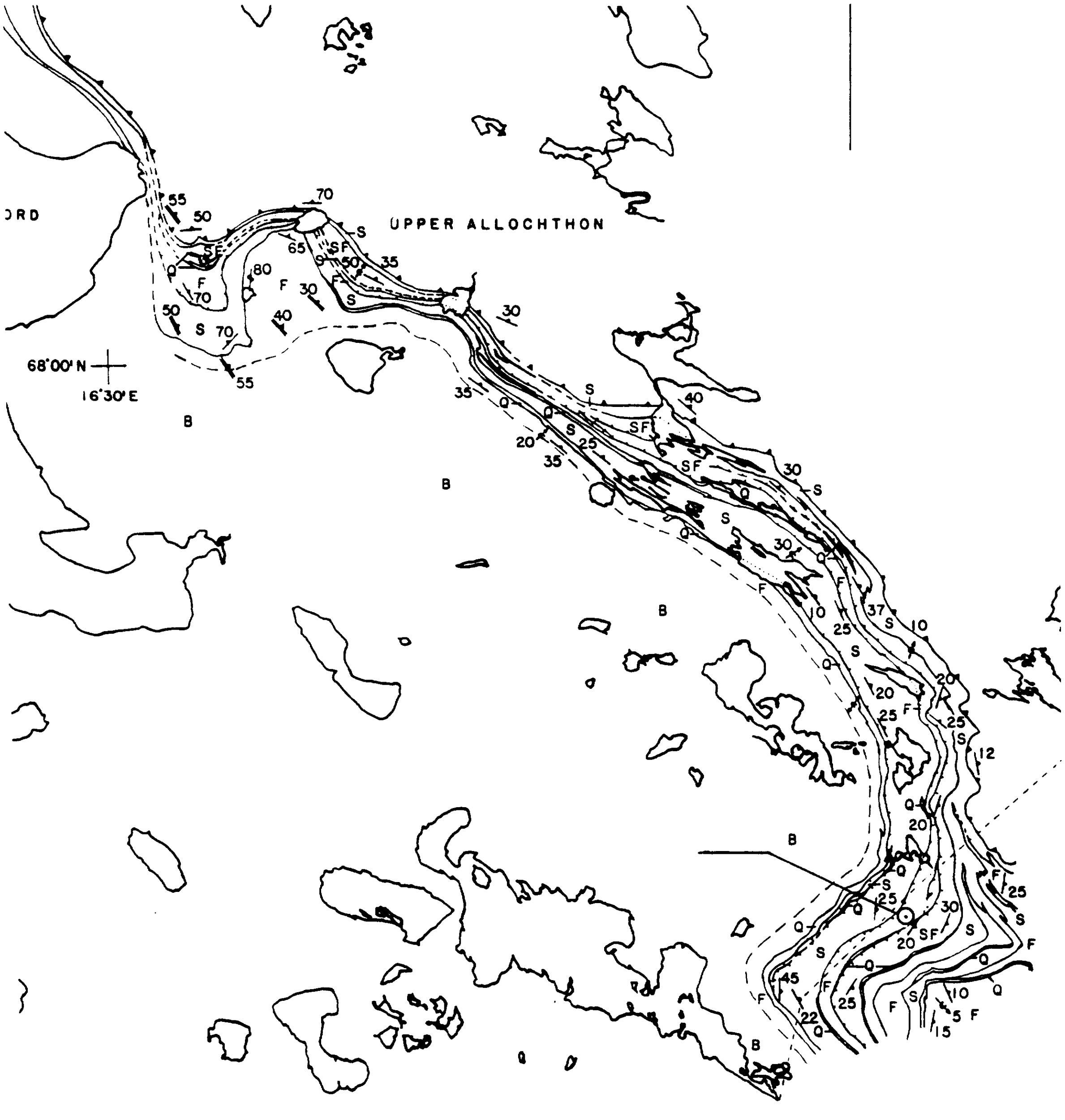


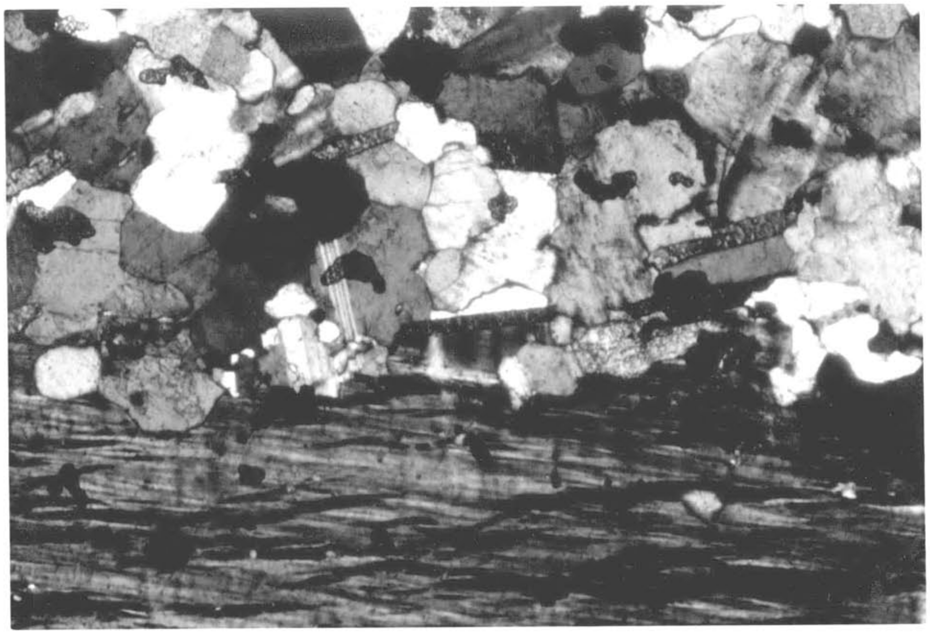
Photograph A10: Granite sample 0-77
(X polars; field is 1.8 mm wide)



Photograph A11: Quartzite sample 0-66
(X polars; field is 1.8 mm wide)

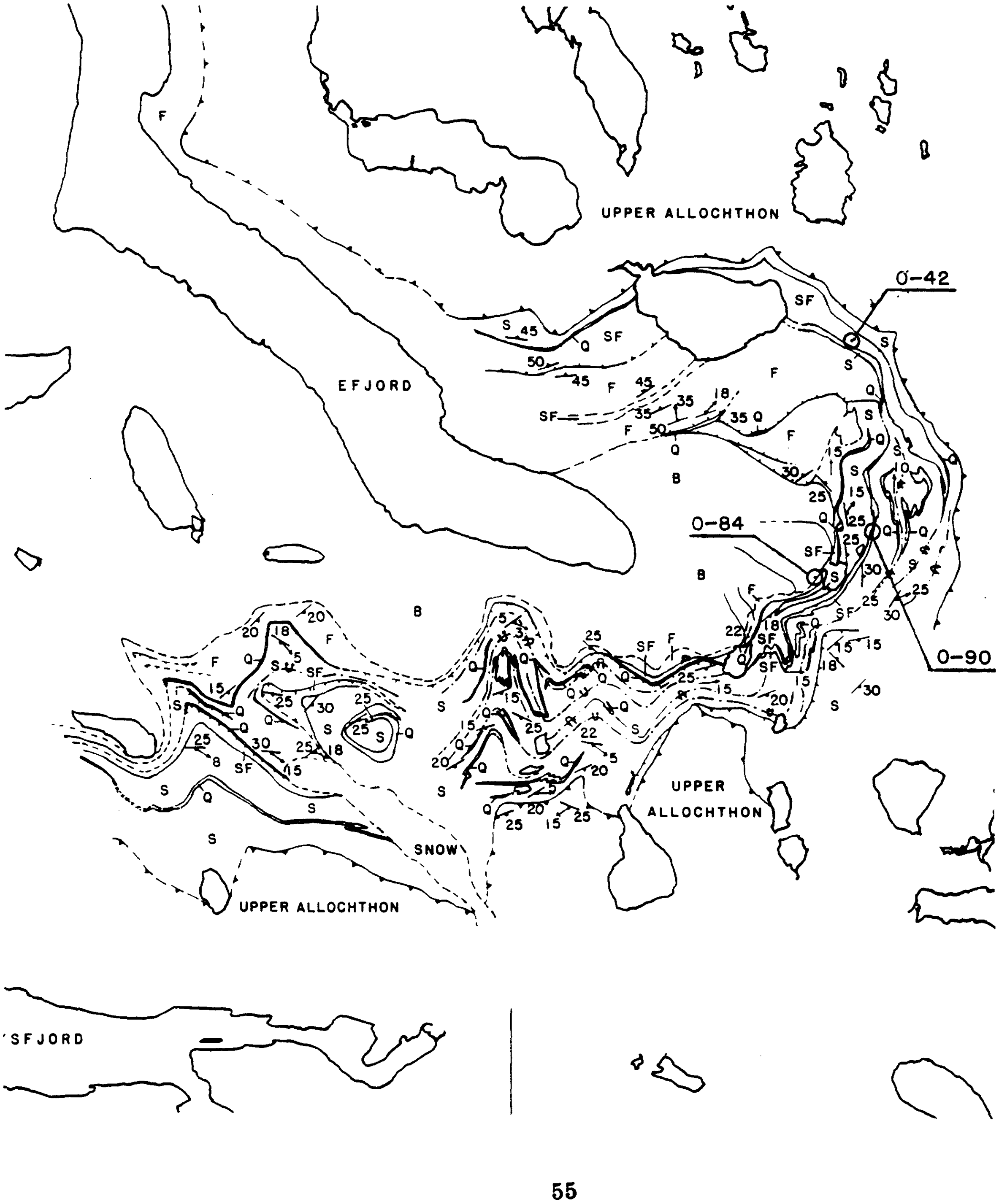
NATIONAL BORDER

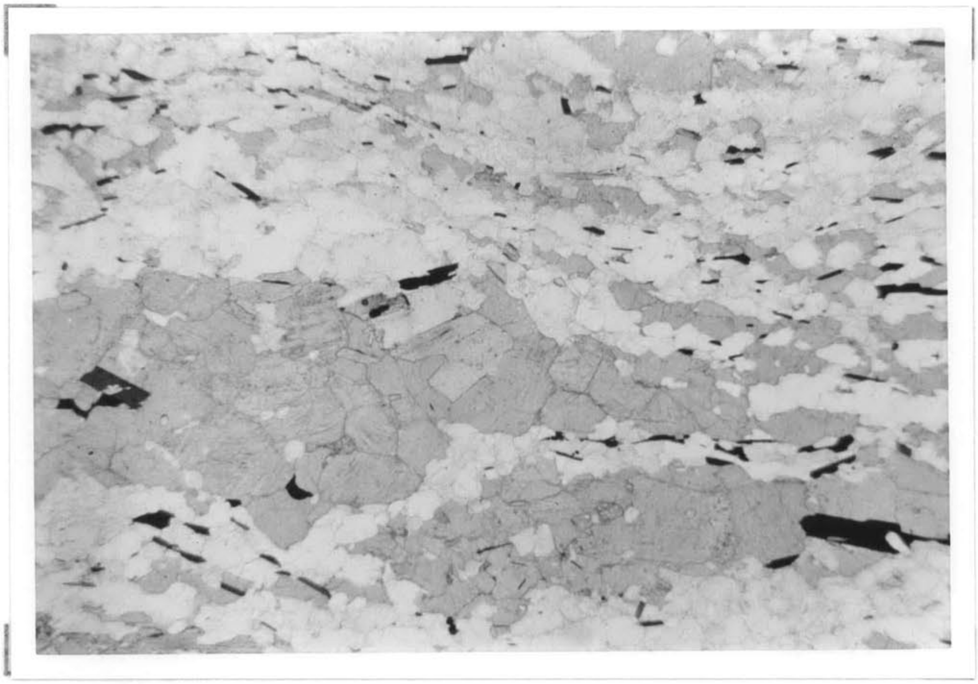




Photograph A12: Granite sample BC-6
(X polars; field is 1.8 mm wide)

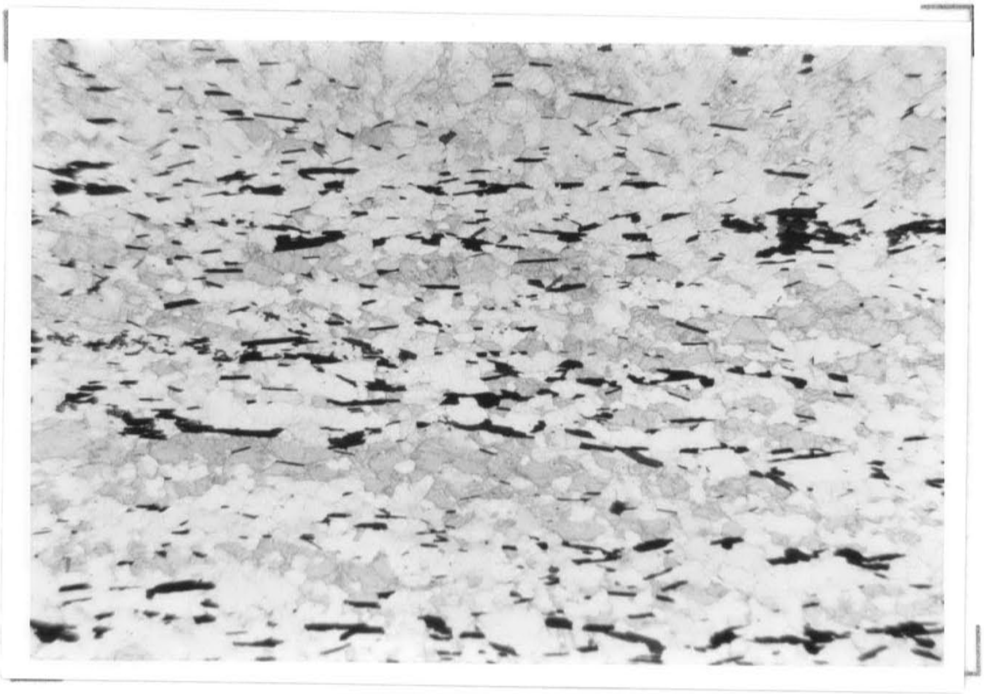
EFJORD CULMINATION



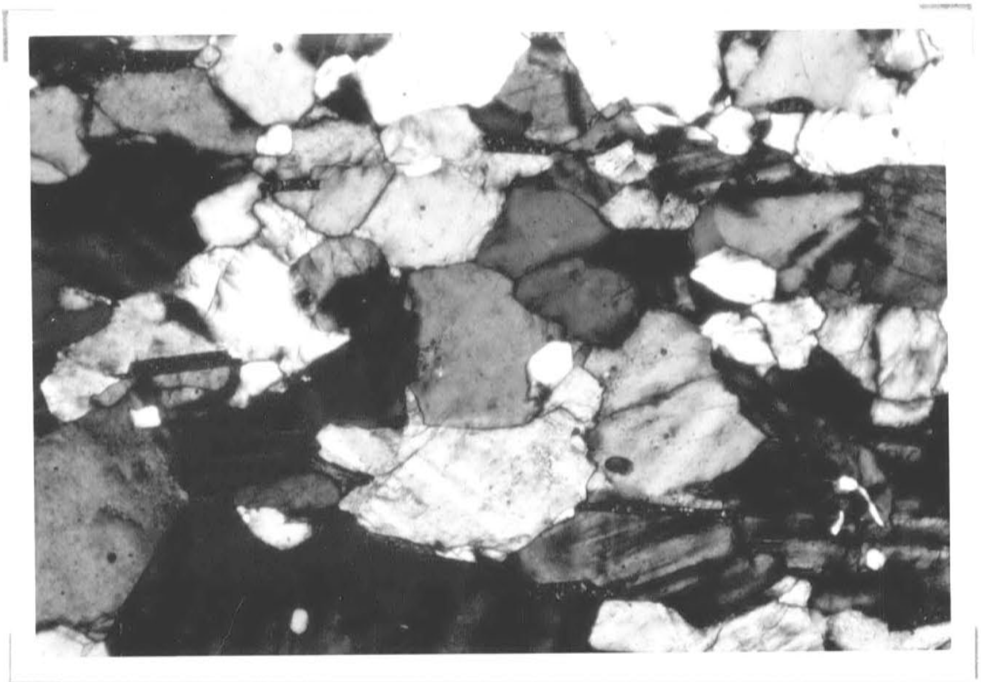


Photograph A13: Granite sample 0-42
(ll polars; field is 13.3 mm wide)

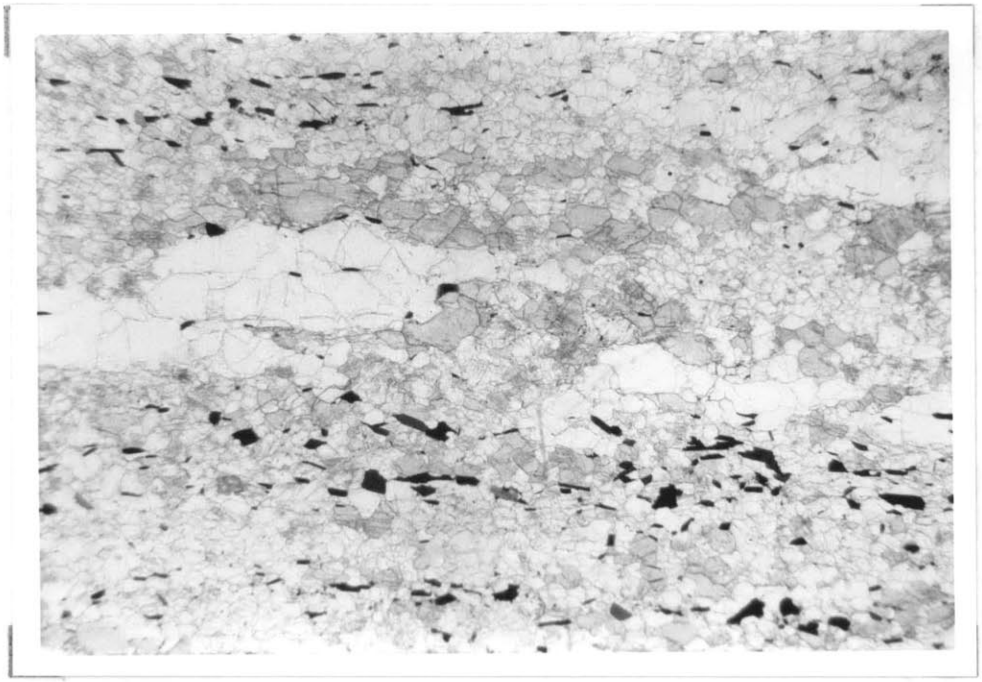
Photograph A14: Granite sample 0-42
(X polars; field is 13.3 mm wide)



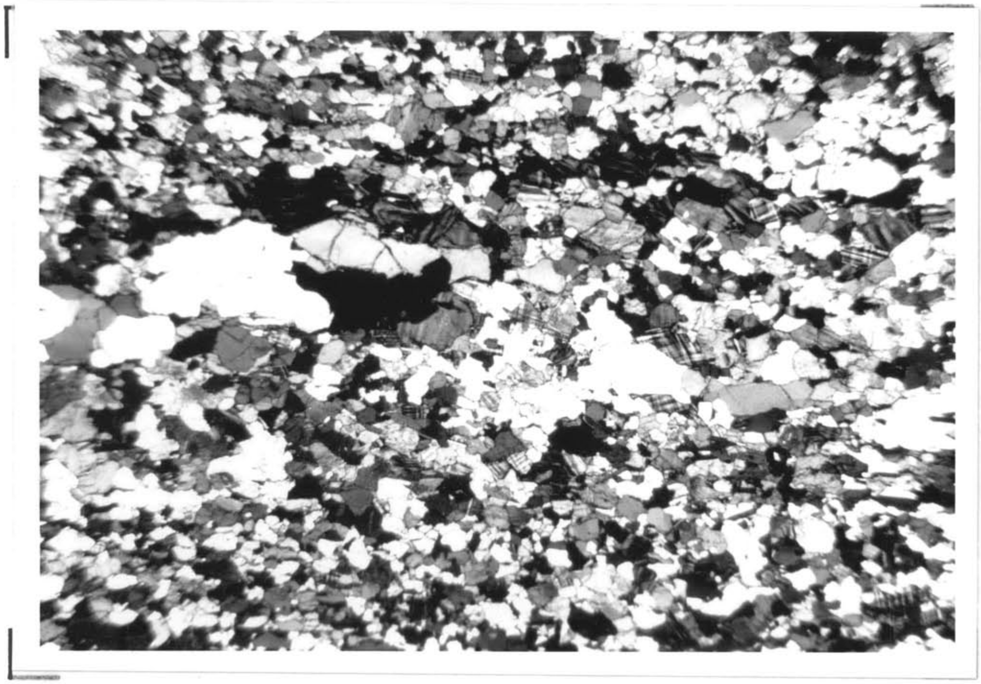
Photograph A15: Granite sample 0-84
(ll polars; field is 13.3 mm wide)



Photograph A16: Granite sample 0-84
(X polars; field is 13.3 mm wide)

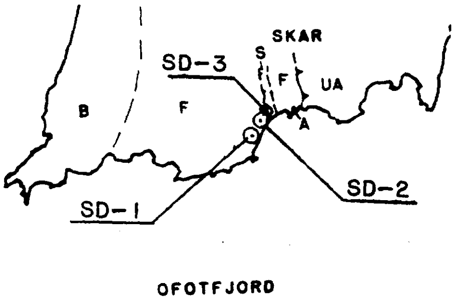


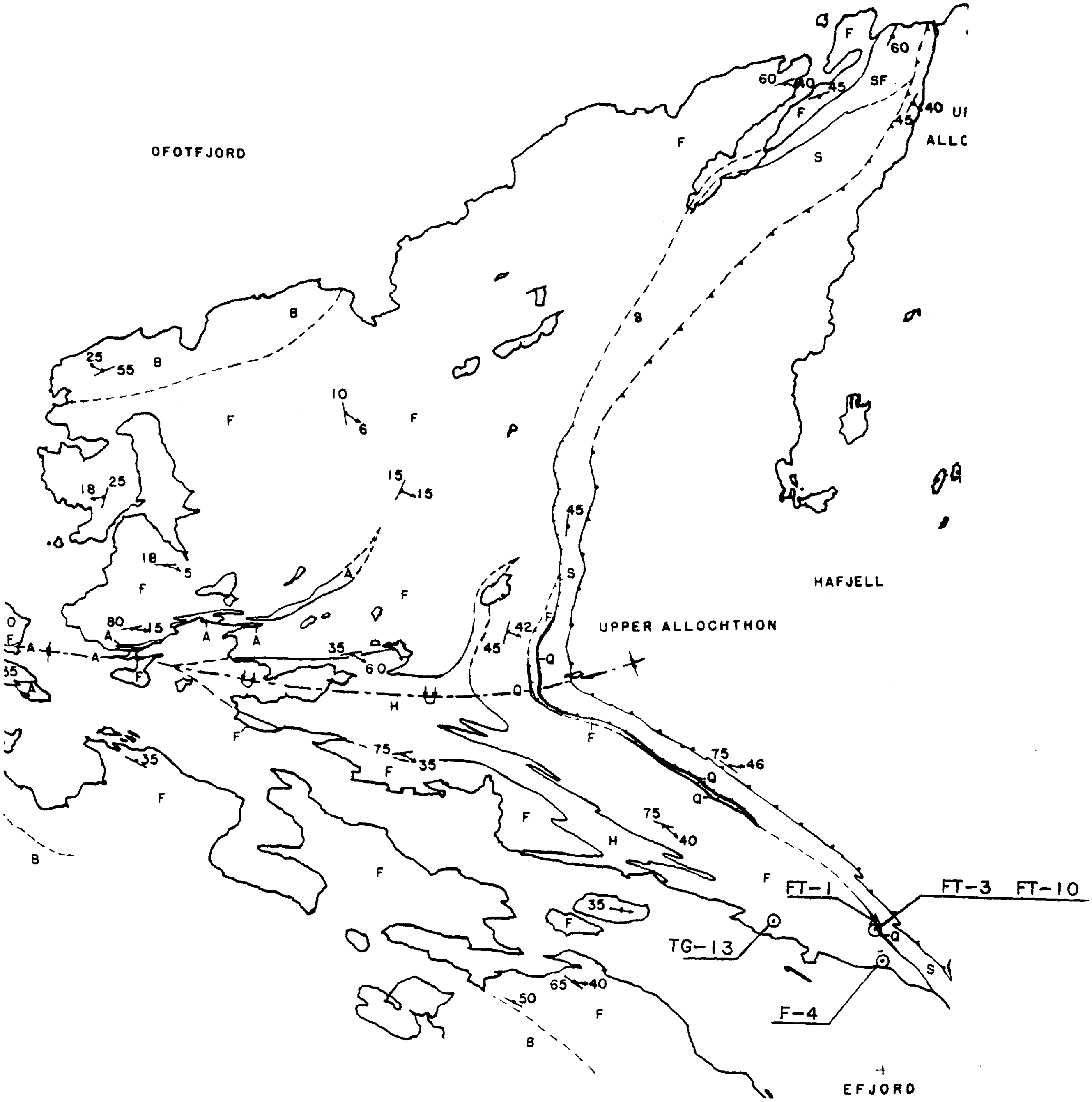
Photograph A17: Granite sample 0-90
(ll polars; field is 13.3 mm wide)

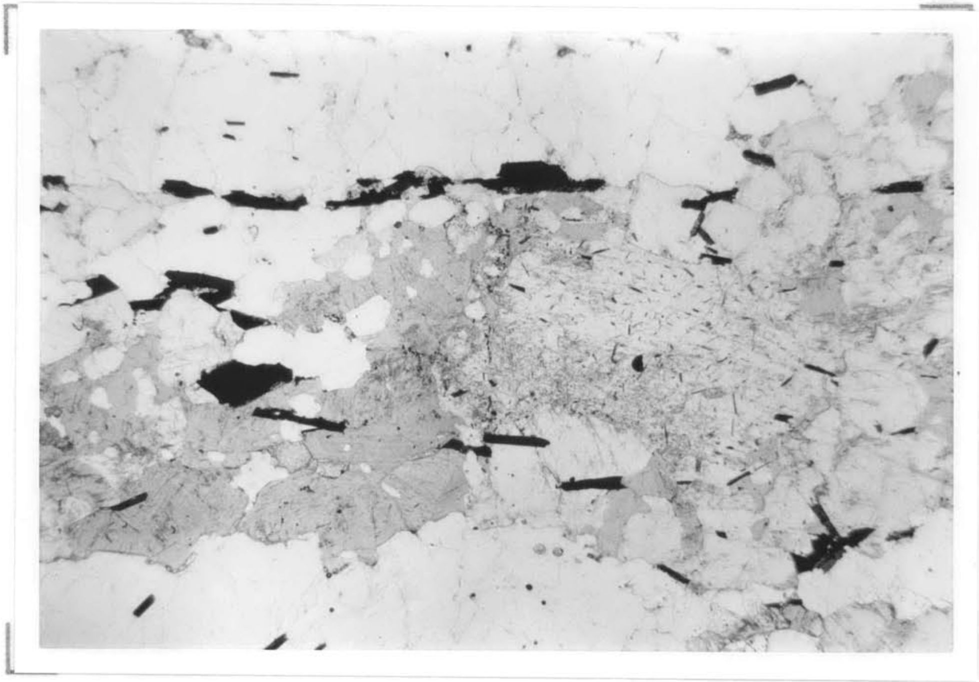


Photograph A18: Granite sample 0-90
(X polars; field is 13.3 mm wide)

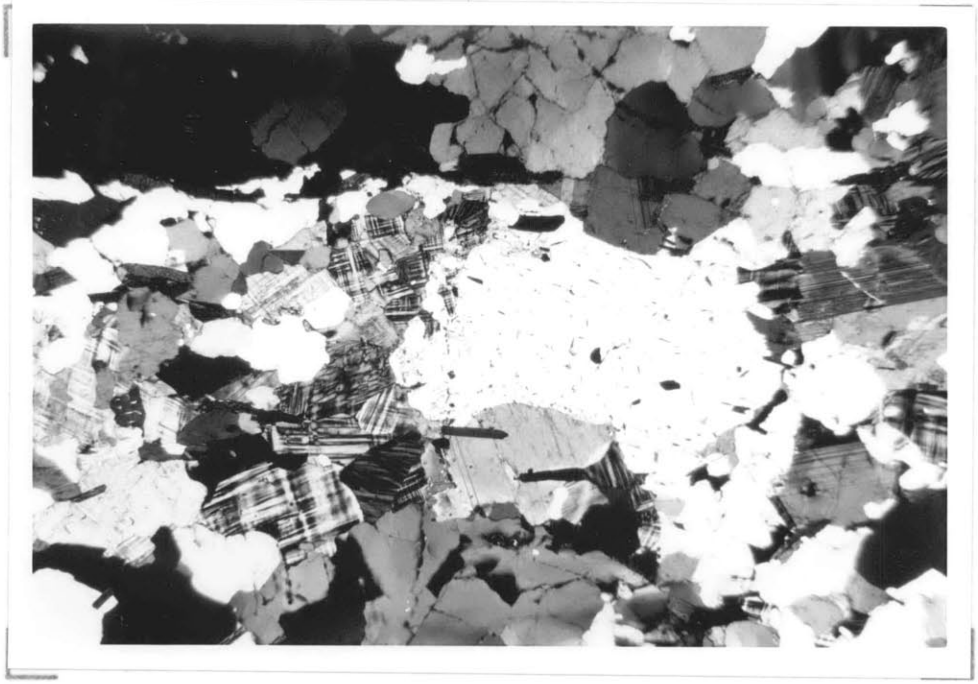
HAFJELL AND SKAR



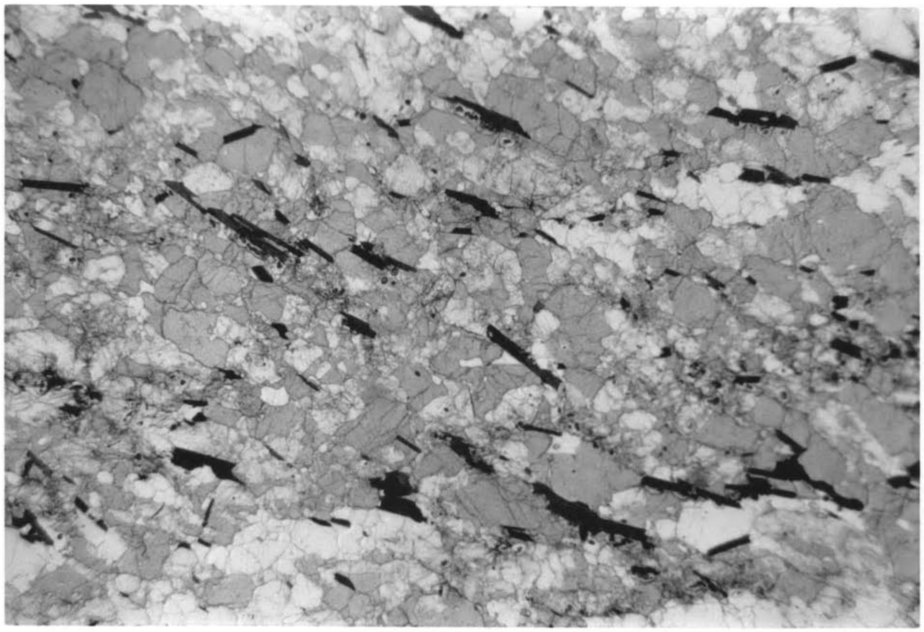




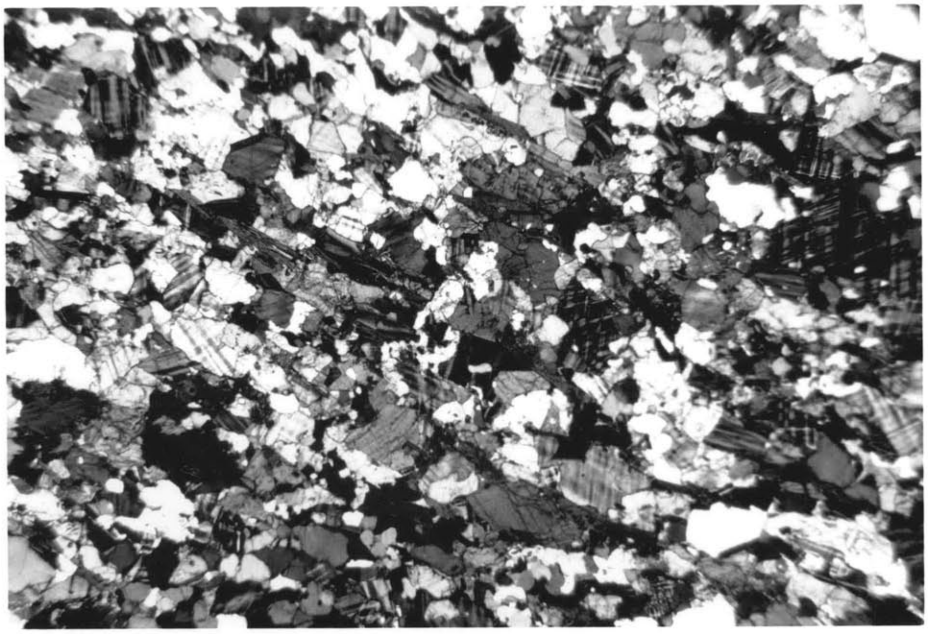
Photograph A19: Granite sample TG-13
(‖ polars; field is 13.3 mm wide)



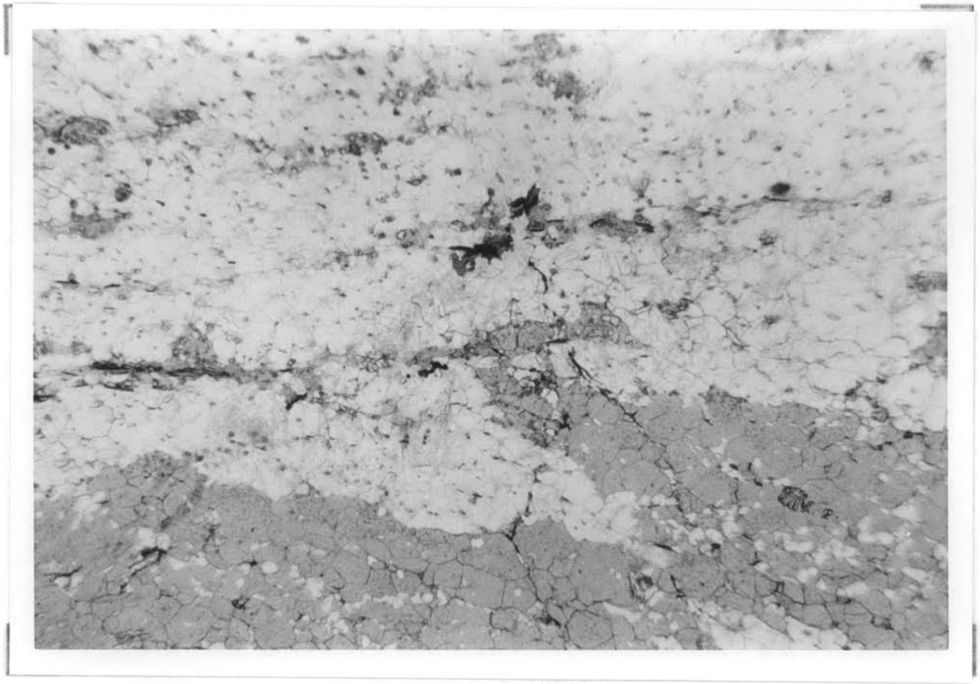
Photograph A20: Granite sample TG-13
(X polars; field is 13.3 mm wide)



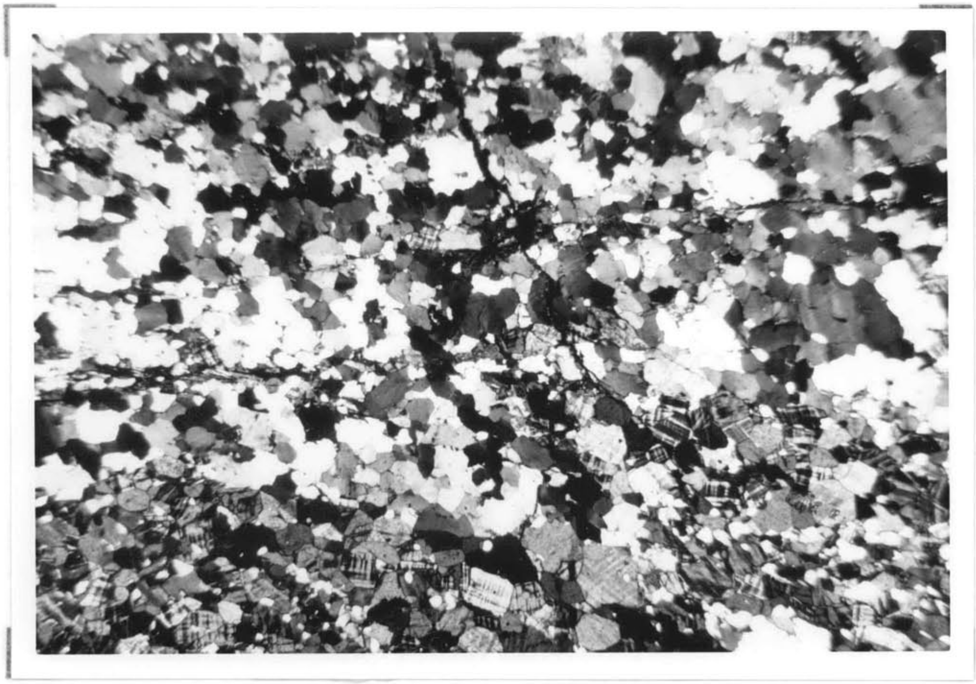
Photograph A21: Granite sample F-4
(|| polars; field is 13.3 mm wide)



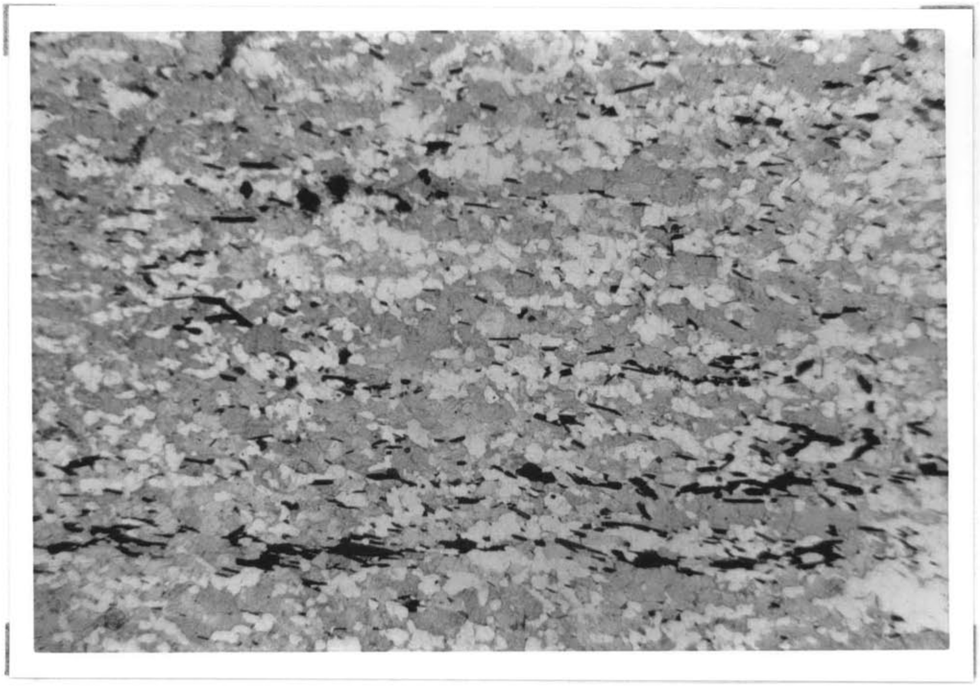
Photograph A22: Granite sample F-4
(X polars; field is 13.3 mm wide)



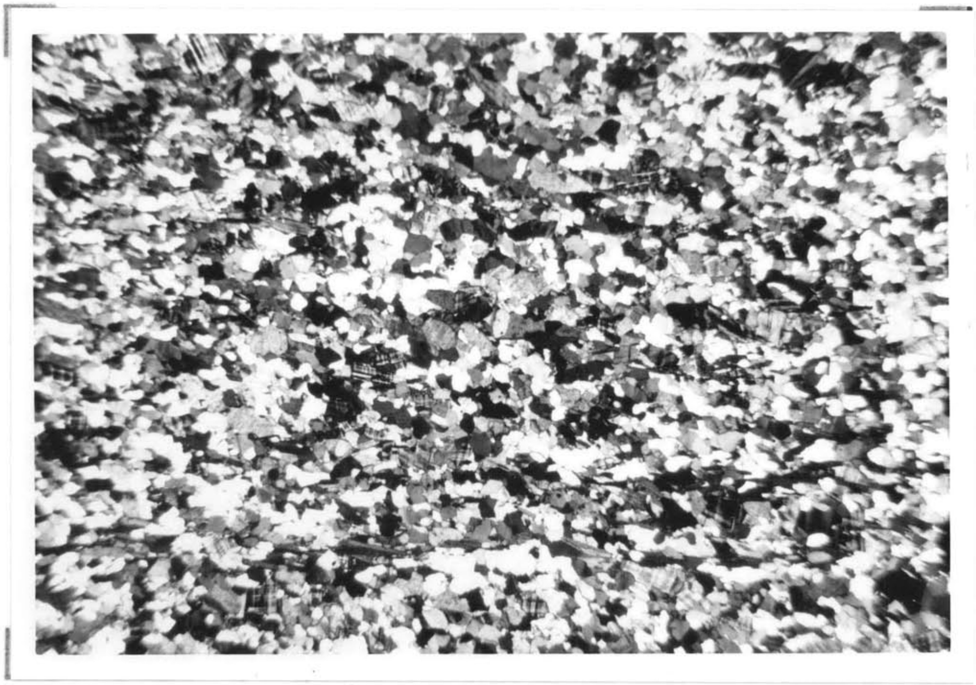
Photograph A23: Granite sample FT-3
(‖ polars; field is 13.3 mm wide)



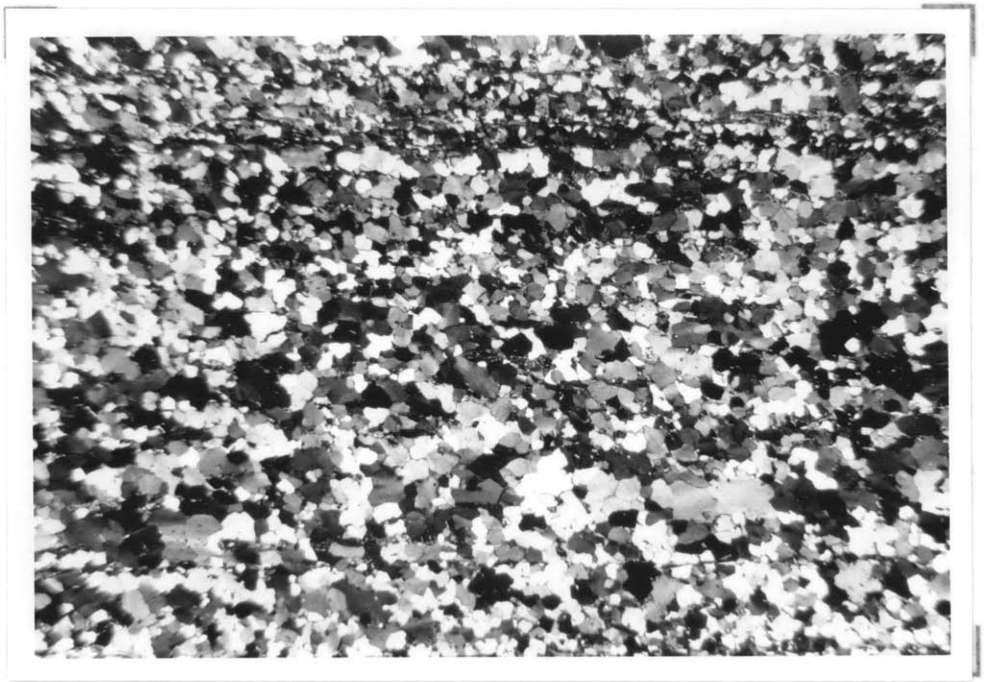
Photograph A24: Granite sample FT-3
(X polars; field is 13.3 mm wide)



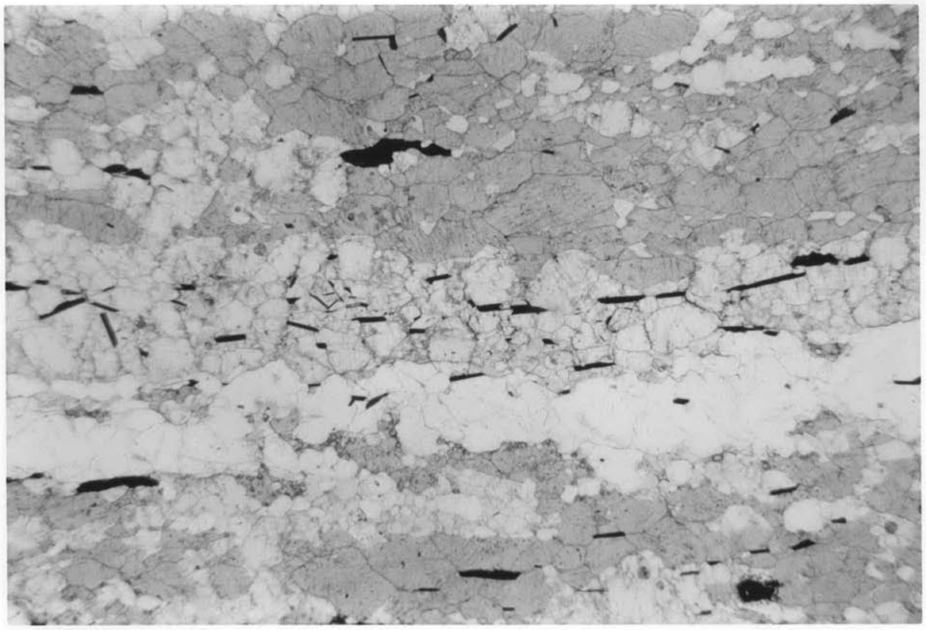
Photograph A25: Granite sample FT-10
(|| polars; field is 13.3 mm wide)



Photograph A26: Granite sample FT-10
(X polars; field is 13.3 mm wide)

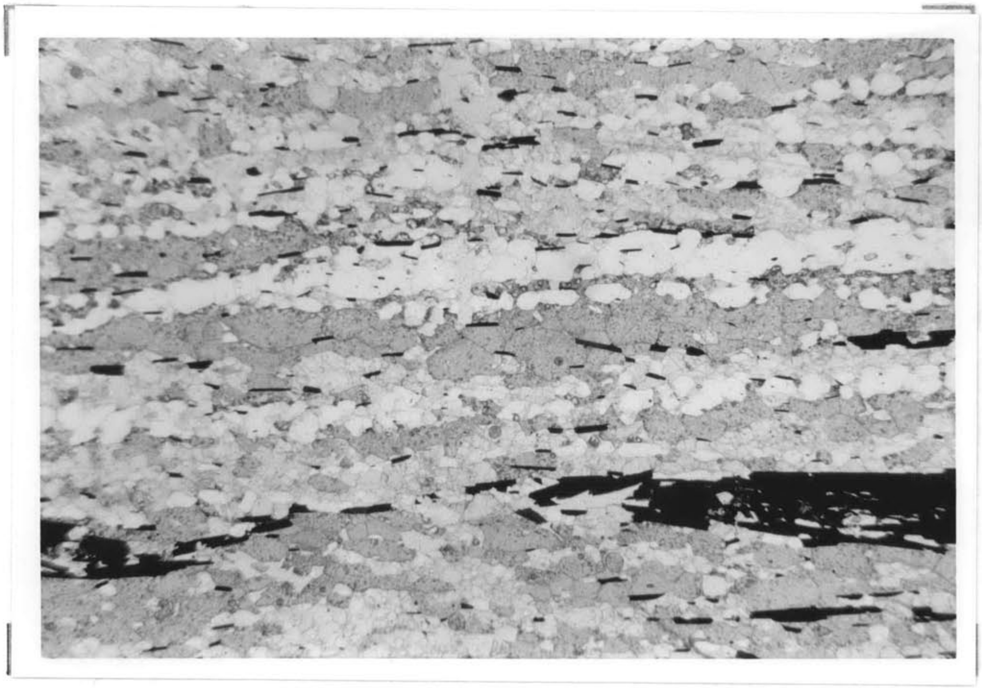


Photograph A27: Quartzite sample FT-1
(X polars; field is 13.3 mm wide)

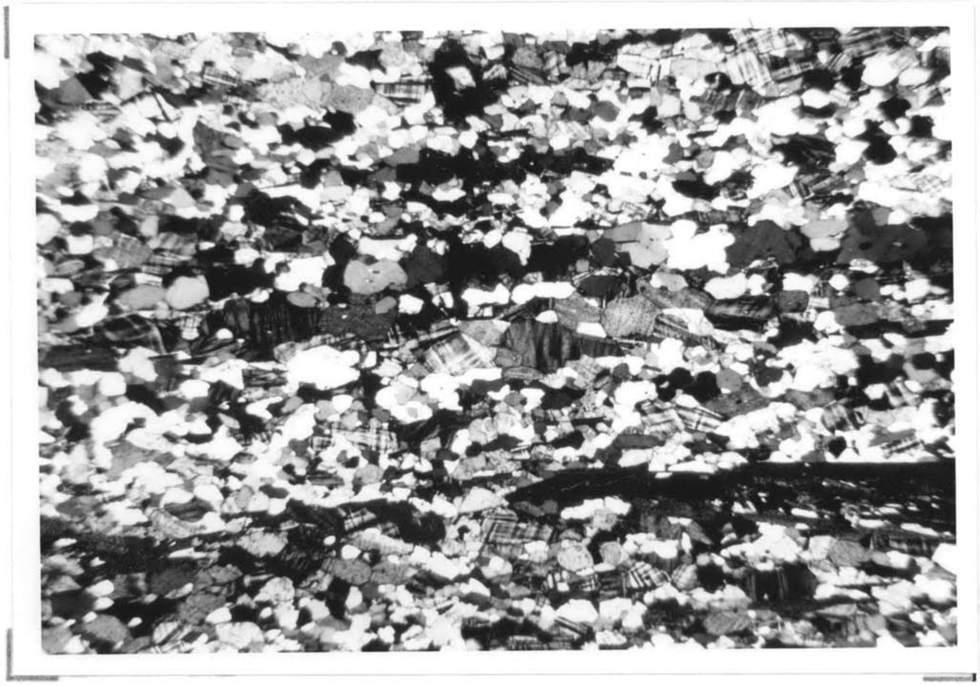


Photograph A28: Granite sample SD-1
(‖ polars; field is 13.3 mm wide)

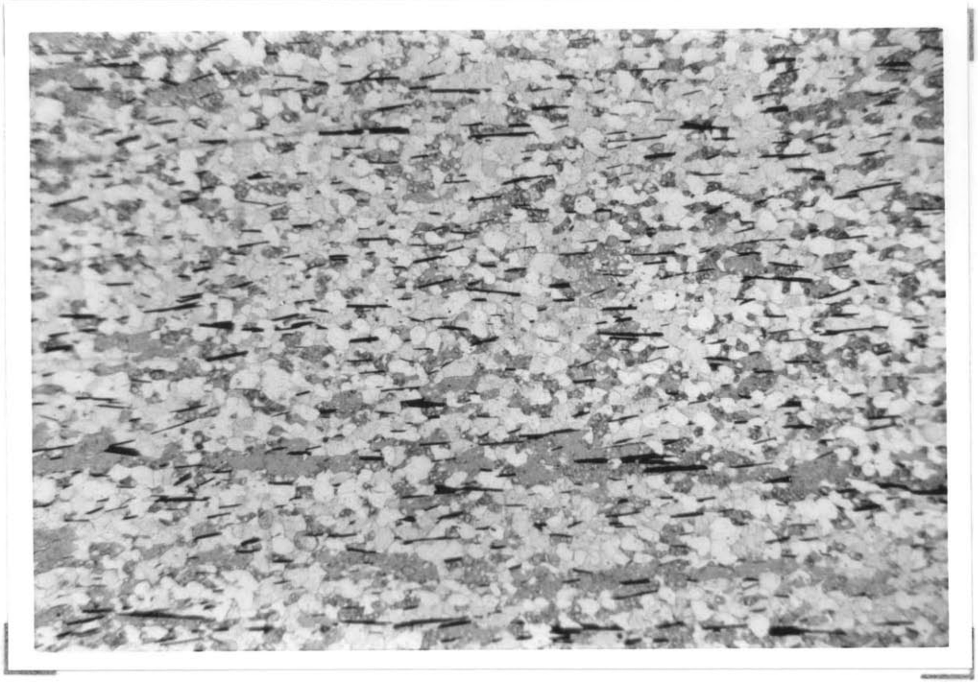
Photograph A29: Granite sample SD-1
(X polars; field is 13.3 mm wide)



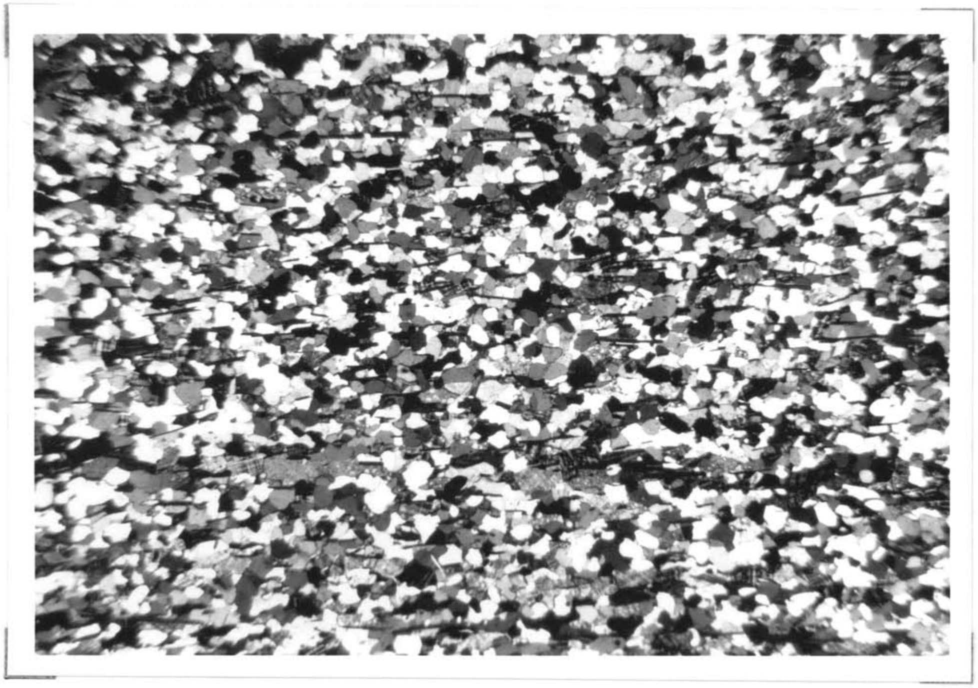
Photograph A30: Granite sample SD-2
(ll polars; field is 13.3 mm wide)



Photograph A31: Granite sample SD-2
(X polars; field is 13.3 mm wide)

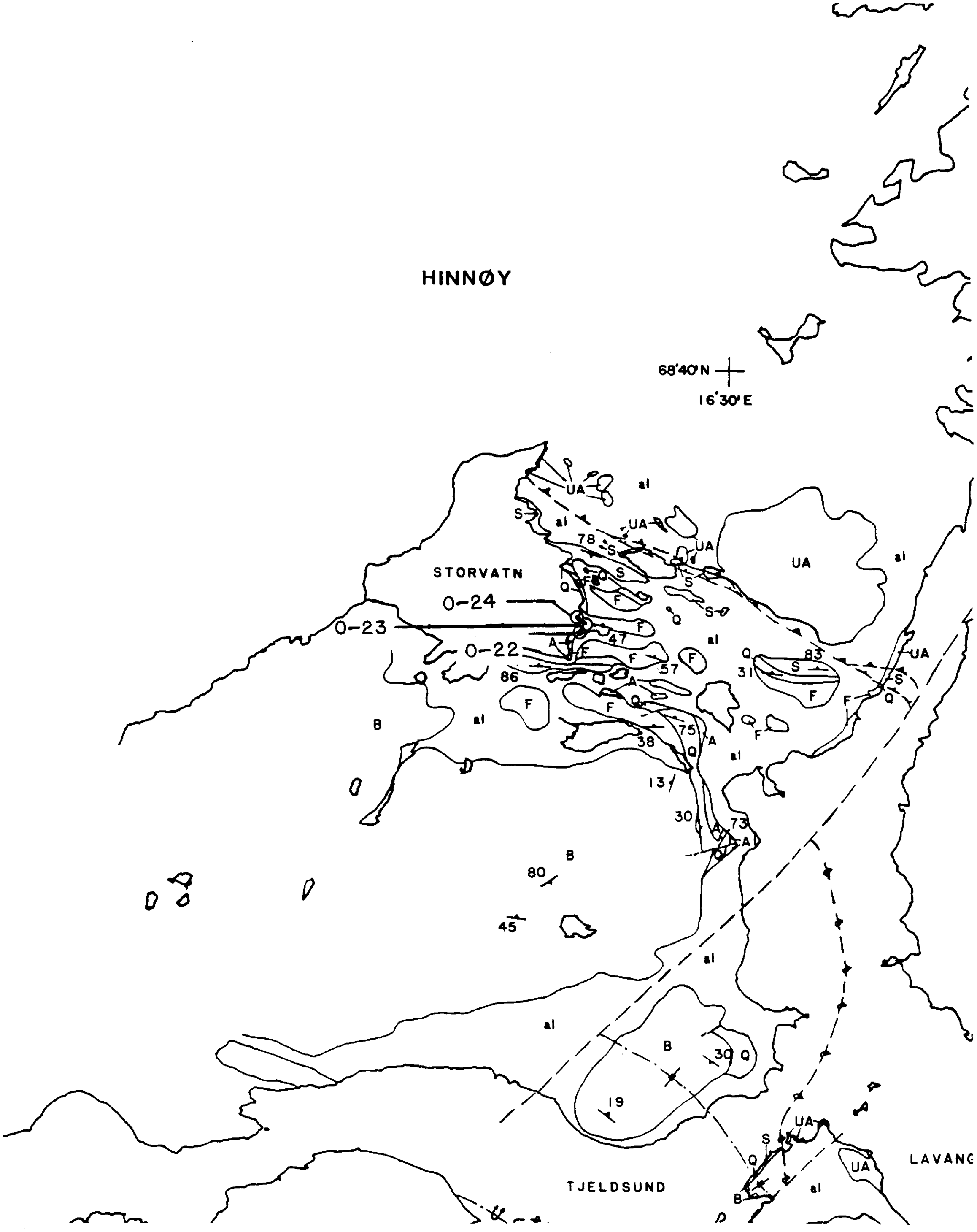


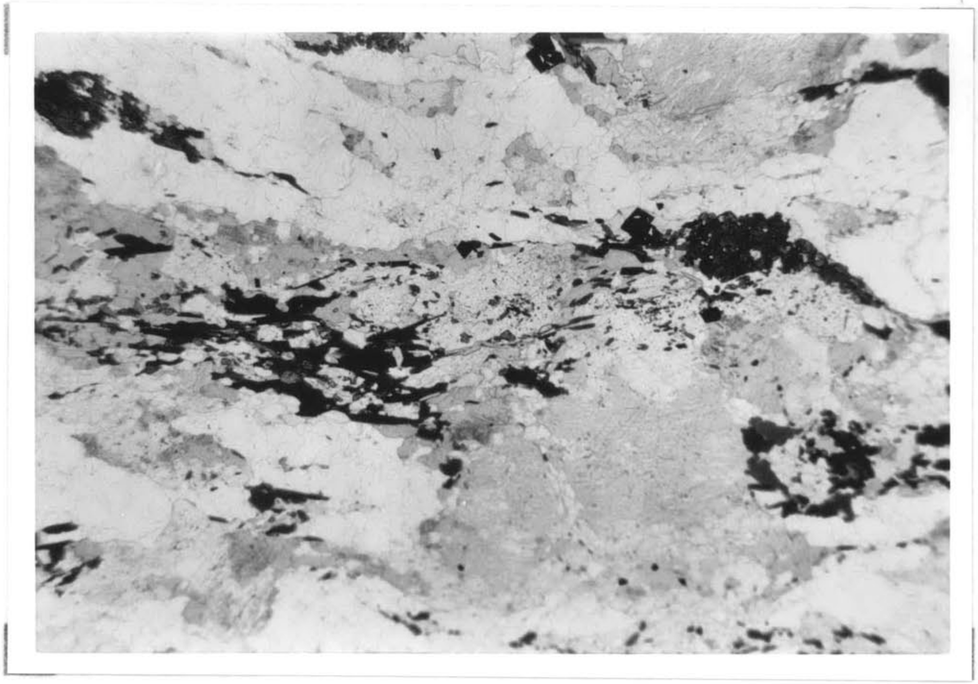
Photograph A32: Granite sample SD-3
(II polars; field is 13.3 mm wide)



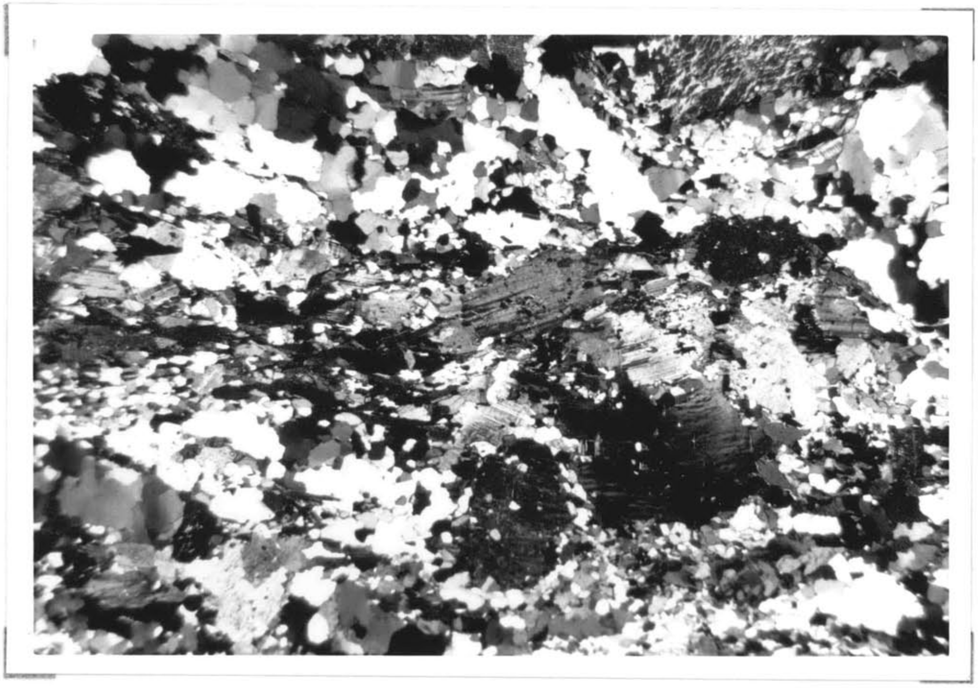
Photograph A33: Granite sample SD-3
(X polars; field is 13.3 mm wide)

EAST HINNOY

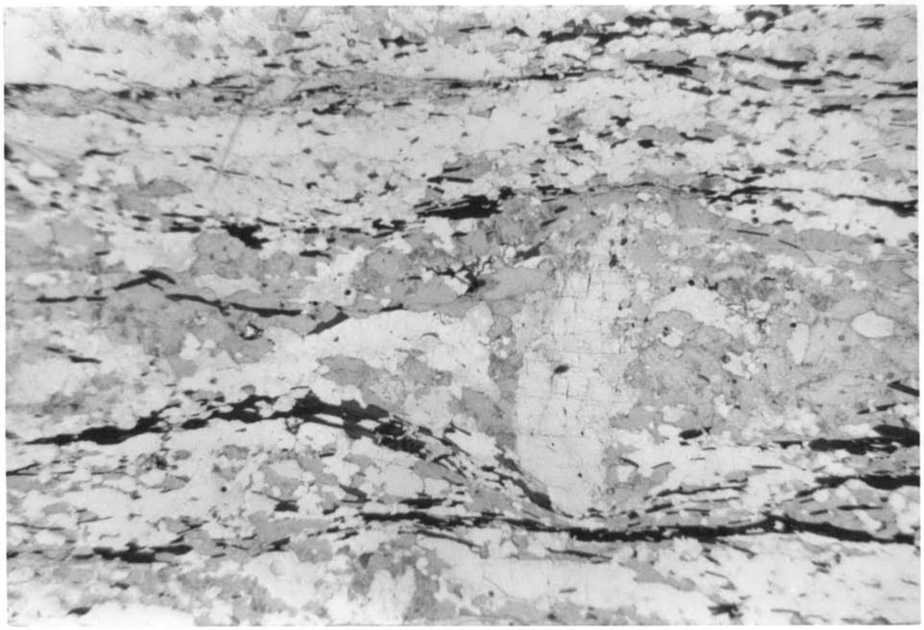

HINNØY
68°40'N
16°30'E
STORVATN
0-24
0-23
0-22
UA
al
S
78
Q
F
A
47
57
86
B
83
31
75
38
13
30
73
80
45
19
30
TJELDSUND
LAVANG



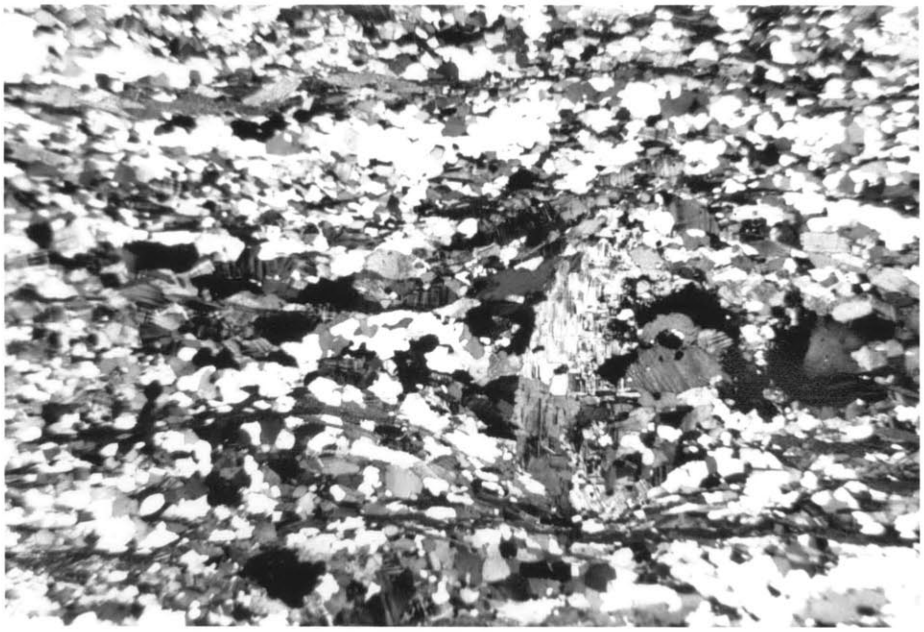
Photograph A34: Granite sample 0-22
(|| polars; field is 13.3 mm wide)



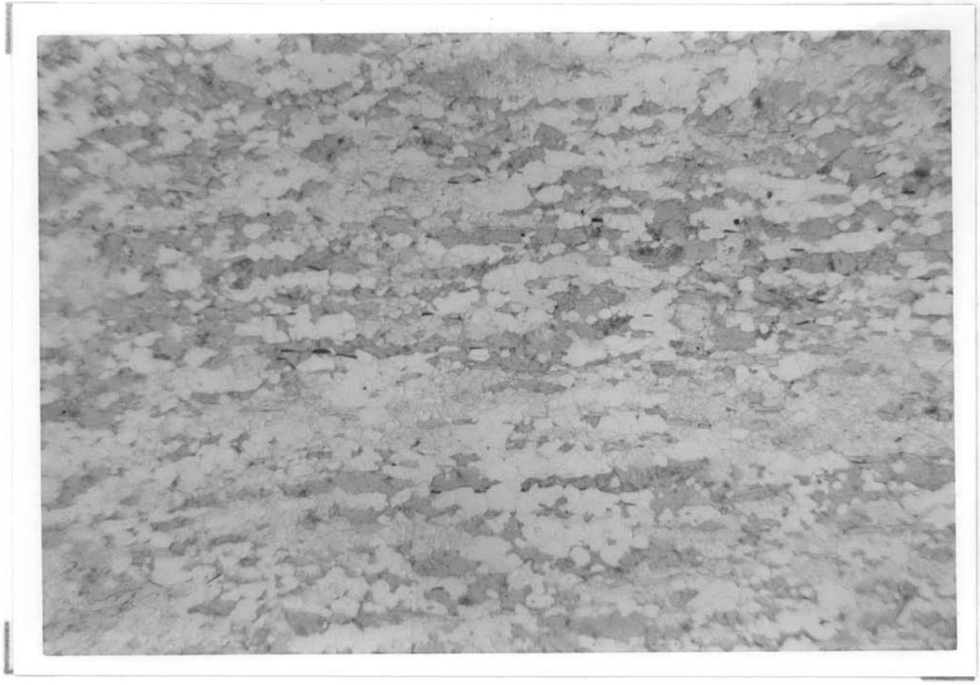
Photograph A35: Granite sample 0-22
(X polars; field is 13.3 mm wide)



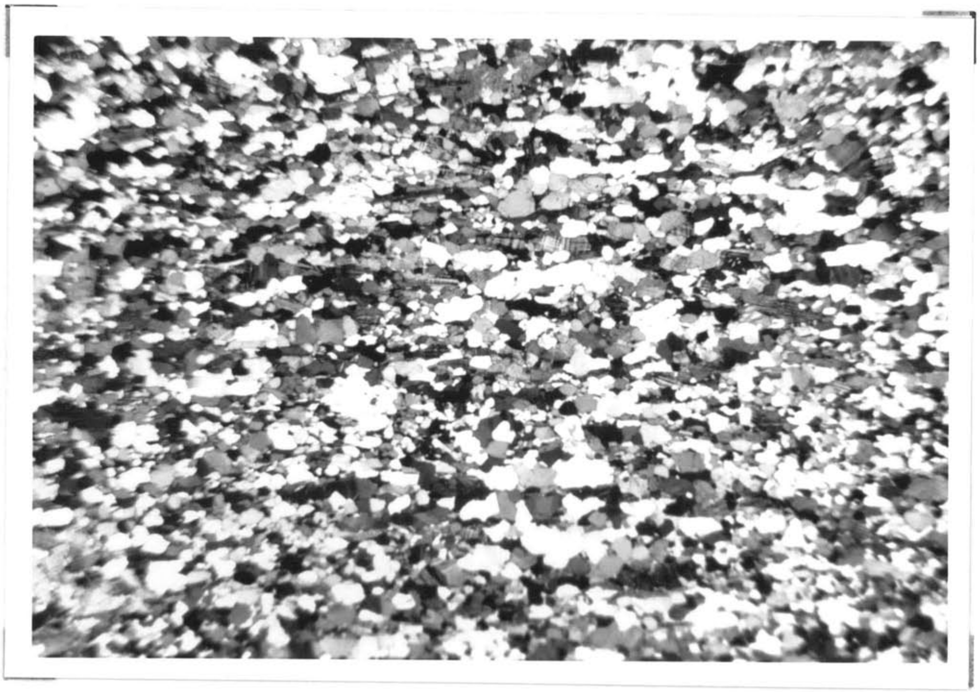
Photograph A36: Granite sample 0-23
(II polars; field is 13.3 mm wide)



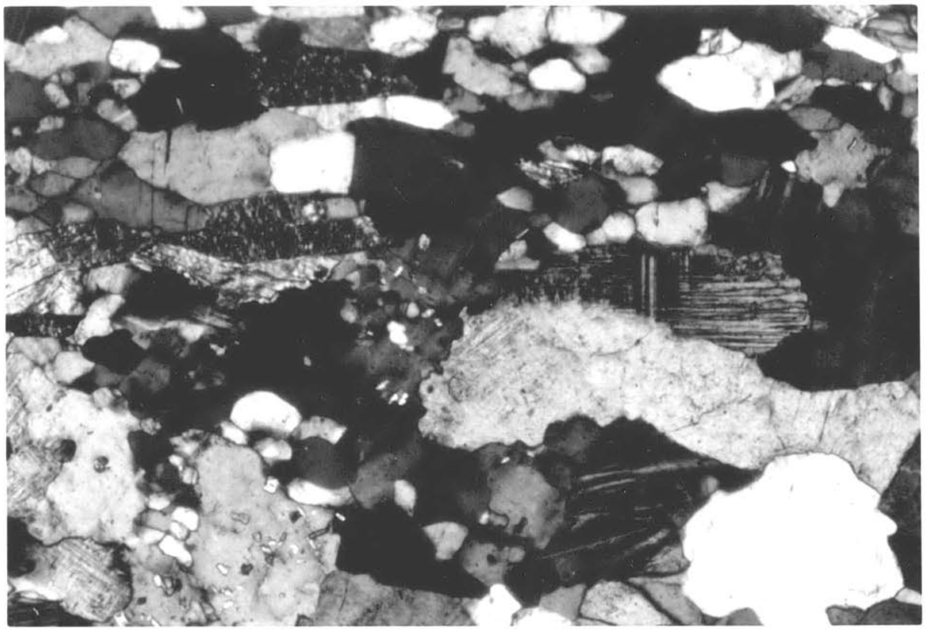
Photograph A37: Granite sample 0-23
(X polars; field is 13.3 mm wide)



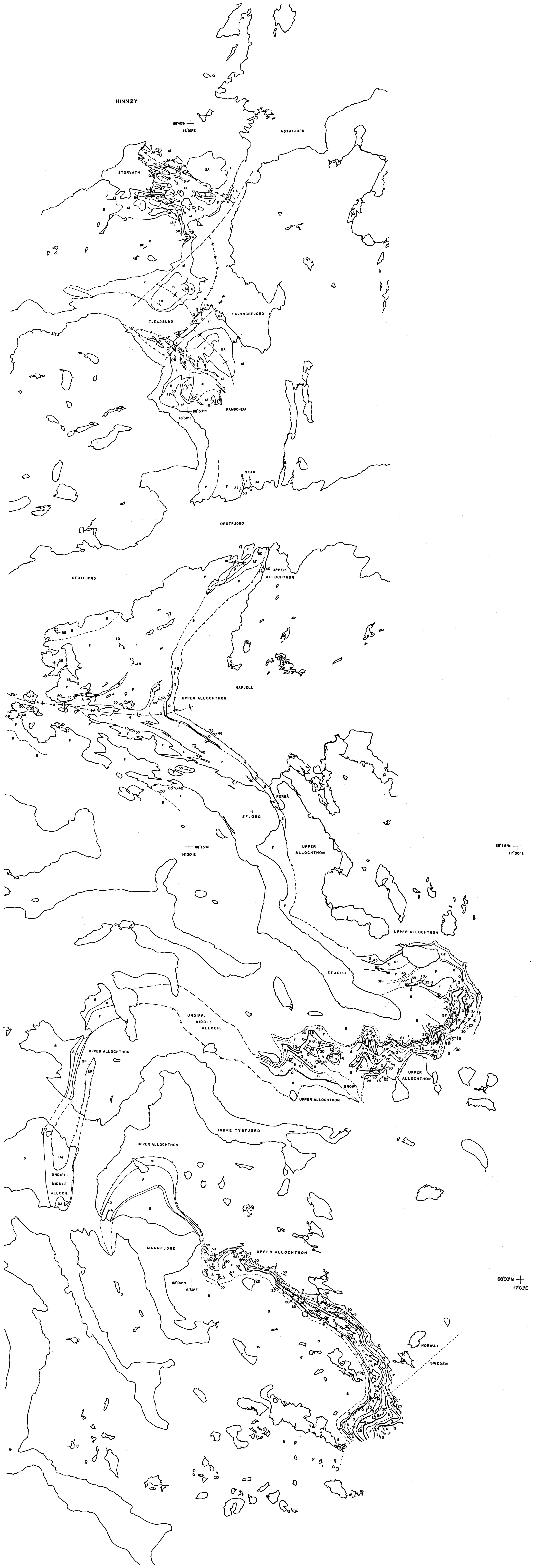
Photograph A38: Granite sample 0-24
(ǁ polars; field is 13.3 mm wide)



Photograph A39: Granite sample 0-24
(X polars; field is 13.3 mm wide)

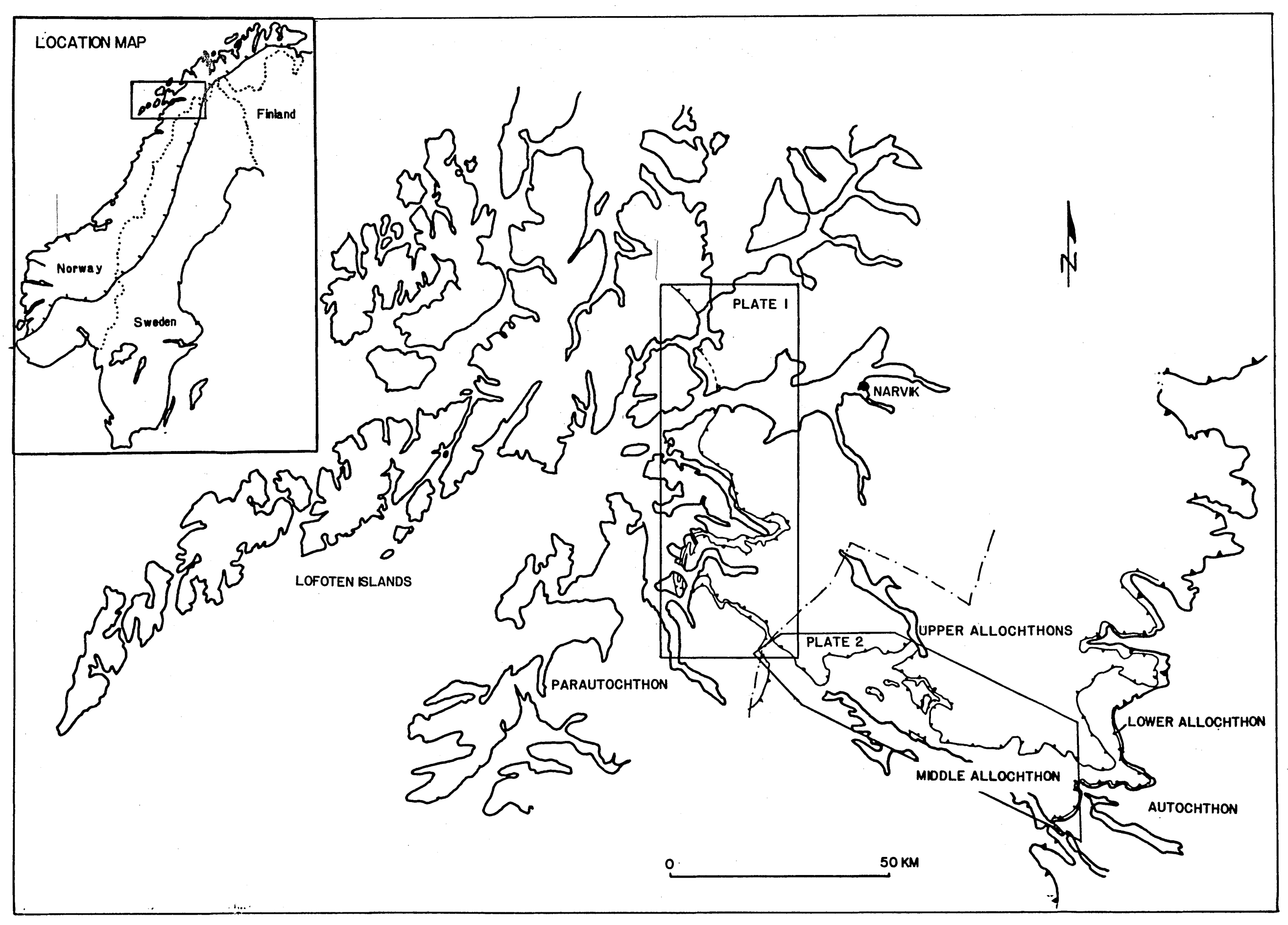


Photograph A40: Granite sample 0-24
(X polars; field is 1.8 mm wide)

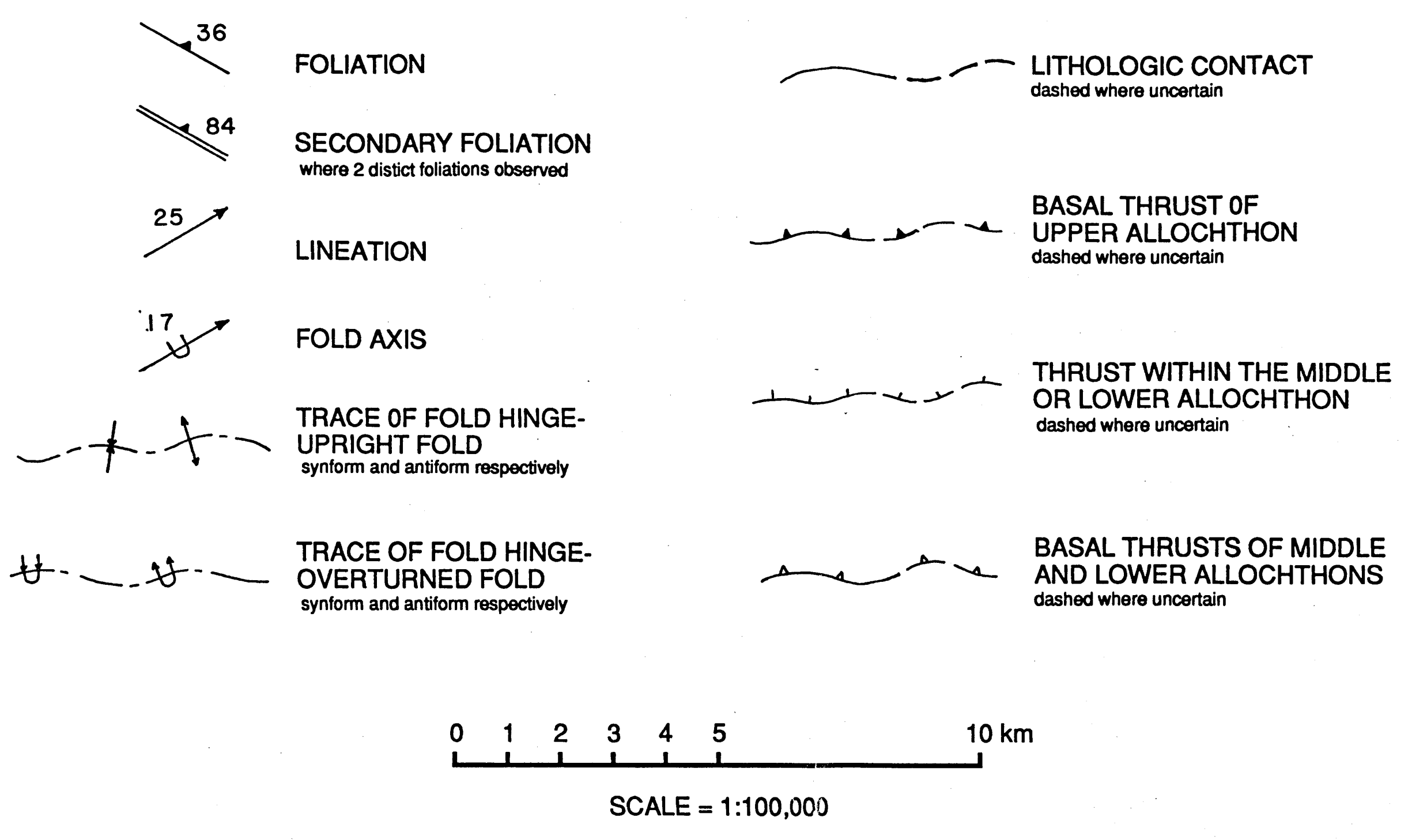


GEOLOGY OF THE MIDDLE ALLOCHTHON AND RELATED THRUST ROCKS 68° N, SCANDINAVIA

PLATE 1



SYMBOLS



FOLIATION

SECONDARY FOLIATION
where 2 distict foliations observed

LINEATION

FOLD AXIS

TRACE OF FOLD HINGE-UPRIGHT FOLD
synform and antiform respectively

TRACE OF FOLD HINGE-OVERTURNED FOLD
synform and antiform respectively

LITHOLOGIC CONTACT
dashed where uncertain

BASAL THRUST OF UPPER ALLOCHTHON
dashed where uncertain

THRUST WITHIN THE MIDDLE OR LOWER ALLOCHTHON
dashed where uncertain

BASAL THRUSTS OF MIDDLE AND LOWER ALLOCHTHONS
dashed where uncertain

SCALE = 1:100,000

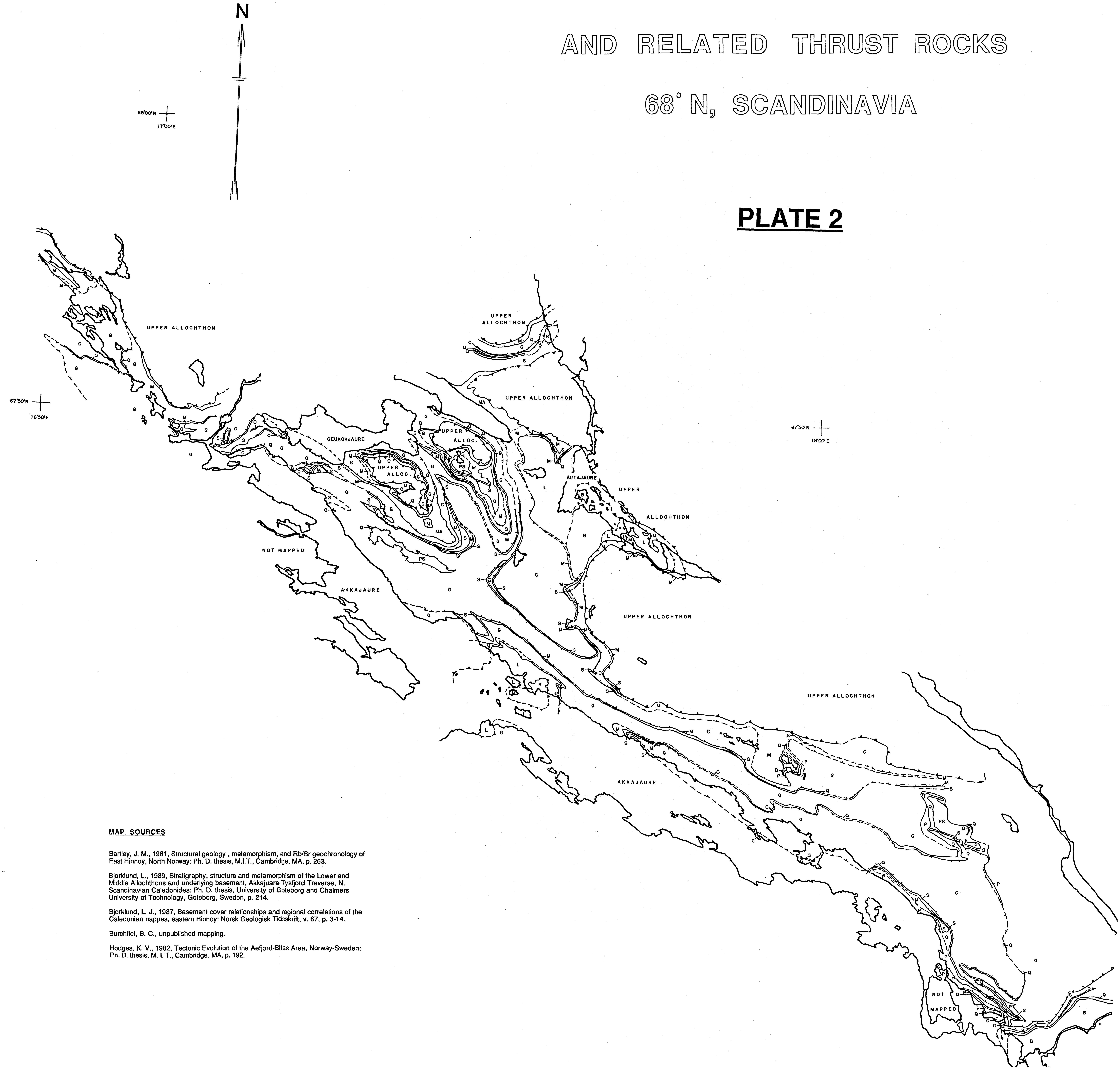
LEGEND

TECTONIC UNITS	LITHOLOGIC UNITS	
	al	ALLUVIUM
UPPER & UPPERMOST ALLOCHTHONS	UA	UNDIFFERENTIATED
MIDDLE ALLOCHTHON LOWER ALLOCHTHON	MA	UNDIFFERENTIATED MIDDLE ALLOCHTHON
	L	UNDIFFERENTIATED LOWER ALLOCHTHON
	S	PHYLLITE, SCHIST, & GNEISS (DIVIDAL GP. EQUIVALENTS)
	Q	QUARTZITE
	P	PORPHYRY
	PS	PRECAMBRIAN META-SEDIMENT
	A	AMPHIBOLITE
	M	MYLONITIC GRANITE
	SF	STRONGLY FOLIATED GRANITE
	F	FOLIATED GRANITE
	G	UNDEFORMED GRANITE
PARAUTOCHTHON/ AUTOCHTHON	S	PHYLLITE, SCHIST, & GNEISS (DIVIDAL GP. EQUIVALENTS)
	Q	QUARTZITE
	A	AMPHIBOLITE
	H	HORNBLENDE GRANODIORITE
	B	BASEMENT GRANITE GNEISS & MINOR META-SEDIMENTS

See PLATE 2 for source references.

GEOLOGY OF THE MIDDLE ALLOCHTHON
AND RELATED THRUST ROCKS
68° N, SCANDINAVIA

PLATE 2



MAP SOURCES

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