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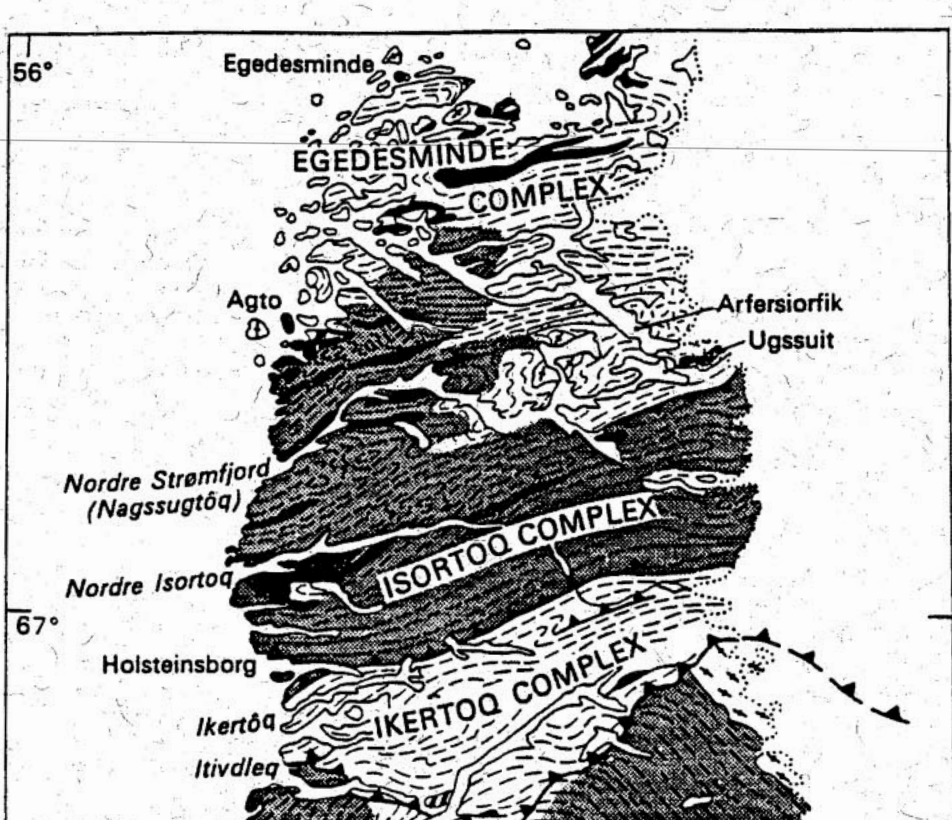
Petrographic Characterization of Some Precambrian Crystalline Rocks from the Sondre Stromfjord Area, West Greenland

Thomas C. Mowatt
A. S. Naidu



Acknowledgements

The late June C. Mowatt- geologist, wife, friend- is remembered for her contributions to this work, and other geological endeavors, as well as in so many other ways.

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Preface

Many people are concerned about the possibility of significant changes in portions of the earth's external cycles due to human activities, particularly global warming. These concerns are of fundamental importance to global biology, including human society, and efforts are underway worldwide to study this matter. One aspect of this is to develop data bases sufficient for rational investigation and evaluation, as well as to indicate such courses of action as may appear to be warranted.

An aspect of fundamental importance is to attempt to learn more about the character and patterns of changes of global climate from the past to the present. This involves a variety of considerations; much in fact, relates to studies of relatively recent geologic history.

The Polar Ice Coring Office (PICO), located at the University of Alaska-Fairbanks, is involved in supporting investigations of the geologic record provided by the present-day ice sheet, the "Inland Ice," which covers a major portion of Greenland, the world's largest island. Programs are underway to drill into this ice mass, retrieve samples via coring procedures and analyze them to develop information about paleoclimates.

It has been pointed out that additional fundamental geologic information about the character of sub-ice materials (such as bedrock and/or glacio-fluvial material) might be obtained by sub-ice drilling and sampling. Additional efforts should significantly expand geologic knowledge into areas now totally unknown. Mineralogical-geochemical characteristics of bedrock materials immediately subjacent to the ice may well yield clues as to paleo-climate/weathering conditions existing prior to the deposition of the overlying ice horizons.

Also, sub-ice sampling would seem to represent an unusually attractive opportunity to efficiently add to the sum total of human knowledge regarding the geology of a region which is acknowledged as being key to a variety of global geologic concerns. These include the early history of the earth itself, subsequent geologic events through time, and related processes. A principal aspect is that of present and past plate-tectonic relationships and related paleogeography. This, in turn, of course, has decided implications in terms of paleo-climates.

A project was initiated at the University of Alaska-Fairbanks, in collaboration with investigators from other organizations, to pursue the matter of sub-ice sampling. A fundamental aspect is that of engineering methods and equipment required. A principal concern was to endeavor to the provide a geologic context, in terms of types of geologic materials likely to be encountered during sub-ice drilling in Greenland, and the facilitation of recovery of such materials.

The U. S. Department of the Interior Bureau of Land Management (BLM) is supportive of research in the environmental and geo-sciences. This report represents in part a contribution by a bureau scientist to contemporary research. A previous report (Mowatt and Naidu, 1992) addressed general features of the regional geology of Greenland, and engineering aspects of bedrock types likely to be encountered by the drill beneath the Inland Ice. This work has been carried out through informal collaboration with the University of Alaska-Fairbanks.

Petrographic Characterization of Some Precambrian Crystalline Rocks from the Sondre Stromfjord Area, West Greenland

Abstract

As part of investigations of the nature and characteristics of rocks likely to be encountered below the Inland Ice of interior Greenland, four samples collected from bedrock outcrops in the region at the eastern end of Sondre Stromfjord, West Greenland were analyzed petrographically. These represent materials from the Ikertoq gneiss complex, within the Nagssugtoqidian mobile belt, of Precambrian age. Of particular concern were characteristics of these rocks which would be informative as to engineering/technological considerations related to sub-ice drilling and sample retrieval. Principal factors of interest in this context were mineralogical and textural attributes of these samples.

Two of the samples are medium-grained microcline-bearing granites, one is a medium-grained orthoclase-bearing granite, and one is a coarse-grained microcline-bearing granitic rock with decided gneissic characteristics. All exhibit features characteristic of metamorphism and structural deformation subsequent to their original, presumably igneous crystallization.

All possess the qualities of coherent aggregates of the principal constituent rock-forming minerals feldspar(s) and quartz, with attendant mineral component hardnesses of 6-7 on the Mohs scale. Although some degree of intra- and, to a lesser degree, intergranular fracturing is evident in each of these outcrop samples, such features are not deemed likely to appreciably affect the behavior of rocks such as these when encountered by the drill beneath significant thicknesses of overlying ice.

1. Introduction

A. General Comments

This report was originally prepared in December of 1992. In the interior of Greenland prior to 1991, only two ice cores had been drilled through to the underlying bedrock, at the Camp Century and Dye 3 sites. There is an ongoing effort under the NSF-sponsored GISP2 project to obtain samples of continuous ice cores down to the bedrock; in July, 1993, drilling through a record thickness of 3,054 meters of ice was accomplished near the Summit site in central Greenland. Additionally, a 1.5-meter-long core sample of the subjacent bedrock was retrieved- a most significant technological achievement, as well as one of great scientific import. Analysis and characterization of these materials should afford information of uncommonly great value to geological science.

Preliminary examination of this core sample indicates that it consists of rocks of leucocratic granitoid gneissic character, with readily discernible variations in color, composition and structure throughout the length of the core. There also appear to be manifestations of weathering exhibited over some 40 centimeters downward from the top of the core. Thus our earlier predictions (Mowatt and Naidu, 1992) as to the nature of bedrock most likely to be encountered below the Inland Ice in the study area in central Greenland appear to have been borne out.

The present report describes some results of petrographic studies carried out as an extension of our previous work regarding the nature of bedrock likely to be encountered beneath the Inland Ice, and related concerns as to engineering characteristics of such materials in terms of drilling and sample retrieval. Prior to the 1993 drilling and sub-ice sampling, we had summarized matters as follows (Mowatt and Naidu, 1992):

> Prediction/inference as to the nature of geological materials extant sub-ice within the project study area verges on informed speculation, at best, even in such general terms as the "terranes/regions/provinces" as discussed above. To essay an attempt at greater detail (as to specific lithologies) is still more uncertain. There is little compelling evidence to indicate that anything other than "crystalline basement"—in whatever particular guise(s) or lithologic character that may in fact be—is likely to underlie the Inland Ice, within the "radar grid" study area. Whether it, in fact, is representative of "Archaean," "Nagssugtoqidian," "Rinkian," "Ketilidian," or not is—to some degree—a moot point. Relevant to the present immediate concerns as to drilling technology, it seems sufficient to suggest that rock types characteristic of other "terranes," such as unmetamorphosed sedimentary rocks, for example, are rather less likely to be encountered by the drill sub-ice.
>
> Thus, in keeping with present knowledge of lithologies (types, relative abundances, distributions spatially and temporally), a "hierarchy" of sorts might be offered. In order of decreasing likelihood of sub-ice occurrence, such a list of lithologies might not unreasonably be suggested to appear as follows:
>
> 1. Gneisses; quartzo-feldspathic, principally derived from acid or intermediate igneous precursorial "protoliths". By far the most common lithology recognized in the various "crystalline" terranes. Of hornblende granulite -upper amphibolite metamorphic facies. These would consist principally of quartz- feldspar (plagioclase, potassium feldspars) mineralogies, with subordinate "mafic" minerals: amphibole, pyroxene, biotite, +/- lesser amounts of apatite, opaque minerals (magnetite, etc.).
>
> Igneous "granitoid" rocks would be quite similar in most respects, though lacking the characteristic banded-foliated textures of gneissic rocks, as imposed by metamorphism.
>
> Thus, taken together, gneisses of this type, plus granitic rocks, would constitute the "most likely" lithologies- in the general sense- to be anticipated in the present context.
>
> 2. "Amphibolites" (general sense). Much less abundant, volumetrically, than the above rock types. Mineralogies include predominant amphibole(s), plagioclase, quartz in particular, as well as a variety of generally less abundant constituents (opaque minerals, sphene, micas, pyroxene; +/- garnet, epidote, etc.). Derived mainly from volcanic rock protoliths, via metamorphism ranging from hornblende amphibolite-greenschist facies. Rock textures range from relict igneous-schistose.
>
> 3. Meta-anorthosite/norite/gabbro; associated meta-basic igneous rocks. The anorthositic/noritic/gabbroic rocks consist principally of calcic plagioclase, with subordinate/subequal proportions of mafic minerals (principally pyroxene, amphibole,+/- biotite) and lesser amounts- generally- of opaque minerals (chromite, magnetite, etc.). The meta-basic rocks consist of predominant plagioclase and mafic minerals- pyroxene and/or amphibole, with lesser amounts of other minerals (opaque minerals; biotite; etc.). Metamorphic grades range over the spectrum hornblende granulite-amphibolite-

greenschist facies. Rock textures range from relict igneous-schistose.

4. Meta-sedimentary rocks. A relatively subordinate component of the Precambrian crystalline terranes. Various protoliths. Now consist principally of quartzites, ironstones, meta-pelites/siltstones, calcareous/calc-silicate rocks. Textures range from massive-layered- schistose.

5. Rock types associated with the Tertiary igneous rock provinces of East Greenland and West Greenland. Principally extrusive mafic rocks- generally basaltic in general character- and related intrusive variants. The mineralogies feature predominant plagioclase and pyroxene, with subordinate opaque minerals; amphibole, quartz, biotite are other phases not uncommonly present. These provinces also contain other types of intrusive igneous rocks, of generally "granitoid-gabbroic" character, at least texturally. Principal mineral constituents include potassium and plagioclase feldspars (+/- feldspathoids), quartz, mafic minerals (amphibole, pyroxene, micas), and a variety of other minerals- usually in minor/trace amounts. Rock textures are principally igneous in character, ranging from fine to coarse in grain sizes.

6. Sedimentary rocks. Principally sandstones, siltstones, shales; conglomerates, limestones, dolomites. Subordinate evaporites, coals. Variations are essentially infinite, texturally and mineralogically. Inferred as the least likely lithologies to be encountered sub-ice within the study area- though, of course, their possible presence cannot be completely discounted.

The foregoing "hierarchy" assumes indurated bedrock in place as the material to be encountered below the ice. Alternatively, there is the possibility of encountering unconsolidated materials- presumably of glacial/glacio-fluvial character. Further analysis of this is deferred here, lacking reasonable data upon which to base substantive discussion. Suffice to say that such materials could run the gamut of particle sizes- clay and larger- depending upon specific conditions, processes, and substrate/source materials. Thus, the planned drilling program might well include provision for eventualiies involving encountering unconsolidated/ semi-consolidated ("less-than-lithified", i. e.) materials- clays, silts, sands, gravels, boulders; or more likely, a poorly-sorted mix thereof.

With the foregoing assessment in mind, limited ("opportunistic") outcrop bedrock sampling was undertaken by PICO personnel, during the course of their regular activities in Greenland, in order to further our understanding of physical and engineering characteristics of potential sub-ice materials, as relevant to drilling and sample recovery. The present report represents petrographic analysis of four such samples from West Greenland.

B. Brief Summary of Geology of Greenland

Our previous report (Mowatt and Naidu, 1992) endeavored to present an overview of this subject, based on literature review and first hand knowledge. A formidably large international technical literature has been developed dealing with various aspects of the geology of Greenland. Much of this represents work carried out by, or under the aegis of, the Geological Survey of Greenland (Gronlands Geologiske Undersogelse, or GGU). We have followed this development for many years ourselves, during the course of other work. Our recent computer-assisted search of this literature resulted in a listing of 9,380 references dealing with the geology-geomorphology-glaciology of Greenland. Three thousand seven hundred and fourteen of these were dated 1980 or more recently; 91 between 1990 and 1992 alone. It is somewhat daunting to consider attempting any sort of meaningful summarization of this vast amount of accrued knowledge.

At a somewhat detailed level, our literature survey confirmed that the volume *Geology of Greenland*, edited by A. Escher and W. S. Watt, and published by the Geological Survey of Greenland in 1976, remains in a class by itself as a source of information, particularly in the context of the present summary here. This admirable volume presents a series of twenty-one succinct, cogent discussions, at technical levels quite commensurate with a work of its' kind. Intended principally as a synoptic overview, in fact this exemplary volume does much more. It is a well-conceived and executed effort, in the classical tradition; well-written, informative, copiously illustrated. It presents a thorough, systematic, and integrated survey- insofar as this is feasible, given the incomplete state of geological knowledge of this enormous area. Overall, it achieves an excellent balance between generality and detail, quite commensurate with the principal intent of the work.

Though now somewhat out-of-date in certain particulars, it nonetheless remains the fundamental keystone in the technical literature on the geology of Greenland. We have found it an excellent and informative source on previous occasions, hence resort to it once again here. In particular, the chapter "Summary of the Geology of Greenland," written by A. Escher and W. S. Watt (p. 10-16) is noteworthy for our present purpose, providing, as it does, an effective synopsis. Thus, their (p. 11) "Introduction" is quoted here as follows:

> Greenland is the largest island in the world with a surface area of 2 186 000 km(sq) about 80 per cent of which is covered by the Inland Ice. The ice-free margin is up to 250 km broad and the highest peak is 3733 m. The major units of the geological column in Greenland can be matched with rocks of similar age and lithology in North America and northern Europe, and their character and distribution are consistent with the idea that Greenland represents a fragment of a single North Atlantic land mass.
>
> The largest part of the ice-free area is made up of crystalline rocks of the Precambrian shield. Rocks from part of the shield in the Isua region have given the oldest reliable isotopic ages of any terrestrial rocks. The shield acted as a stable block on which sediments accumulated at various times throughout the Precambrian and were deformed and metamorphosed.
>
> In North and East Greenland sedimentation continued into the Palaeozoic and some of the deposits were involved, together with the underlying basement, in tectonic and metamorphic events in mid-Palaeozoic time. Folded Palaeozoic rocks are overlain by Upper Paleozoic and younger platform sediments in North Greenland; in East Greenland Upper Palaeozoic continental and marine deposits followed by thick successions of mainly marine Mesozoic sediments lie on the folded Palaeozoic and Precambrian rocks.
>
> Along the west coast of Greenland a sedimentary basin developed during the Mesozoic and is represented onshore by Cretaceous and Tertiary sediments. In both West and East Greenland there was considerable volcanic activity in the early Tertiary.

Figures 1 and 2 are taken from Escher and Watt (1976; Figures 1 and 378).

By way of amplification, in the context of the present report, the following comments of Peel (1982) seem appropriate:

> Most of Greenland consists of Precambrian crystalline rocks representing the northeastern extension of the Canadian Shield... Five subdivisions can be recognised, with an old Archaean block flanked by the late Archaean and Early Proterozoic Nagssugtoqidian and Ketilidian mobile belts. The Rinkian mobile belt lies to the north... and is succeeded by extensive exposures of Precambrian Shield rocks in northwest Greenland, to the north.
>
> The Archaean block has been

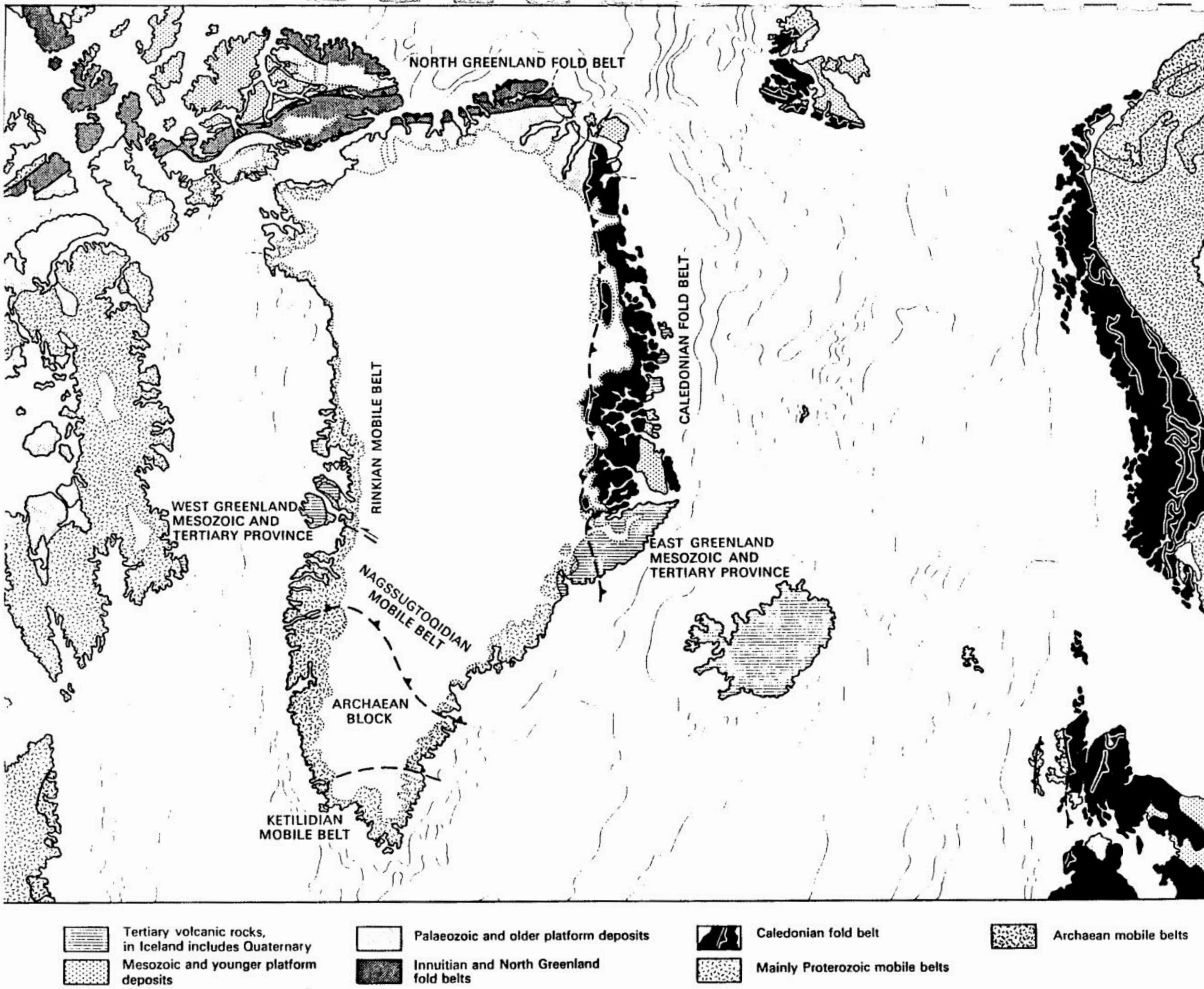

Figure 1. The structural divisions of Greenland in relation to the neighbouring land areas. (From Escher and Watt, 1976, p. 10).

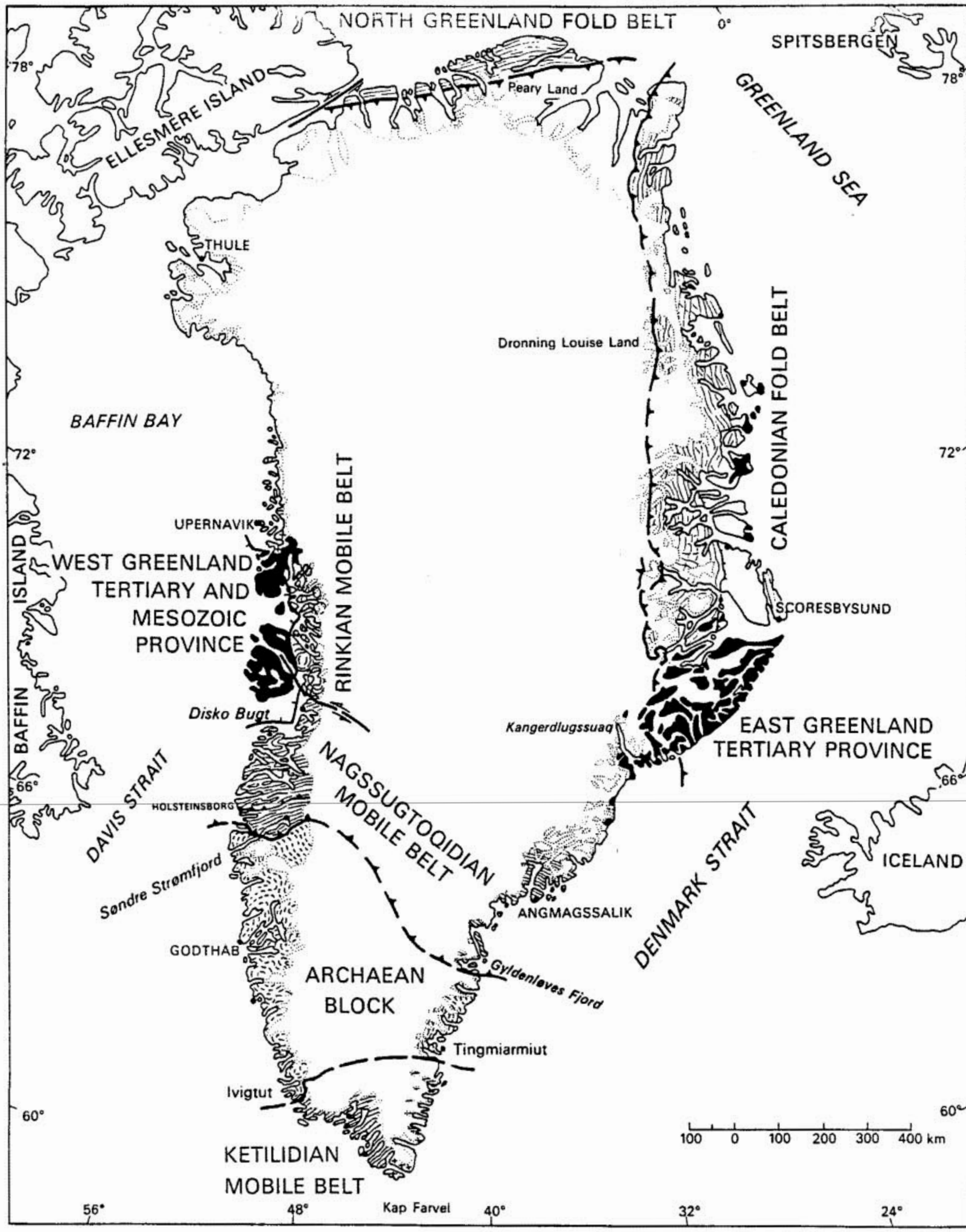

Fig. 378. The main geological divisions in Greenland.

Figure 2. From Escher and Watt, 1976, p. 462.

essentially unaffected by major metamorphism during the last 2500 m. y. (Bridgwater et al., 1978). Supracrustal rocks dated at 3800 m. y. have yielded supposed microfossils, but Bridgwater et al. (1981) reviewed the occurrences, dismissing them as evidence of early Archaean life. The Nagssugtoqidian mobile belt is mainly composed of reworked Archaean gneisses deformed at about 2700 m. y. The Ketilidian mobile belt contains sediments and volcanics overlying the Archaean block along its southern boundary and is extensively intruded by large granite plutons giving ages from about 1740 m. y. to 1850 m.y. The Rinkian mobile belt is characterised by large-scale folds and nappes in strong contrast to the regional planar fabric of the adjacent Nagssugtoqidian mobile belt. The complex is continuous with Rinkian-Archaean crystalline strata in northwest Greenland which can be closely compared with adjacent Ellesmere Island (Frisch and Dawes, 1982). Exposures of Precambrian Shield also occur in southern Wulff Land (Dawes and Peel, 1981) and within the East Greenland fold belt (Henriksen and Higgins, 1976; Henriksen, in press; Hurst et al., in press).

2. Petrology

The rocks described in the present report are samples of bedrock collected from outcrops in the Nagssugtoqidian terrane, in the region about the eastern end of Sondre Stromfjord, West Greenland. As such, they represent materials from an area which was described in the early literature (Ramberg, 1948) as the "Ikertoq Gneiss Complex.". Ramberg (p. 319-320) states:

> The main picture of the Ikertoq and the Egedesminde gneiss complexes is rather similar. A granodioritic gneiss carrying biotite, and often green hornblende and/or epidote, is the main rock in both complexes. Often its composition approaches a potash granite. In this gneiss are included bands, boudinages, and other remnants of amphibolitic composition.

Escher and Watt (1976; p.12) provide general comments:

> The Nagssugtoqidian mobile belt consists mainly of Archaean gneisses which were reworked in a major tectonic zone about 300 km wide in both East and West Greenland. This zone is characterised by a pronounced regional planar fabric parallel to the boundary with the Archaean block, the so-called linear belts alternating with areas of less deformed rock.
>
> Isotopic dates suggest that the main phase of Nagssugtoqidian deformation and metamorphism took place about 2700 m. y. ago although the belt was active until about 1700 m. y. ago. Supracrustal rocks form thin layers interlayered and deformed together with the Archaean gneisses. The gneisses are mostly in amphibolite facies though granulite facies gneisses occur in the central part of the mobile belt. The strong deformation of Nagssugtoqidian rocks is probably partly due to horizontal shear movements associated with overthrusting of the Nagssugtoqidian block onto the Archaean block to the south. Deformation is not equally developed throughout the belt; islands of Archaean rocks occur which are almost unaffected by Nagssugtoqidian movements and show a complex pattern of dome and basin structures.

Escher, Sorensen and Zeck discuss the "Nagssugtoqidian mobile belt in West Greenland," in Escher and Watt, 1976, pages 76-95. Figure 3 is taken from their excellent summary of this extensive and complex terrane. Relevant excerpts from their text include the following (p. 77, 79, and 93):

> The rocks forming the northern part of the Archaean block in West Greenland are cut by dense swarms of dolerite dykes. Towards the north the dykes, together with their country rocks, are progressively deformed and metamorphosed resulting in a reorientation and parallelisation of dykes and country rock structures. These changes were the basis on which Ramberg (1949)

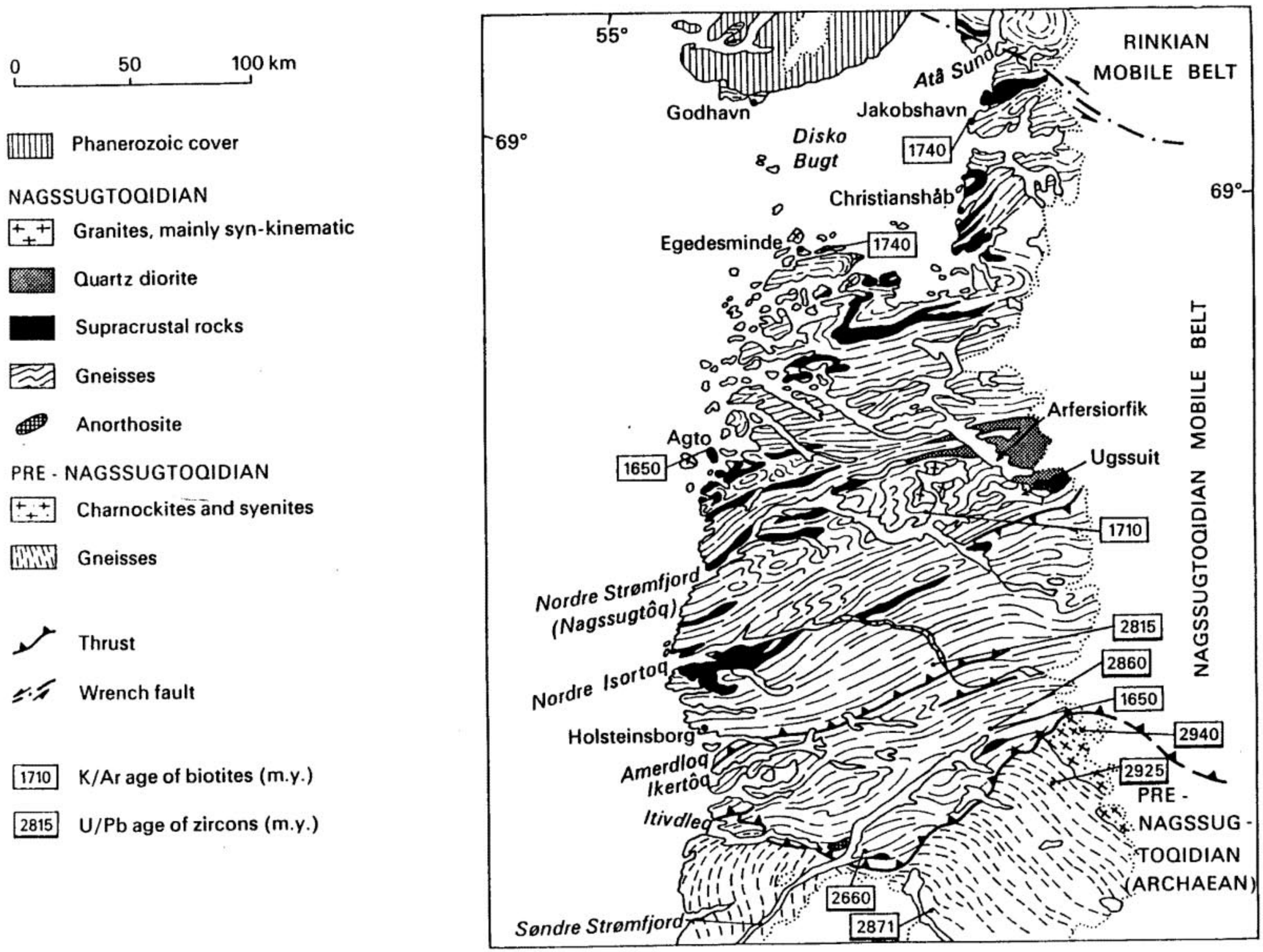

Fig. 71. Geological sketch map of the Nagssugtoqidian mobile belt in West Greenland.

Figure 3. From Escher and Watt, 1976, p. 79.

distinguished a Nagssugtoqidian complex from a pre-Nagssugtoqidian (Archaean) complex in West Greenland. Similar observations by Bridgwater & Gormsen (1968) in South-East Greenland made it possible to correlate the Nagssugtoqidian mobile belt from West to East Greenland. It forms a ca. 300 km wide belt characterised by a pronounced regional fabric oriented parallel to the boundary with the Archaean block (fig. 70). In West Greenland this regional fabric is cut to the north by the wrench fault zone which separates the Nagssugtoqidian from the Rinkian mobile belt. Although K-Ar dating of Nagssugtoqidian rocks gives ages within the range 1740-1650 m. y. (Larsen & Moller, 1968), U-Pb dating of zircons (Chessex et al., 1973) suggests that the main phase of Nagssugtoqidian deformation and metamorphism is much older and probably took place at the beginning of the Proterozoic or at the end of the Archaean (fig. 71).....

The Nagssugtoqidian belt is made up mainly of reworked pre-Nagssugtoqidian basement gneisses and granites, locally with interlayered and folded belts of metasediments and metavolcanics (supracrustals). The basement gneisses are mostly amphibolite facies gneisses with granulite facies gneisses in the central part of the belt. Supracrustal rocks form thin belts interlayered and deformed together with basement gneisses. Nowhere has an unconformity been recognized, the original contact always having been obliterated by later movements. Basic to intermediate intrusives are mainly found in the southern and central part of the belt as deformed and metamorphosed dykes and sheets.

South of the Nagssugtoqidian boundary, the northern part of the Archaean block is composed mostly of granulite facies gneisses, probably derived from intrusive charnockites, syenites, and granites by shear-deformation.....

Ramberg (1949), on the basis of reconnaissance mapping, divided the rocks between Egedesminde and Sondre Stromfjord into three metamorphic complexes (fig. 90). The southernmost Ikertoq complex, and the northernmost Egedesminde complex are characterised by rocks belonging to the amphibolite facies, while the central Isortoq complex contains granulite facies rocks. Later work has confirmed the relevance of this division. Only locally has knowledge of the Nagssugtoqidian metamorphism been established in more detail.

In general the metamorphic events responsible for the highest grade parageneses outlasted the main Nagssugtoqidian periods of deformation. In the majority of rocks niether the textures nor the number of phases contradict the view that these parageneses represent an equilibrium.....

Figure 4 (following Ramberg, 1948, Fig. 1), is taken from Escher, Sorensen and Zeck (p. 93, figure 90), in Escher and Watt (1976). The general area from which the four outcrop samples for the present work were collected is near the eastern end of Sondre Stromfjord. Samples 92-4-21-1-A and 92-4-21-1-B were obtained from the "summit" south and east of the Air Force Base; samples 92-4-21-1-C and 92-4-21-1-D from "fresh rock chipped from cliff above valley; glacier polished" (J. Kelley, personal communication, 1992), across the river from the Air Force Base.

3. Petrography

A. Methodology

The rock samples were studied prior to thin-section preparation, using hand-lenses, and a stereo microscope. Each of the four samples reported on here was prepared as a standard petrographic thin-section, including staining for both potassium and plagioclase feldspars, by a commercial laboratory. Unfortunately, the staining procedures were not done sufficiently well to be particularly useful in straightforward characterization of the constituent feldspars. This resulted in

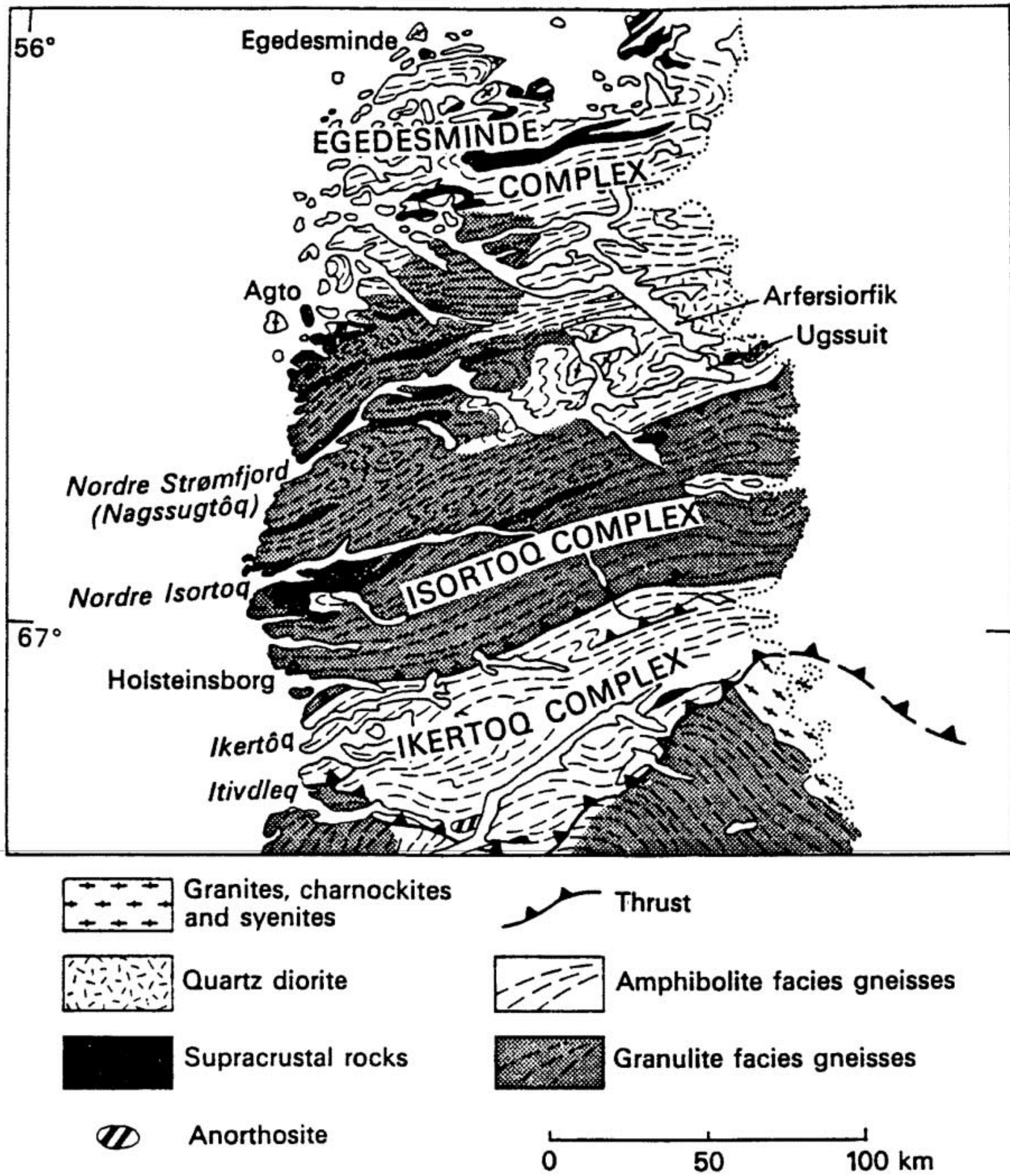

Fig. 90. Map of the main metamorphic complexes within the Nagssugtoqidian mobile belt.

Figure 4. From Escher and Watt, 1976, p. 93.

making the elucidation somewhat more difficult in some instances. However, utilization of various optical properties and crystallographic features permitted reasonably definitive analyses to be carried out; it is felt that the results presented here are reasonably representative of petrologic reality for each of these samples. The thin-sections were examined utilizing standard procedures, using a Nikon petrographic microscope in transmitted light, supplemented by inclined reflected light illumination. Each thin-section was subjected to modal analysis by standard point-counting procedures. Petrographic classification follows Streckeisen, 1967. Plates 1-4 show salient features of these samples in thin-section.

B. Analytical Results

SAMPLE 92-4-21-1-A

Modal analysis:

Plagioclase	33.24%
Microcline	31.56%
Quartz	27.21%
Biotite	4.77%
Muscovite	2.81%
Sphene	0.28%
Epidote (?)	0.14%
Zircon	trace
Apatite	trace
Calcite	trace

Mineral descriptions:

Plagioclase- anhedral/subhedral; tendency to assume triple-junction boundaries with quartz, potassium feldspar and other plagioclase grains; grains noted are 4.3mm and smaller; slightly-moderately altered to calcite and sericite (?); especially seen along cleavages; cores of plagioclase grains sometimes feature extremely fine-grained opaque minerals and/or optically indeterminate materials as well; crystals are twinned (albite, +/-), and zoned, and commonly exhibit "semihedral" rims of clear unaltered plagioclase; the twinning persists across the "core/rim" boundary; the interiors of the crystals are on the order of An14 in composition (optically), while the rims are approximately An8; these rims often appear to extend into adjacent potassium feldspar grains; plagioclase crystals often enclose biotite, sphene, and rounded-elongate quartz "blebs;" rare but excellently developed myrmekite, adjacent to potassium feldspar grains.

Microcline- tendency toward development of triple -junction boundaries with plagioclase, quartz, and other microcline grains; some excellent examples of this are present; grains noted are 4.3mm and smaller; alteration effects are slight/nil; crystals exhibit the typical tartan-twinning of microcline; they are intergrown with quartz and plagioclase; some grains contain rounded "blebs" of quartz; there is some evident granulation/recrystallization along mutual borders with other microcline grains, frequently associated with grains which are also in triple-junction contact configurations; a slight-moderate amount of string perthite is developed, though discerned in only some microcline crystals in this thin-section.

Quartz- anhedral; tendency to assume triple-junctions, on a broad thin-section scale, with plagioclase and microcline; some of the quartz, however, appears to have been a later crystallizing phase than the feldspars; also intergrown with biotite and sphene, though apparently subsequent to their crystallization; 3.9mm and smaller; exhibits strongly undulose/composite/mosaic extinction

Biotite- subhedral/irregular; 2.1mm and smaller; encloses apatite, subhedral zircon grains (with slight metamict zones discernible), +/- blebs of quartz; also surrounded by muscovite, often in seeming optical continuity; alteration essentially nil; perhaps (?) slightly, in places, to muscovite (rather, more likely, a manifestation of the common spatial association of the two micas; rare alteration to chlorite, especially where in association with sphene; seems to represent an equilibrium phase in the mineral assemblage in this thin-section

Muscovite- subhedral/irregular; 1.0mm and smaller; often spatially associated with biotite (occasionally intergrown); some seems to be replacive of plagioclase especially along cleavages; one patch shows a biotite "core" surrounded by/replaced by muscovite/"sericite" (a rare case of biotite textural disequilibrium in this thin-section); evidence of retrograde metamorphism (?)

Sphene- euhedral; 1.6mm and smaller; often contains a core/nucleus, or associated with "epidote" (?); often associated with earlier apatite crystals, and zircon grains (zircon also occurs as extremely fine-grained inclusions in sphene crystals- zircons have metamict haloes, and are sometimes zoned)

Epidote (?)- subhedral; 0.4mm and smaller; high 2V, biaxial (-); moderately pleochroic, light yellow to yellow-green, with blue-green core; occurs as discrete crystals (one twinned group), as well as associated with sphene; an earlier crystallizing phase than plagioclase, sphene, quartz, microcline

Zircon- subhedral; 0.15mm and smaller; associated with sphene, biotite, "epidote"

Apatite- sub-euhedral; 0.2mm and smaller; generally associated with sphene, often as/in the core of a sphene crystal, or partially enclosed

Calcite- sub-anhedral; 0.4mm and smaller; occurs as alteration of/within plagioclase; also as intergrowth with feldspars-quartz-muscovite

Summary and engineering characteristics:

This sample presents the aspect of an originally granitoid rock, with the mineralogical composition of a granite. It is presently of medium grain size, and appears to exhibit features of an originally interlocking mosaic of intergrown crystals, likely of igneous origin. This texture appears to have been subsequently modified somewhat, via recrystallization attendant upon metamorphism and related structural deformation. There are patchy areas of granulated grain borders, and appreciable amounts of "strained"/intergrown grain margins. Trace amounts of hematite occur along a few microcline intergranular boundaries. Some intragranular fractures were noted; a very few transect more than one grain. No through-going fractures were observed in this thin-section. The sample presents a coherent aggregate of intergrown mineral grains, principally (65%) made up of feldspars (Mohs hardness =6), and subordinate (27%) quartz (Mohs hardness = 7).

SAMPLE 92-4-21-1-B

Modal analysis:

Plagioclase	33.22%
Orthoclase	31.32%
Quartz	27.09%
Biotite	5.80%
Magnetite	2.15%
Apatite	0.33%
Zircon	0.08%
Pyrite	trace
Amphibole	trace
Garnet (?)	trace

Mineral descriptions:

Plagioclase- anhedral; intergrown with potassium feldspar and quartz, often with rounded quartz "blebs" included; also occurs in myrmekitic intergrowths adjacent to potassium feldspars; appears to be (in part at least) an earlier crystallizing phase than potassium feldspar; there appear to be some patches/zones of micrographic intergrowths with potassium feldspar +/- quartz; a later crystallizing phase than biotite, apatite, "ores;" 1.2mm and smaller; twinned, zoned (slightly; An20-17); some grains exhibit discrete clear rims of albite (An<10); some is essentially unaltered, some shows slight/moderate alteration ("saussuritization"); also some apparent replacement by biotite, +/- (?), in several patches/zones in the thin-section, often preferably along one set of twins

Orthoclase- anhedral; most as "megacrysts;" intergrown with plagioclase and quartz, often in apparent micrographic intergrowth; a later crystallizing phase than biotite, apatite, "ores;" some plagioclase; 3.2mm and smaller; traces of cross-hatching/tartan-twinning(?) in a few grains; most grains exhibit string perthitic intergrowths (on the order of up to 20% plagioclase, by visual estimate); some grains feature myrmekitic growths, where adjacent to plagioclase grains in the thin-section; essentially unaltered; some grains are slightly fractured, with biotite infillings

Quartz- anhedral; some are "megacrysts;" a late-crystallizing phase, in part at least coeval with some biotite, plagioclase, potassium feldspar, but later than most "ores" and apatite; interlocking texture with other major rock-forming silicate minerals, for the most part; some smaller granulated/recrystallized grains along the borders of larger quartz grains; also some associated with "reaction zones"/(?) with mafics-ores-apatite-carbonate material-secondary biotite; 2.5mm and smaller; moderately deformed, with development of undulose-extinguishing zones/patches within individual grains ("mosaic," ie.).

Biotite- Two generations (?): 1. eu-subhedral; primary, a later crystallizing phase than apatite, some of the "ores;" 2.2mm and smaller; 2. sub-anhedral; secondary (hydrothermal ?/reaction products ??/ metamorphic ?); developed from previously existing amphibole (?),+/-(?) inclusions-crystals-lenses (?); associated with ores, garnet, quartz, plagioclase, carbonate material; occurs as rims around some ore, potassium feldspar, quartz grains; <2.2mm; some moderately altered to chlorite

Magnetite "ore"- subhedral-irregular-rounded; 0.5 mm and smaller; often associated with apatite, biotite; a later crystallizing phase than apatite; esentially coeval with much of the biotite, although often rimmed with biotite; perhaps two generations of magnetite/ore here- a primary, and a secondary, the latter associated with lenses/ patches of altered/reacted mafic minerals, associated as well with pyrite/hematite

Apatite- eu-subhedral; an early-crystallizing phase (perhaps the first in this thin-section); often associated with biotite, ores; preceded the formation of the biotite; appears to occur within "linears" of intermittent "strings" of crystals, subparallel to other such "linears" (of biotite, especially) in this thin-section (relict flow features ?); 0.5mm and smaller

Zircon- subhedral-rounded; an early-crystallizing phase in this thin-section, often associated with apatite; exhibits moderate-strong metamictization; 0.15mm and smaller

Pyrite- sub-anhedral; associated with altered lenses/patches of mafic minerals; often rimmed to some extent by hematite; 0.2mm and smaller

Amphibole- sub-anhedral; a primary rock-forming phase, subsequently resorbed, in part (?); apparently associated with "lenses/zones" of mafic minerals-ores-, +/ - (?); perhaps these represent relict inclusions (?); strongly altered to quartz, garnet, biotite, +/- chlorite, +/- ores

Summary and engineering characteristics:

This sample presents the aspect of an originally granitoid rock, with the mineralogical composition of a granite. Presently of medium grain size, it appears to exhibit features of an originally interlocking mosaic of intergrown crystals, likely of igneous origin. There is evidence of subsequent metamorphism, attended by deformational stress. The sample shows a vague subparallel alignment of the principal rock-forming minerals, as well as apparently linear/planar trends of other constituent minerals, in particular apatite, to some degree biotite, and zones of "inclusions". There are indications of the development of triple-junction boundaries among some grains of the principal rock-forming minerals. Also noted are small granulated/recrystallized patches of quartz along the margins of larger quartz grains. Some intragranular fractures occur in feldspars and quartz; very few persist into adjacent grains. There is no evidence of throughgoing fractures in this thin-section. The sample represents a coherent aggregate of intergrown mineral grains, principally (64%) made up of feldspars (Mohs hardness = 6), and subordinate (27%) quartz (Mohs hardness = 7).

SAMPLE 92-4-21-1-C

Modal analysis:

	(1)	(2)
Plagioclase	40.40%	44.38%
Microcline	29.20%	26.10%
Quartz	27.07%	26.42%
Biotite	3.33%	3.10%
Muscovite	trace	trace
Epidote(?)	trace	trace
Zircon	trace	trace
Apatite	trace	trace
"Magnetite"	trace	trace

(1) "plagioclase" defined as only those feldspar grains present which exhibit discernible plagioclase twinning; all other feldspars present considered to be potassium feldspar
(2) "plagioclase" defined as all feldspars present which do not exhibit cross-hatched/tartan twinning

Mineral descriptions

Plagioclase- anhedral/irregular; intergrown with, as well as often enclosing quartz, potassium feldspar grains; some myrmekitic intergrowths developed, where adjacent to potassium feldspars; a later-crystallizing phase than (at least some) biotite; some triple-junction grain boundaries are developed, especially against other plagioclase crystals; there are zones of granulation at the borders of some of the plagioclase grains, often with development of "sericite" along the borders as well; 7.4mm and smaller; twinned, moderately zoned (An15/25 to An<5), often with clear albite rims; some twin lamellae are bent/deformed, presumably due to deformational stress; slight degree of alteration, to sericite, particularly parallel to cleavage (only noted on some grains); slight amount of fracturing, sporadically developed, associated with cleavages

Microcline- anhedral/irregular; some appears to be a later-crystallizing phase than plagioclase in this thin-section, although some seems to be coeval with plagioclase; often encloses rounded "blebs" of quartz; there are some granulated/sutured grain boundaries, especially where adjacent to other microcline crystals- this is often associated with flamboyant "recrystallization" flame perthite development toward the borders of the microcline grains; 6.0mm and smaller; exhibits tartan twinning; slight/moderate development of perthitic stringers and patches, here and there within the grains; nil alteration

Quartz- anhedral/irregular; some as rounded "blebs" within feldspar; intergrown with the plagioclase and microcline; some apears to be a relatively early-crystallizing phase in this thin-section, but much is also coeval with and/or possibly later than some of the feldspars; some quartz is in triple-junction contact with microcline and/or plagioclase; there are also areas of granulated borders, presumably due to deformational stress (due to metamorphic processes, and/or attendant upon late-stage cooling/crystallization ?); 7.0mm and smaller; composite/mosaic crystals formed, to a moderate degree, due to stress

Biotite- subhedral; an early-crystalliing phase in this thin-section; preceded crystallization of the feldspars; pre-coeval with muscovite, with which it is frequently rimmed/bordered; often associated with muscovite, "epidote", apatite, ores; 1.7mm and smaller; nil alteration

Muscovite- subhedral; often associated with biotite, frequently rimming/bordering biotite grains; 0.42mm and smaller

Epidote (?)- sub-euhedral; commonly associated with biotite, frequently enclosed thereby; 0.6mm and smaller; high 2V; biaxial (-); pleochroic- golden yellow brown/green to lighter yellow

Zircon- sub-euhedral; an early-crystallizing phase in this thin-section; commonly associated with biotite, "epidote;" 0.3mm and smaller

Apatite- sub-euhedral; associated with zircon, magnetite/ores; 0.2mm and smaller.

Magnetite/ores- subhedral; associated with zircon; an early-crystallizing phase in this thin-section; pre-plagioclase; 0.45mm and smaller

Summary and engineering characteristics:

This sample presents to some degree the aspect of a metamorphic gneissic rock, with the overall mineralogical composition of a granite. It is presently a coarse-grained rock. Although perhaps originally of igneous origin, this sample features vague-slight subparallel alignment of the mafic grains, in particular, and some apparent banding/segregation of the principal rock-forming minerals which seems to reflect differing grain sizes as well. Some intragranular fractures occur within the principal mineral phases present, but very few persist into adjacent grains. Hematite, and/or other optically indeterminate materials occupy many of these fractures- perhaps most likely as the result of weathering. In general aspect, however, this rock consists of an interlocking mosaic of crystalline minerals, sometimes featuring sutured grain boundaries. It has undergone structural deformation, as well as some degree of metamorphism, with attendant recrystallization manifested. The sample may be termed a gneissic granite/granitic gneiss, consisting now of a coherent aggregrate of intergrown mineral grains, principally (approximately 70%) made up of feldspars (Mohs hardness =6), and subordinate (26-27%) quartz (Mohs hardness =7).

SAMPLE 92-4-21-1-D

Modal analysis:

Plagioclase	41.60%
Quartz	28.61%
Microcline	25.04%
Biotite	3.49%
Muscovite	0.63%
Zircon	0.63%
Apatite	trace
Epidote (?)	trace

Mineral descriptions:

Plagioclase- anhedral; intergrown with quartz, potassium feldspar; often with included rounded "blebs" of quartz; some development of myrmekitic intergrowths where adjacent to potassium feldspar grains; a later-crystallizing phase than biotite, zircon, epidote (?) in this thin-section; 5.3mm and smaller; crystals are twinned; some are zoned (An18/24 to An5), with clear albite rims; twin lamellae are often deformed, here and there, including deformation/bending of the twins in the albite rims; slight alteration to sericite, preferentially on certain twins, and along cleavages

Quartz- anhedral/irregular; also as rounded "blebs" enclosed in plagioclase and potassium feldspar; a late-crystallizing phase in this thin-section, subsequent to biotite, zircon, epidote,(?), some plagioclase, some potassium feldspar; also intergrown with the latter two phases as well; 5.5mm and smaller; moderately-strongly deformed, to undulose-composite-granulated-partially recrystallized grains; very large crystals, frequently broken up

Microcline- anhedral/irregular; intergrown with plagioclase and quartz; principally a late-crystallizing phase in this thin-section, with inclusions of plagioclase, quartz, biotite; at least 5.7mm, and smaller;

tartan/cross hatched twinning developed; one grain shows quite well appreciable offset of a possibly stress-related zone of tartan twinning, due to deformation coeval with/ subsequent to formation of the microcline grain; microperthitic, with development of some flamboyant flames/stringers; nil alteration

Biotite- subhedral; associated with zircon, epidote (?), muscovite; often interleaved with, and/or rimmed by muscovite; relatively free of inclusions- some extremely fine-grained magnetite/ore, and a few zones of possibly metamict material associated with extremely fine-grained zircon inclusions; an early-crystallizing phase in this thin-section, pre-microcline, quartz, plagioclase; in places, biotite appears to have crystallized later than muscovite; 2.1mm and smaller; slightly altered, featuring zones of hematite development (weathering?); also some muscovite on grain borders, and interleaved

Muscovite- subhedral; interleaved with, and/or bordering biotite; some at least, appears to be pre-biotite; some occurs as alteration of plagioclase; 0.7mm and smaller

Zircon- sub-euhedral; most occurs in association with micas in this thin-section, but only in relatively minor amount as included material; pre-biotite; some within biotite crystals, surrounded by metamict haloes; 0.5mm and smaller; commonly altered to metamict material; some, in particular an area on a weathered edge of the sample, is altered (weathered ?) to an assemblage of zircon and optically indeterminate materials

Apatite- sub-euhedral; associated with the micas, generally; 0.3mm and smaller

Epidote (?)- sub-euhedral; often associated with micas; an earlier-crystallizing phase than plagioclase, biotite in this thin-section; 0.3mm and smaller; questionable identification

Summary and engineering characteristics:

This sample presents the aspect of an originally granitoid rock, with the mineralogical composition of a granite. Presently of coarse-medium grain size, it appears to exhibit features of an originally interlocking mosaic of intergrown crystals, likely of igneous origin. This texture appears to have been subsequently modified somewhat, attendant upon metamorphism and related structural deformation. The principal rock-forming minerals- plagioclase, microcline, and quartz- exhibit a tendency toward the formation of triple-junction grain boundaries. There is a fair development of foliation of biotite grains, as well as gneissic banding in this sample. Trace amounts of hematite occur along fractures, a few of which are presently through-going in this sample. In hand specimen, this outcrop rock sample is semi-friable. However, at depth, this rock is likely to be a relatively strong, coherent material, given the petrographic character in terms of textural relationships and constituent minerals. The principal rock-forming minerals are feldspars (67%), with Mohs hardness = 6; and quartz (29%), with Mohs hardness = 7.

4. Conclusions

Petrographic analysis of these four bedrock samples taken from outcrop has confirmed their essentially gneissic granite character, as anticipated from previous studies (cf. references above) of the Nagssugtoqidian of this part of West Greenland. Sample 92-4-21-1-A is a medium-grained microcline-bearing granite, while sample 92-4-21-1-B obtained nearby is a medium-grained orthoclase-bearing granite. Each manifests features characteristic of metamorphism and structural deformation subsequent to original igneous crystallization. Sample 92-4-21-1-C is a coarse-grained microcline-bearing granitic rock, with a decided gneissic aspect. Sample 92-4-21-1-D obtained nearby is a coarse- to medium-grained microcline-bearing granitic rock, also somewhat gneissic in aspect. Each of these latter two samples contains somewhat higher proportions of plagioclase as compared to potassium feldspar. All four rocks are mineralogically "granites", in the sense of Streckeisen (1967), although each bears imprints of metamorphism subsequent to their apparent original crystallization in igneous environments. These rocks represent materials which likely would act as coherent aggregates, of appreciable hardness (6-7 on the Mohs scale), if encountered during sub-ice drilling amd attempted sample retrieval.

5. References

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PLATE 1

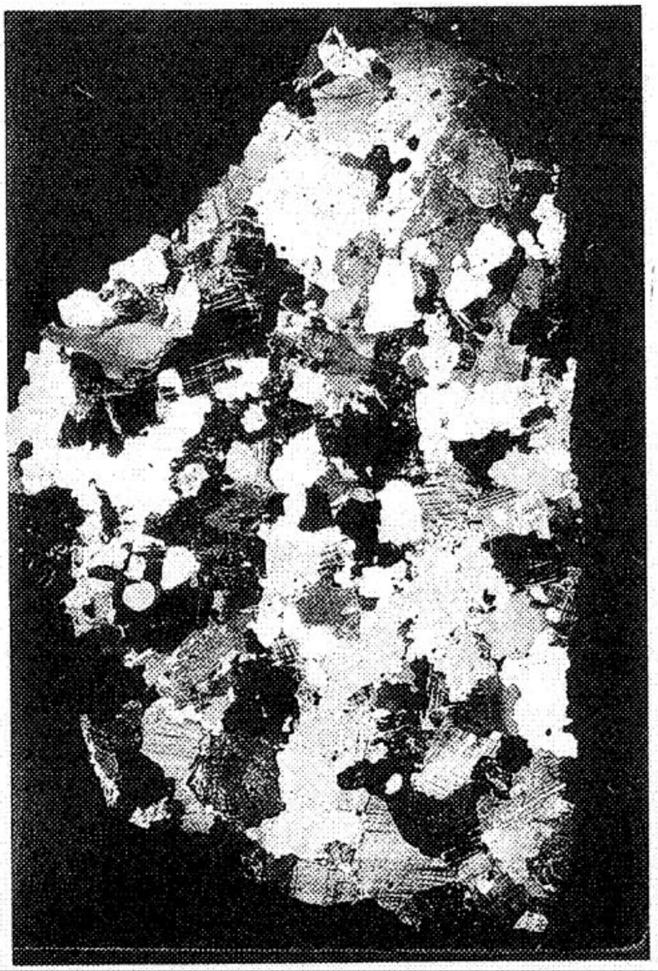
92-4-21-1-A

A. Photographed at 1X magnification, in transmitted light, using crossed polarizing filters. Printed photograph = 3.6X magnification. Presents an overview of fabric and textural relationships. Mineralogy features "tartan-twinned" microcline, pinkish-hued (staining/ alteration) plagioclase, clear quartz, with subordinate biotite, muscovite and sphene. The quartz exhibits extinction characteristics attributable to strain due to deformational stresses. Note the departure from an apparent original typically granitoid texture towards one manifesting aspects of a moderate-appreciable degree of subsequent metamorphic/ deformational modification.

B. Photographed at 12.5X magnification, in transmitted light, using crossed polarizing filters. Printed photograph = 45X magnification. Illustrates the principal rock-forming minerals: plagioclase (grey, with typical "albite" twinning, and slight-moderate development of muscovitic alteration as shown by the yellow-golden areas within the large plagioclase grain); microcline (dark grain, exhibiting tartan twinning); quartz (white grains). A euhedral wedge-shaped crystal of sphene (brownish/multi-hued) is prominent as well. Note the nature of the grain boundaries among these phases.

C. Photographed at 12.5X magnification, in transmitted light, using crossed polarizing filters. Printed photograph = 45X magnification. Shows textural relationships among grains of microcline (tartan-twinned, slightly perthitic grain) and plagioclase (grey grain with faint twinning, and with a rim of cream-colored clear albite where adjacent to microcline; greyish-white grain with clear white albite rim; dark grain within the microcline grain, exhibiting a grey border of albite adjacent to the potassium feldspar). Note the nature of the grain boundaries among these phases.

D. Photographed at 12.5X magnification, in transmitted light, using crossed polarizing filters. Printed photograph = 45X magnification. Depicts textural relationships among grains of microcline (grey-dark, tartan-twinned), plagioclase (grey-dark, with patches of gold-yellow muscovitic alteration, and lighter grey to cream-colored rims of clear albite; within the darker microcline grain there is also a grain of enclosed plagioclase which exhibits a grey central core and associated patches of rounded myrmekitic intergrowths, together with a white rim of clear albite), and quartz (white, showing a rounded border with adjacent microcline, and a somewhat irregular border next to a plagioclase grain). Appreciable development of triple-junction grain boundaries seems apparent, particularly among the feldspars.



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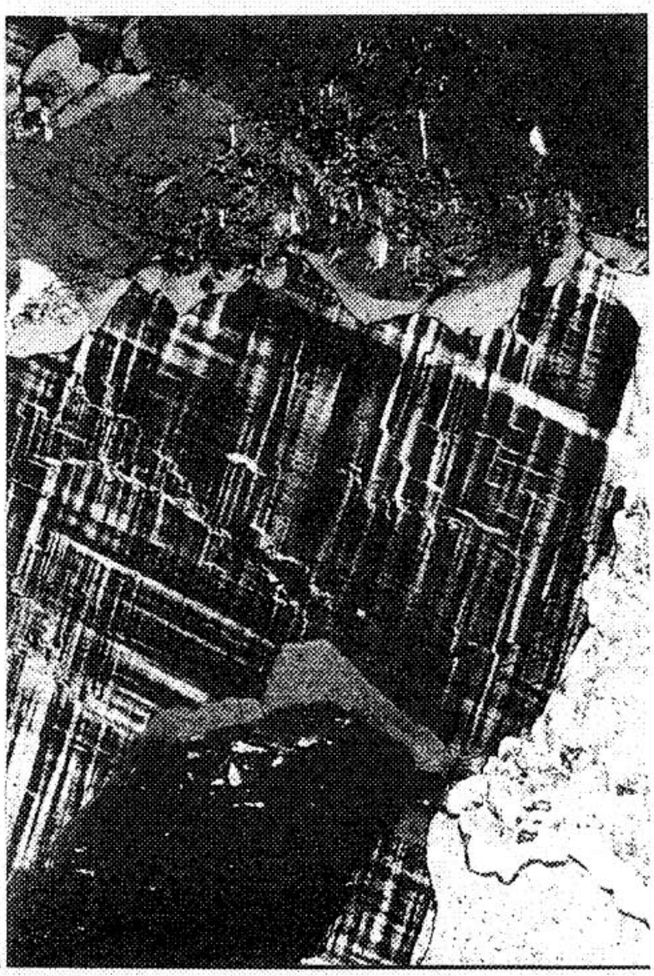

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PLATE 2

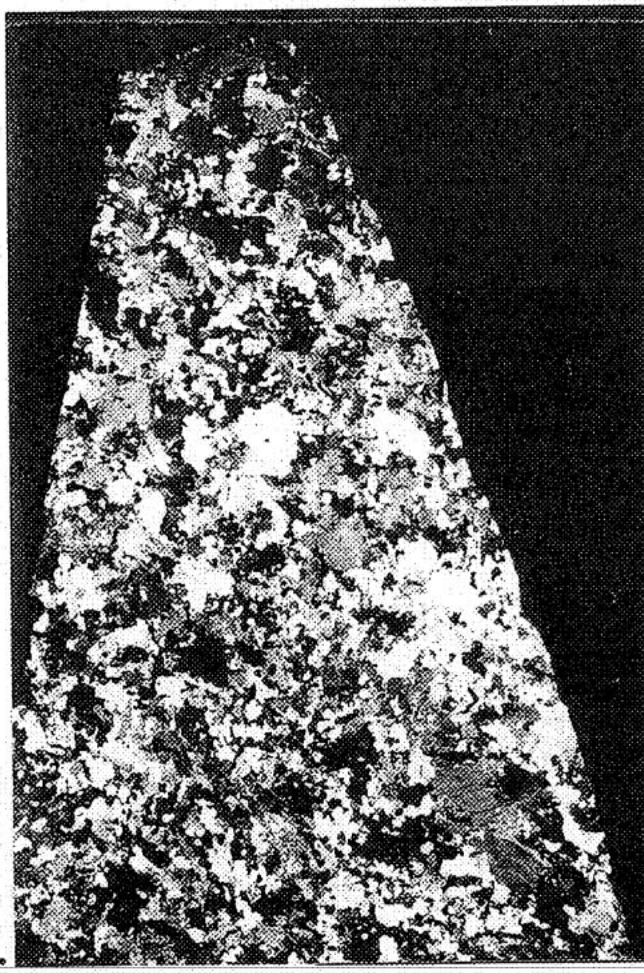
92-4-21-1-B

A. Photographed at 1X magnification, in transmitted light, using crossed polarizing filters. Printed photograph = 3.6X magnification. Presents an overview of fabric and textural relationships. A tendency toward subparallel alignment of constituent mineral grains, as well as a vaguely banded character of the rock overall appear to be discernible. The former is especially reflected in the distribution of biotite (brownish-orange-gold materials), the latter as well in the distribution of the principal rock-forming minerals- plagioclase, orthoclase, quartz-, in part at least apparently attributable to different grain sizes). The overall aspect seems to be that of an originally granitoid texture which has been modified subsequently, to some extent, by metamorphism/deformation.

B. Photographed at 12.5X magnification, in transmitted light, using crossed polarizing filters. Printed photograph = 45X magnification. Shows a portion of the specimen comprised of an assemblage of smaller grains of the principal rock-forming minerals. Distinguishable in this view are plagioclase (whitish-grey-dark, often exhibiting typical "albite" twinning), orthoclase (whitish-grey-dark, occasionally manifesting appreciable perthitic character as irregular lamellae within the orthoclase), and quartz (white-grey-dark, clear, some show undulose-composite extinction). Several grains of biotite (brownish-gold, mottled) appear in this view as well. Note the textural relationships among these phases, and the tendency toward development of triple-junction mutual boundaries (well-developed in some instances).

C. Photographed at 12.5X magnification, in transmitted light, using crossed polarizing filters. Printed photograph = 45X magnification. Shows a somewhat coarser-grained portion of the specimen. View features grains of orthoclase (whitish-grey-dark, with well-developed perthitic lamellae), plagioclase (whitish-grey-dark, with some vague twinning discernible), and quartz (white-grey-dark, with appreciable development of undulose-composite-mosaic extinction). A few scattered grains of biotite (gold-orange-brownish) also appear. Note the textural relationships, in particular the general aspect of a mosaic of irregularly intergrown grains, somewhat modified (relatively slightly, here) toward development of triple-junctions and granulated borders. Some manifestations of deformation/recrystallization seem discernible.

D. Photographed at 12.5X magnification, in transmitted light, using crossed polarizing filters. Printed photograph = 45X magnification. In addition to the principal rock-forming minerals plagioclase, orthoclase and quartz, as well as subordinate biotite, this view illustrates a typical occurrence of amphibole (olive-green/gold) which is present in this sample in trace amount.



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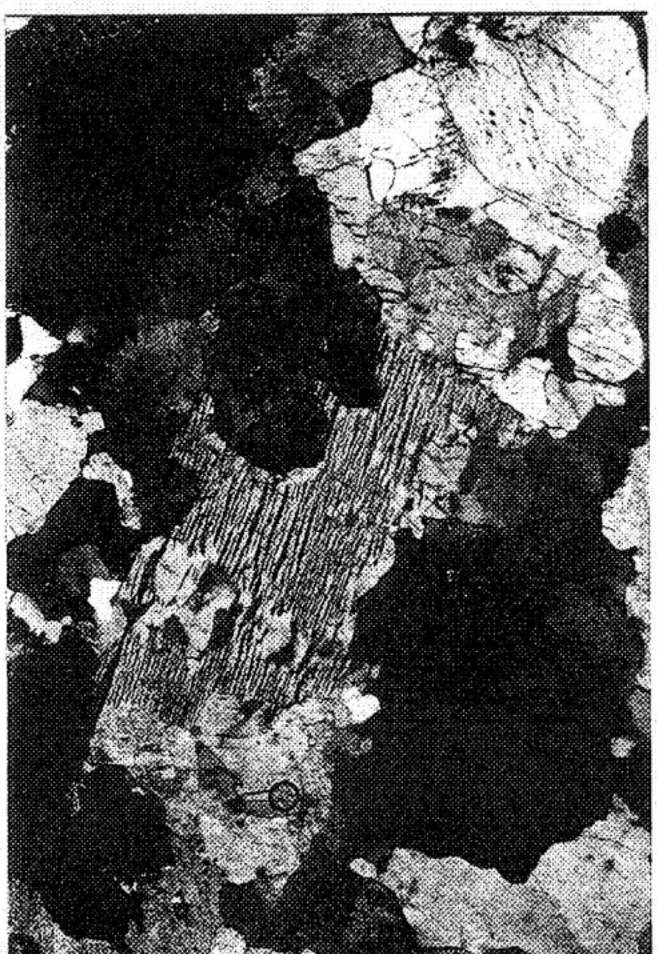

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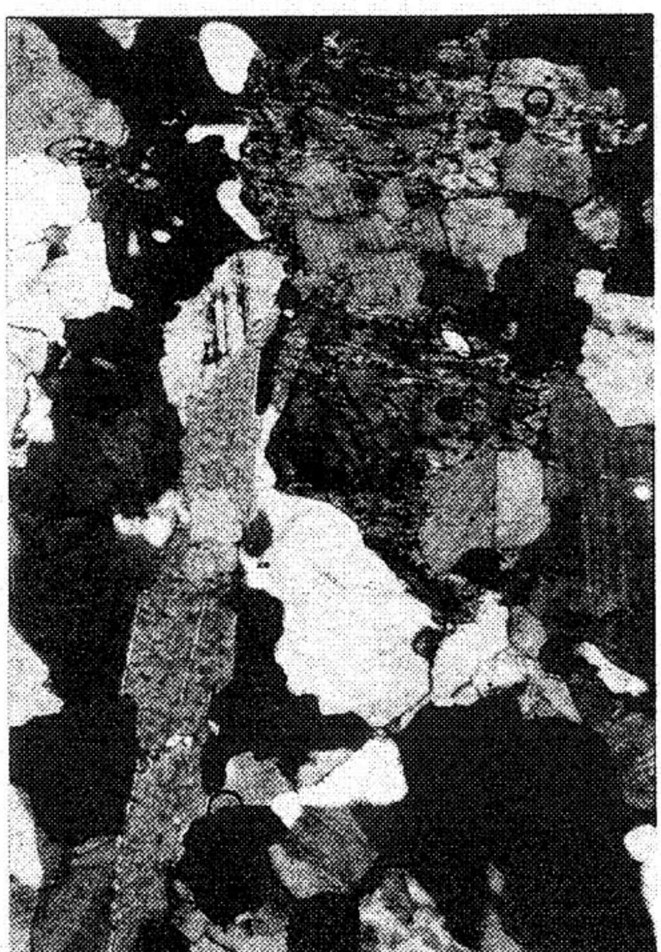

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PLATE 3

92-4-21-1-C

A. Photographed at 1X magnification, in transmitted light, using crossed polarizing filters. Printed photograph = 3.6X magnification. An overview of textural and fabric relationships. Note the generally relatively coarse grain sizes. Mineralogy features plagioclase (pinkish-grey-dark, often exhibiting typical "albite" twinning), microcline (whitish-grey-dark, with some tartan-twinning apparent), and quartz (white-grey-dark, often showing undulose-mosaic extinction). Subordinate biotite (brownish-golden), and trace muscovite (gold-yellow) also are discernible. An overall banded aspect seems apparent; the specimen gives the impression of an originally granitoid rock which has been subsequently subjected to, and modified to some extent by, metamorphism/deformation.

B. Photographed at 12.5X magnification, in transmitted light, using crossed polarizing filters. Printed photograph = 45X magnification. Illustrates the principal rock-forming minerals : plagioclase (grey-dark, with vague to well-developed "albite" twinning, as well as some development of clear albitic rims and/or myrmekitic intergrowths where adjacent to microcline grains); microcline (displays typical tartan-twinning); quartz (white-brownish grey-yellowish, shows vague undulose extinction in this view). Trace amounts of muscovite (golden-yellow) occur along portions of some grain boundaries. A grain of biotite (dark-brownish) is present, adjacent to a microcline, a plagioclase, and a quartz grain. Note the nature of the grain boundaries, in particular the tendency toward the assumption of triple-junctions.

C. Photographed at 12.5X magnification, in transmitted light, using crossed polarizing filters. Printed photograph = 45X magnification. View features several microcline grains (typical tartan-twinning) intergrown with plagioclase (grey, with typical "albite" twinning), and quartz (white-yellowish-grey-dark). The microcline exhibits various degrees of development of relatively coarse perthitic lamellae, particularly at/near grain margins. Fractures within grains here are evidence of significant deformation, while apparent recrystallization, and perhaps the development of the perthite as well, suggest related metamorphism. Note the nature of the grain boundaries in this view.

D. Photographed at 25X magnification, in transmitted light, using crossed polarizing filters. Printed photograph = 90X magnification. View features a grain of plagioclase with a dark core, with discernible "albite" twinning, surrounded by a light grey rim of albitic composition where adjacent to microcline (whitish-grey-dark, with vague to well-developed tartan-twinning). Also evident in this view is another plagioclase grain (grey), a grain of quartz (white), and traces of muscovite (yellow), biotite (brownish) and reddish hematite (?).

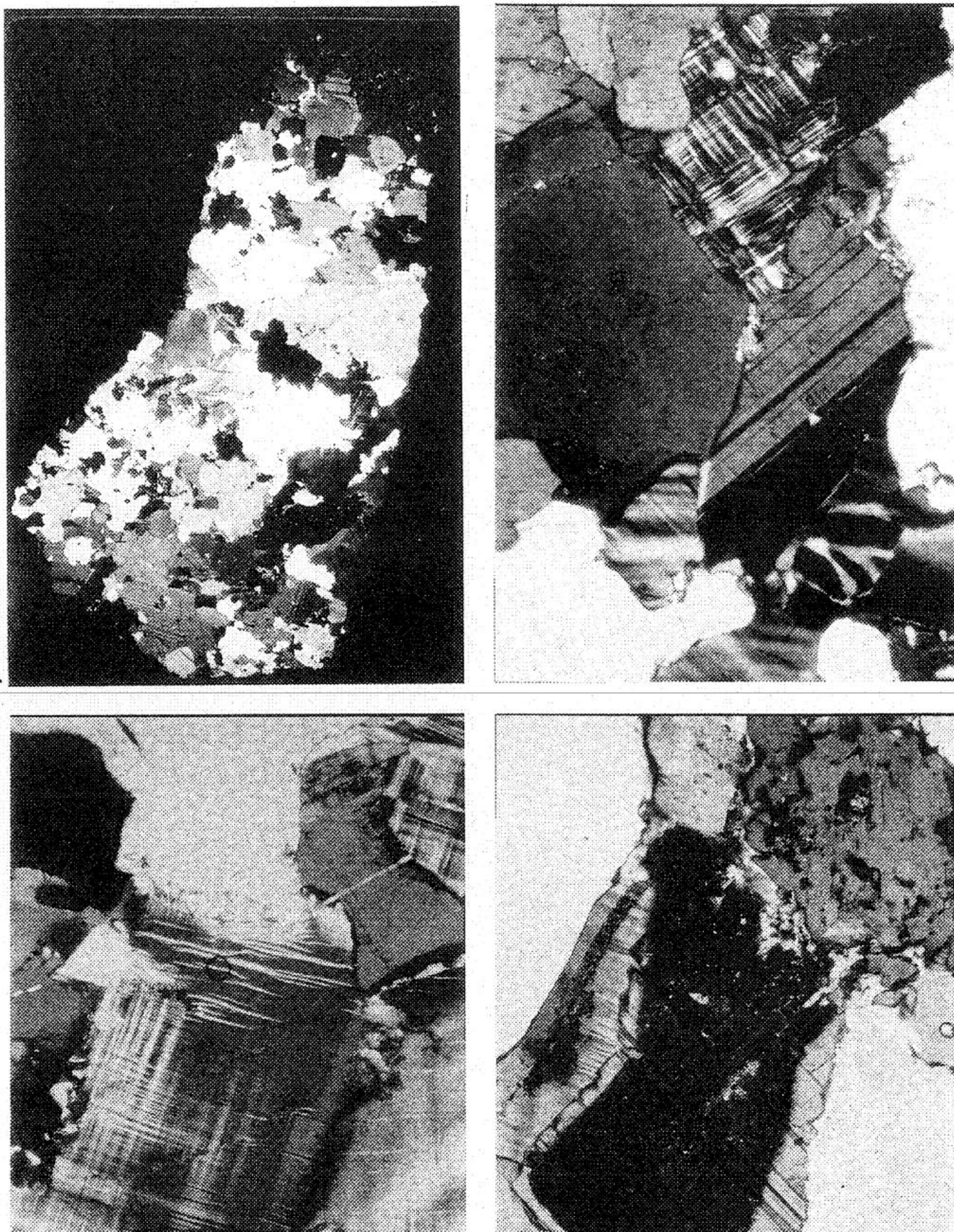

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PLATE 4

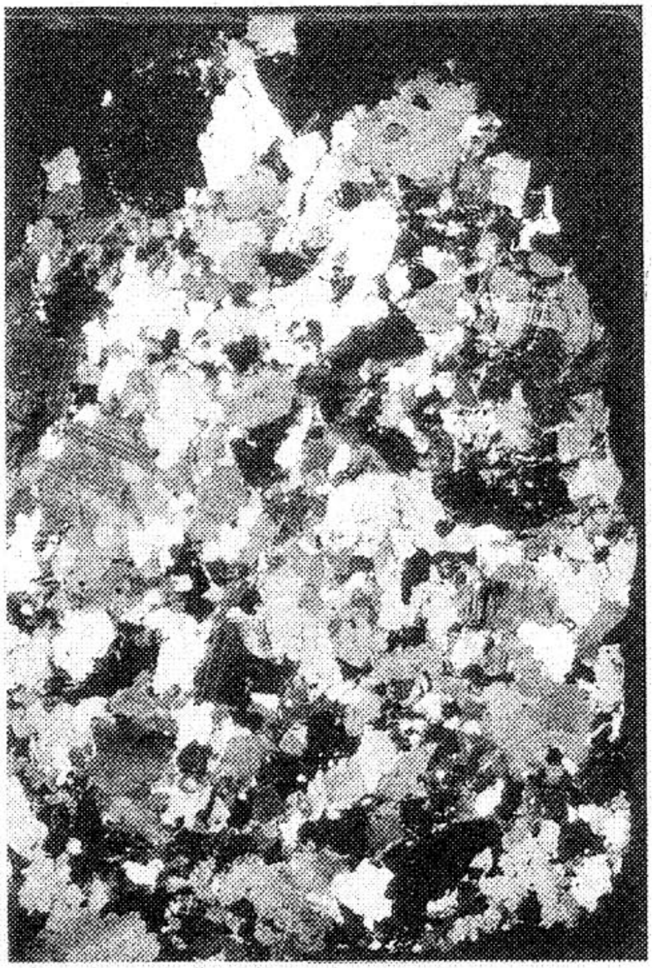
92-4-21-1-D

A. Photographed at 1X magnification, in transmitted light, using crossed polarizing filters. Printed photograph = 3.6X magnification. Overview of fabric and textural relationships. Mineralogy features plagioclase (pinkish-grey-dark, typically exhibiting "albite" twinning), quartz (whitish-yellowish-grey-dark, frequently exhibiting undulose-composite extinction), and microcline (typically tartan-twinned). Subordinate biotite (brownish-reddish-golden), with development of a subparallel alignment of grains, in segregated foliae. The other principal rock-forming minerals- feldspars, quartz- also appear to occur in a somewhat vaguely-defined preferred orientation arrangement of gneissic character. The specimen gives the impression of an originally granitoid texture which has subsequently been subjected to metamorphism/deformation.

B. Photographed at 12.5X magnification, in transmitted light, using crossed polarizing filters. Printed photograph = 45X magnification. Several microcline grains (grey-dark) are shown, with slight development of perthitic intergrowths, apparently principally near the margins of the grains. Several (smaller, grey, with vague "albite" twinning) plagioclase grains also are shown, with development of clear albitic rims where adjacent to microcline. Several quartz grains (white-dark) are intergrown with these feldspars. Note the nature of the grain boundaries, with a tendency for formation of triple-junctions.

C. Photographed at 12.5X magnification, in transmitted light, using crossed polarizing filters. Printed photograph = 45X magnification. Intergrowth of quartz (white-grey-yellowish-dark, showing undulose-composite extinction in some grains), tartan-twinned microcline, "albite" twinned plagioclase, biotite (dark olive-green), and traces of muscovite (yellow-orange). A nicely-twinned plagioclase grain features a partially-developed clear rim of apparently albitic composition, where adjacent to microcline. A small dark grain of microcline near the lower-central portion of the photograph exhibits a zone/band of incipient tartan-twinning which shows appreciable offset, the relationships suggesting that deformational stress and attendant recrystallization may well have been essentially penecontemporaneous. Note the nature of the mutual grain boundaries, with the tendency toward the formation of triple-junction contacts..

D. Photographed at 12.5X magnification, in transmitted light, using crossed polarizing filters. Printed photograph = 45X magnification. An intergrowth of biotite (olive green-brown-dark), tartan-twinned microcline, plagioclase (whitish-grey, one grain shows well-developed "albite" twinning, with a clear albitic rim where adjacent to microcline), and quartz (whitish-grey, with undulose extinction), as well as some muscovite (golden-yellow-red). Note the nature of the grain boundaries, as well as some fracturing within some of the feldspars.



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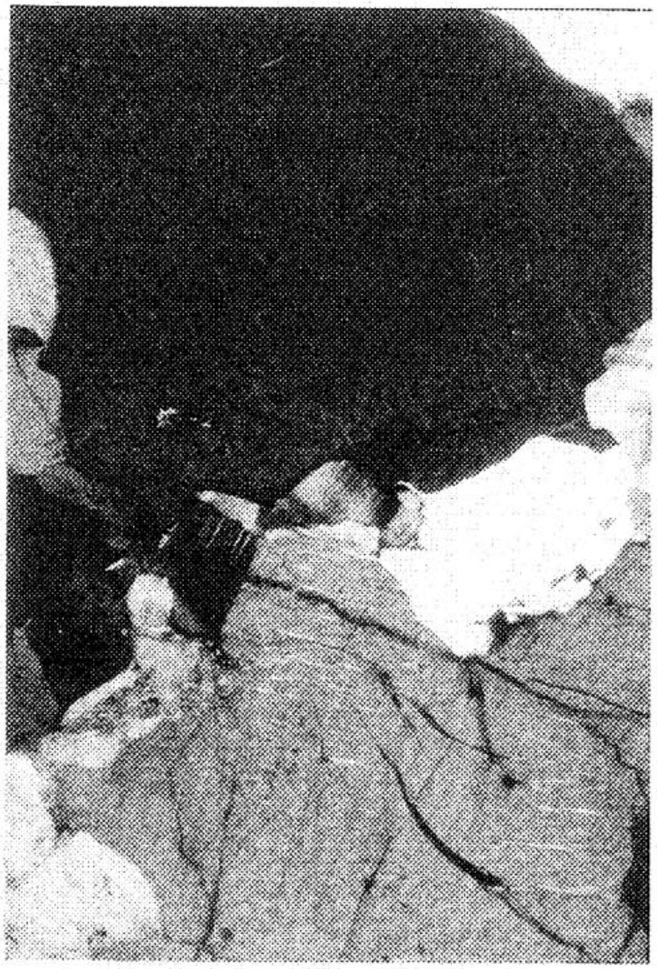

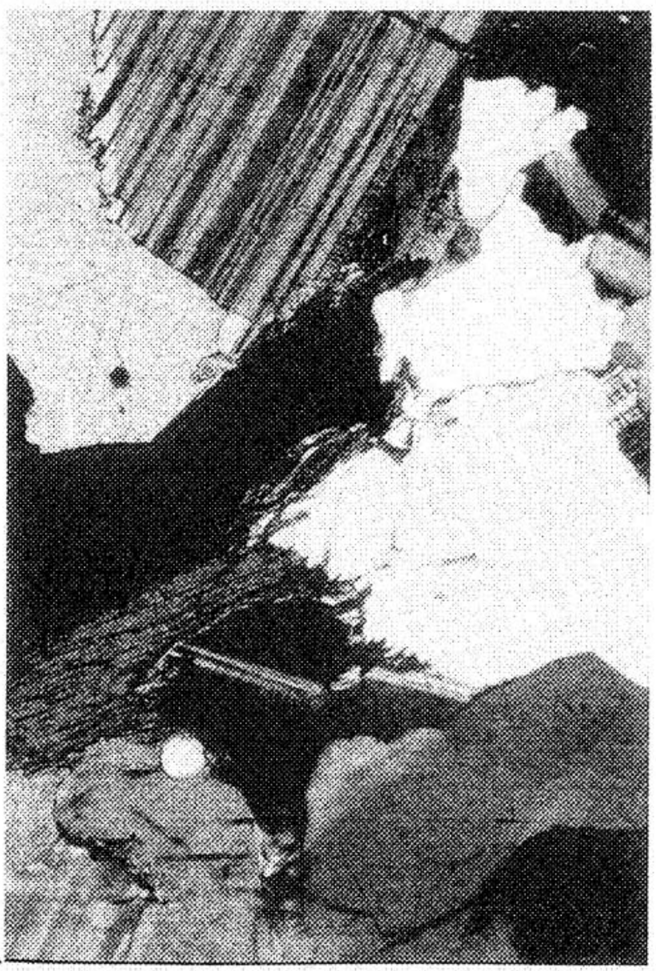

C.