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ISUKASIA AREA—REGIONAL GEOLOGICAL SETTING

(Includes Excursion Guide)

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INTRODUCTION

This brief account of the geology of the Isukasia area (Figure 1) is biased toward the main theme of the itinerary for the area: What has been established about the protoliths of the early Archean rocks of the area—the Isua supracrustal belt and the Amîtsoq gneisses? However, it cannot be stressed too much that central to this is the ability to be able to distinguish the structural, geochemical, and isotopic variations of the rocks when they formed from variations impressed upon them during tectono-metamorphic and metasomatic events of early Archean to mid Proterozoic age. Some aspects of this theme are touched upon here; other aspects are dealt with more fully by *Rosing* (1983).

After a visit by a NATO study group to the area in 1978 (*Bridgwater et al.*, 1979), detailed field work was carried out in the area between 1980 and 1982 supported by GGU, the Royal Society, the Carlsberg Fund, and the Danish NRC. The aim of this work was to investigate the lithological variation and the structural and metamorphic history of the Isua supracrustal belt and adjacent gneisses, so that specialized laboratory investigations could be interpreted on a firm geological basis. This field work was built on the regional mapping by the Kryolit Company of Copenhagen (which first discovered the belt in the mid 1960s), reconnaissance studies by GGU geologists (*Bridgwater and McGregor*, 1974), and subsequent GGU mapping at 1:20,000 scale (*Allaart*, 1976).

The Isua supracrustal belt is a 35-km-long tract up to 4 km wide surrounded by and locally intruded by Amîtsoq gneisses. It consists of complexly folded, highly deformed middle to upper amphibolite facies rocks patchily retrogressed under lowermost amphibolite to greenschist facies conditions. Mafic, ultramafic, felsic, and quartz-rich inclusions occur throughout the known outcrops of the Amîtsoq gneisses and are included under the term Akilia association (*McGregor and Mason*, 1977). The Isua supracrustal belt and the Akilia association probably are derived from a single volcano-sedimentary sequence that was fragmented upon intrusion of the Amîtsoq gneisses (e.g., *Baadsgaard et al.*, 1984). Throughout much of the area the Amîtsoq gneisses are also highly deformed, but in the central gneisses (Figure 1) there is a region of low deformation in which igneous characters of different phases of the Amîtsoq gneisses are locally well preserved.

The area's long and complex tectonometamorphic history of events can be divided into episodes using a combination of dike chronology, isotopic, and petrological studies (Table 1). The earliest dikes, the ca. 3700 Ma Inaluk dikes, intrude the earliest (tonalitic) components of the Amîtsoq gneisses but are themselves cut up by the injection of the younger (granitic and pegmatitic) phases of the Amîtsoq gneisses of the area (*Nutman et al.*, 1983). In areas of low late Archean deformation, strongly deformed early Archean mafic rocks have coarse-grained metamorphic segregations and are cut by virtually undeformed mid-Archean Tarssartôq (Ameralik) dikes (Table 1) devoid of metamorphic segregations. This shows that the area was affected by regional amphibolite facies metamorphism in the early Archean. Late Archean and Proterozoic metamorphic imprints are marked to very strong in the area (*Rosing*, 1983). Much of the early Archean gneiss complex was already highly deformed when the mid-Archean Tarssartôq dikes were intruded. Within the central gneisses the Tarssartôq dikes locally retain igneous textures and mineralogy but elsewhere are recrystallized to form lineated hornblende-amphibolites that in the Isua supracrustal belt and the gneisses to the south locally contain garnet. After regional ductile deformation and amphibolite facies metamorphism the area was cut by pegmatite dikes at ca. 2550 Ma (*Baadsgaard et al.*, 1985). Thus the post-Tarssartôq-dike amphibolite facies metamorphism(s) and associated strong deformation are correlated with deformation and metamorphism in the other parts of the Godthåbsfjord region that were contemporaneous with and perhaps related to intrusion of the Nûk gneisses and younger crustally derived granitoids between ca. 3050 Ma and 2600 Ma (e.g., *Baadsgaard and McGregor*, 1981; *Robertson*, 1983; *McGregor et al.*, 1983). Members of the Proterozoic dike swarms of West Greenland are found in the Isukasia area. They are locally cut by shear zones, in which they develop lowermost amphibolite to greenschist facies assemblages but are otherwise undeformed. Detailed petrological studies and isotopic interpretations have shown that the Isua supracrustal rocks locally recrystallized and severely reacted with hydrous fluids during a Proterozoic amphibolite facies event at ca. 1800 Ma and that kyanite developed in shear zones late in the area's development (*Rosing*, 1983). This means that, added to the complication of nearly total recrystallization in the late Archean, kyanite-bearing assemblages in the Isua supracrustal belt (in the vicinity of Proterozoic shear zones) cannot be used with certainty to determine > 3600 Ma thermal gradients in the supracrustals (see *Boak and Dymek*, 1982). Fluid movement and recrystallization at ca. 1800 Ma is probably associated with major faulting concentrated in the western part of the area (e.g., *Nutman*, 1982). *Kalsbeek et al.* (1980) recorded a ca. 1600 Ma old granite dike that cuts the Isua supracrustal belt.

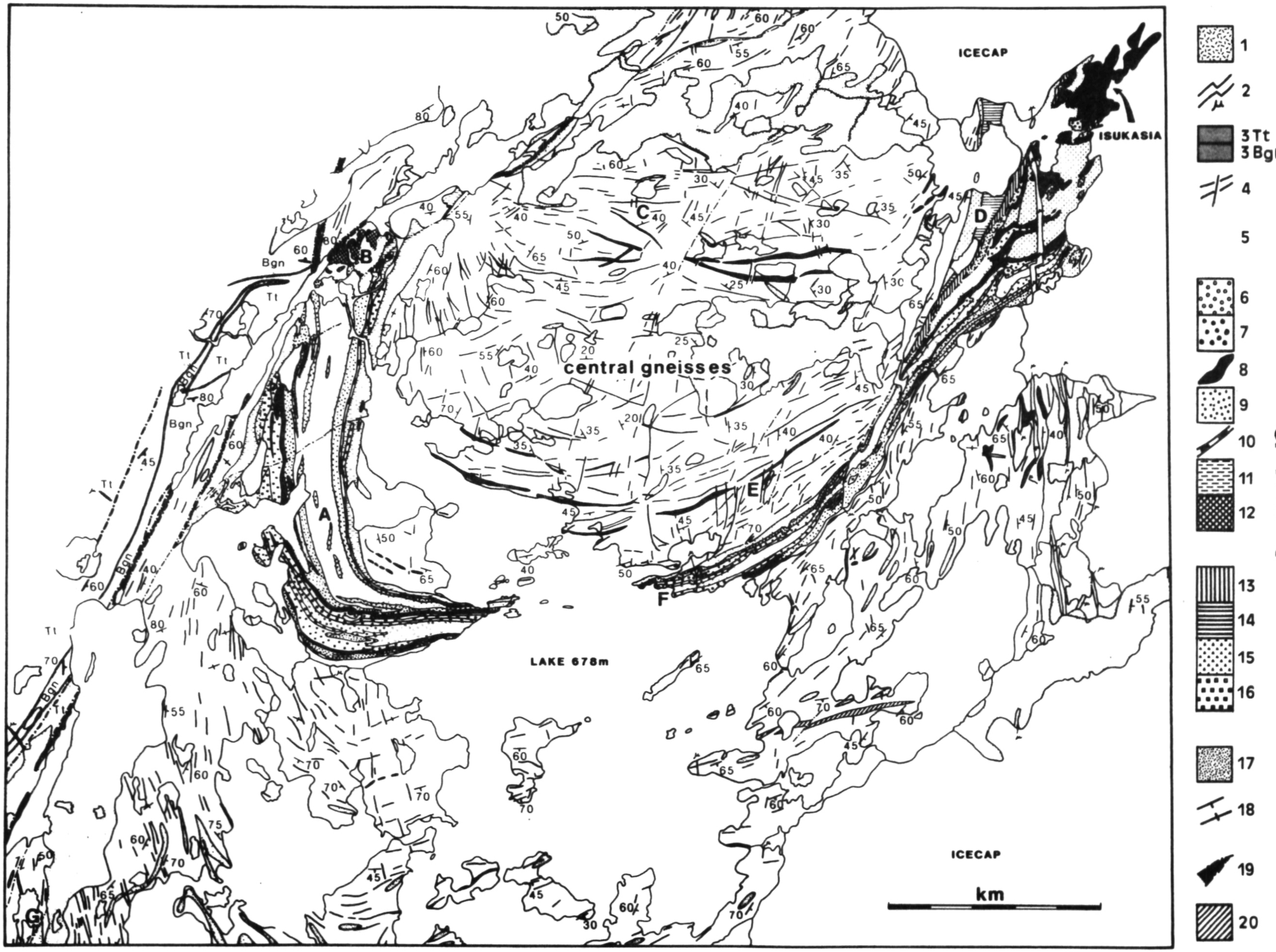

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Table 1. Chronological sequence in the Isukasia area

(10) (youngest) Injection of basic dykes and crustally derived granite sheets. Faulting under lowermost amphibolite facies to greenschist facies conditions, and metasomatism. 1600 to 2100 Ma.

(9) Intrusion of pegmatites; ca. 2550 Ma.

(8) Development of a strong banding with local isoclinal folding (only recognized in the south of the area) followed by linear belts of strong deformation interspersed with southerly plunging folds with wavelengths of up to more than 10 km. Amphibolite facies metamorphism. Local intrusion of granitic-granodioritic sheets. 2600 to 3100 Ma.

(7) Intrusion of Tarssartôq dykes, probably equivalent to the Ameralik dykes in Godthåbsfjord; ca. 3200 Ma.

(6) Deformation giving rise to upright folds.

(5) (c) Intrusion of pegmatic gneisses (ca. 3400 Ma) and thin trondhjemitic sheets. (b) Intercalation of supracrustal and gneiss units. (a) Deformation to produce a strong banding, most important in the south. It is possible that a, b, and c were contemporaneous.

(4) Intrusion of the white gneisses; 3650–3600 Ma.

(3) Intrusion of the Inaluk dikes.

(2) Intrusion of the grey gneisses. This group probably includes early thin tonalitic sheets discussed in *Nutman et al.* (1983). Isoclinal folding of supracrustal rocks (1) may have occurred during intrusion of the grey gneisses; 3750–3700 Ma.

(1) (oldest) Formation of the Isua and Akilia association supracrustal rocks and intrusion of basic and ultramafic rocks into them; ca. 3800 Ma.

ISUA SUPRACRUSTAL BELT

The Isua supracrustal belt (Figure 1) is the largest fragment of ca. 3800 Ma sedimentary and volcanic rocks known. As it comprises the oldest rocks so far discovered, it has attracted considerable interest and detailed research on important aspects of crustal evolution. Because of the antiquity of these rocks and their significance to the study of the early crust, it is tempting to present information from them as giving definitive answers. However, the strong modification of these rocks since their formation means that they are not nearly so well preserved as somewhat younger sequences, such as those in Western Australia. Indisputable sedimentary structures are only preserved in exceptional exposures and are in all cases markedly deformed. The most reliable age of deposition of the Isua supracrustal rocks is 3812^{+21}_{-14} Ma (*Baadsgaard et al.*, 1984; U/Pb concordia intercept for zircons from sediment derived from acid volcanic rocks). The Rb-Sr, Pb-Pb, and Sm-Nd systems give ages of over 3600 Ma but are disturbed by several periods of Archean and Proterozoic metamorphism (*Rosing*, 1983). A summary of early studies of the Isua supracrustal belt is given by *Nutman et al.* (1984).

Early studies showed that the belt consists of layered supracrustal units of detrital, chemical sedimentary, and volcanic origin interdigitated with Mg-Al-rich, massive chlorite leucoamphibolites (the garbenschiefer units), and ultramafic units (dunites, peridotites, and their hydrated and carbonated equivalents). A coherent

Fig. 1. Geological sketchmap of the Isukasia area. Localities of A–G are described in the text. (1) Undifferentiated cover: (2) Proterozoic dyke, (3) Tt-Mid Archean Taserssuaq tonalite, 3 Bgn Archean banded gneisses; (4) Tarssartôq dykes; (5) Amîtsoq gneisses; (6) A6 felsic formation; (7) A5 calc-silicate formation; (8) A4 upper banded iron formation; (9) A3 variegated schist formation; (10) A2 lower banded iron formation; (11) A1 amphibolite formation; (12) Undifferentiated A3–A1; (13) B2 mica schist formation; (14) B1 felsic formation; (15) garbenschiefer amphibolite; (16) ultramafic rocks; (17) Akilia association inclusions; (18) foliation/compositional layering; (19) fault; (20) late Archean (2550 Ma) pegmatite.

stratigraphy (Sequence A) has been established throughout the length of the Isua supracrustal belt and is shown to be repeated about isoclinal folds (*Nutman et al.*, 1984). It is impossible to estimate original thicknesses of individual units because of strong deformation. Excluding units of garbenschiefer and ultramafic rocks, the supracrustal sequences total less than 1 km. The garbenschiefer and ultramafic units transgress lithological divisions in the supracrustal sequence, and the garbenschiefer contains inclusions or screens of metasedimentary rocks. Both these lithologies are interpreted as intrusions into a volcano-sedimentary sequence. Sequence A is divided into formations designated by the dominance at different stratigraphic levels of the sequence by different lithologies: (in ascending order) Al amphibolite formation, A2 lower banded iron formation, A3 variegated schist formation, A4 upper banded iron formation, A5 calc-silicate formation, and A6 felsic formation. Likewise, Sequence B (restricted to the eastern part of the belt) is divided into: (in ascending order) Bl felsic formation and B2 mica schist formation (Figure 2). The way-up of these sequences is based on facing determinations on graded layers of felsic metasediment. A full description of the stratigraphy is given by *Nutman et al.* (1984).

The Isua supracrustal sequences (and Akilia association units of the area) are dominated by interlayered sediments of diverse parentage, and altered, banded basic rocks of igneous parentage (Figure 2; Table 2). Unaltered igneous rocks are rare apart from those that are clearly of intrusive origin. Supracrustal units show marked lateral variation in their lithotype and chemical composition. All terriginous sediments are interpreted as derived from volcanic sources. There is no field or isotopic evidence that older sialic basement or emerging granite plutons contributed to the clastic material. The felsic rocks were probably derived from dacites that underwent alteration (possibly subaerial weathering) at

Table 2. Representative analyses Isukasia area early Archean supracrustal rocks

Sample	225996	292107	158497	67690	58526c	167655	171756	175554	117988a
SiO_2	50.01	87.19	13.74	57.34	66.56	60.92	45.58	49.85	38.84
TiO_2	1.17	0.04	n.d.	0.39	0.51	0.67	0.22	0.31	0.03
Al_2O_3	13.76	n.d.	0.05	16.59	16.34	15.45	15.33	17.08	0.38
Fe_2O_3		10.87	1.18	10.97	0.77	2.19	2.01	0.16	1.73
FeO	15.34		4.07	7.55	3.16	4.29	7.31	9.47	6.00
MnO	0.26	0.11	0.59	0.40	0.07	0.14	0.18	0.25	0.12
MgO	5.52	0.76	16.80	2.64	1.21	2.46	16.30	10.40	48.90
CaO	10.21	0.34	28.22	0.85	2.96	6.08	7.83	7.71	0.09
Na_2O	1.94	0.01	n.d.	0.29	1.63	2.43	0.78	1.36	n.d.
K_2O	0.36	0.10	0.01	1.37	5.86	2.72	0.07	0.10	n.d.
LOI	0.83	2.50	0.22	2.20	0.94	0.92	4.65	1.88	3.27
CO_2			35.06		0.65	1.16			
Total	99.50	99.40	100.11	100.67	100.84	99.52	100.30	98.59	99.45
Rb	1	2	n.d.	65	145	120	n.d.	4	n.d.
Sr	90	n.d.	23	30	75	55	55	61	n.d.
Ba	34	6	60	84	430	182	21	n.d.	27
Y	27	2	9		5		10	16	n.d.
Zr			4	113	164	175	18	28	n.d.
Pb			10		26		1	9	1
Th				1					
Cu			n.d.	38	n.d.	55	n.d.	16	n.d.
V	274	9		98		73		137	
Ni	29	35	6	205	23	85	540	160	3975
Cr	55	28	20	500	65	155	1090	279	1040

225996 - banded amphibolite, upper part of amphibolite formation; 292107 - silica-rich banded iron formation, western part of the upper banded iron formation; 158497 - carbonate rock with calc-silicate layers, upper part of the calc-silicate formation; 167690 - garnet-mica schist, upper part of the mica schist formation; 158526c - layered felsic rock, felsic formation of sequence A; 167655 - layered felsic rock, felsic formation of sequence B; 171756 and 175554 - mafic and felsic garbenschiefer amphibolite unit, respectively; 117988a - metadunite. All these rocks come from the Isua supracrustal belt.

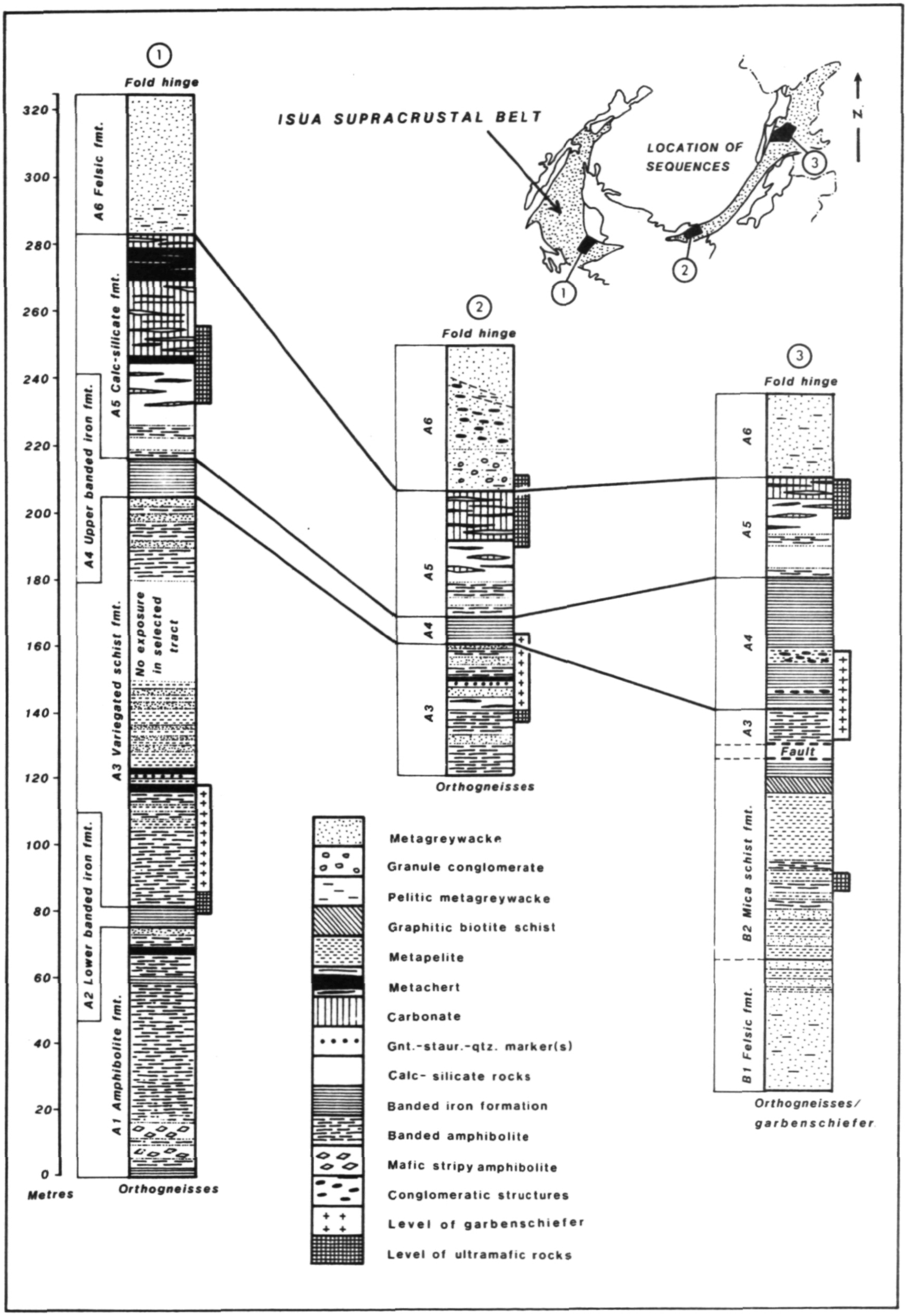

Fig. 2. Schematic stratigraphy for the Isua supracrustal belt.

the time of deposition. Layered amphibolites are interpreted as derived from basic tuffs or from altered basalt and are predominantly of high-Fe tholeiite affinity. Mica schists are interpreted as derived from either weathered basic rocks or from basic tuffs that interacted with water at the time of deposition. The presence of graded bedding and chemical sediments such as banded iron formation and carbonates throughout the succession favors that at least some deposition was subaqueous. Water depths are unknown, but features such as lateral facies changes and possible flat pebble conglomerate units favor shallow water conditions with occasional shoals. The intimate association of chemical sediments with terriginous material occurs on all scales down to that of individual beds. Bouma-type layering preserved in some of the felsic sediments shows that deposition of some of them was from turbidite flows.

The presently favored model for the Isua depositional environment (*Nutman et al.*, 1984), is of a predominantly submarine volcanic area. There is no evidence that the sequence formed on a basement of older sialic crust. Water depths for a least part of the time were shallow. The topography was subdued apart from volcanic centers. Intermittent volcanic activity and associated instability produced clastic sediments, which alternate and in some cases coincide with deposition of chemical sediments.

AMÎTSOQ GNEISSES

Amîtsoq gneisses envelop the Isua supracrustal belt (e.g., *Bridgwater and McGregor*, 1974; *Nutman et al.*, 1983). Deformation in the gneisses is heterogeneous, such that they range from a weakly deformed, polyphase, sheeted meta-igneous complex to strongly banded or schlieric gneisses in which individual phases can no longer be identified with certainty (similar banded gneisses form at least 80% of the early Archean outcrop in West Greenland). In parts of the Isukasia area the regional early tonalitic gneisses and granitic gneiss sheets are virtually undeformed and preserve their intrusive characters. These are the best preserved very early Archean plutonic rocks known.

Published isotopic studies of Amîtsoq gneisses from the Isukasia area are mostly based on the highly deformed, generally well banded lithologies close to the Isua supracrustal belt. Using the Pb-Pb and Rb-Sr systems, ages of ca. 3750 to 3600 Ma have been obtained from them with crustal residence prior to 3600 Ma of not more than 200 m.y. suggested (e.g., *Moorbath et al.*, 1972). Recent Sm-Nd, U-Pb, and Rb-Sr studies based on suites comprising individual phases of Amîtsoq gneisses (*Hamilton et al.*,1983; *Baadsgaard et al.*, 1983 and personal communication, 1982, 1984) do not give evidence that any phase of the gneisses is older than the Isua supracrustal belt. They suggest that the early grey tonalitic phases are ca. 3750 Ma old, the intrusive white granite sheets are ca. 3650 Ma old, and that a younger group of pegmatites separated in the field are ca. 3400 Ma old. Thus the sequence of intrusion of different phases of Amîtsoq gneiss spanned as long as 400 Ma (Table 1).

The least deformed Amîtsoq gneisses occur in the core of the central gneisses (Figure 1), which is the best area for investigating these rocks. Even the best preserved of the gneisses have been subject to some recrystallization and isotopic disturbance during the late Archean and Proterozoic events (P.N. Taylor, unpublished Pb-Pb data; *Baadsgaard*, 1983; and unpublished Rb-Sr, Pb-Pb, Th-Pb, and U-Pb data). The two main groups of gneiss (older, tonalitic grey gneisses and younger, granitic white gneisses) are separated in time by intrusion of mafic dikes (the Inaluk dikes; Table 1). The chronology given in Table 1 is probably applicable for the generally much more deformed gneisses south of the Isua supracrustal belt, because in augen of low deformation there, grey gneisses are cut by Inaluk dikes and then by white gneisses (*Nutman*, 1982).

The grey gneisses are tonalites apart from rare granodiorites and quartz diorites (Figure 3; Table 3). They form about 70% of the central gneisses. They are polyphase, consisting of rafts of mafic tonalite occurring in more voluminous pale tonalite. A plausible origin for the protoliths of the grey gneisses would be partial melting (at depth) of basic rocks like those in the Isua supracrustal belt and Akilia association. Where least deformed they have a schlieric biotite banding and are plagioclase phyric. Hornblende, which is present only in more mafic units, lies within the schlieric biotite fabric and coexists with biotite. Sericitization of plagioclase, rimming of hornblende by either pale amphibole or fine-grained biotite, local breakdown of biotite to white mica, and also overgrowths of epidote and zoisite are widespread. These features are attributed to events ranging in age up to the mid-Proterozoic. Locally, grey gneisses cut by Inaluk dikes contain inclusions of Akilia association (*McGregor and Mason*, 1977) or Isua-type supracrustal rocks (*Nutman et al.*, 1983). Sheets of tonalitic gneisses intrude the Isua supracrustal belt (*Moorbath et al.*, 1977) and other supracrustal units in the area. These sheets are interpreted as equivalent to the regional grey gneisses. Grey gneiss sheets are sparsely distributed through most of the Isua supracrustal belt and other large supracrustal units in the area, even where they lie adjacent to units dominated by grey gneisses. Contacts of supracrustal units not complicated by

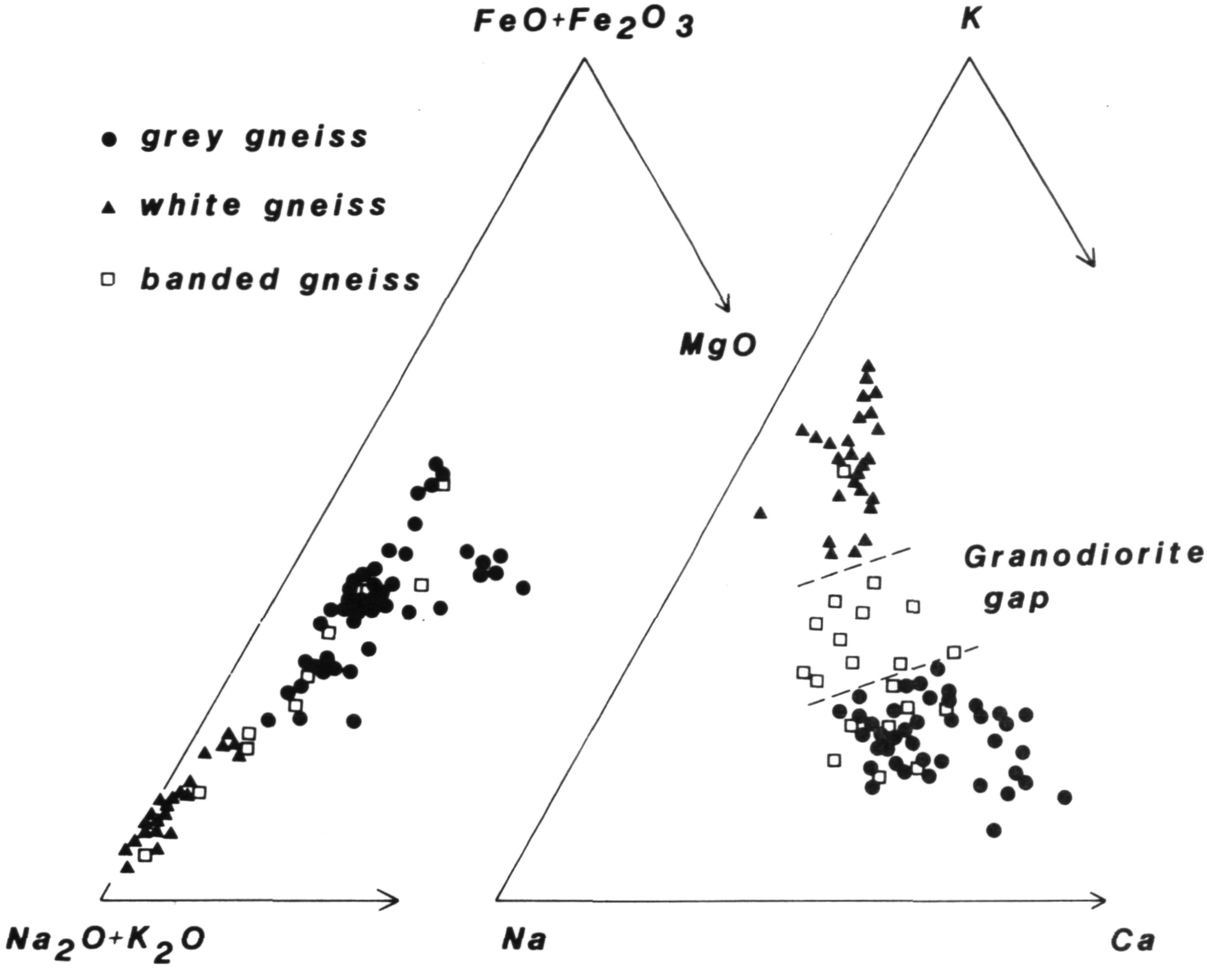

Fig. 3. Compositional variation of the Amîtsoq gneisses in the Isukasia area.

intrusion of ca. 3400 Ma pegmatites are sharp, with biotite banding in the grey gneisses parallel to the contacts. These contacts are interpreted as early to middle Archean faults, possibly rotated thrusts (*Nutman*, 1984).

The Inaluk dikes are sparsely distributed and intrude the grey gneisses. Inaluk dikes have not been found in the major supracrustal units such as the Isua supracrustal belt, but at two localities agmatized mafic amphibolite, probably of supracrustal origin, is cut by them. Inaluk dikes (Table 3) are fine-grained, mafic, biotite- and hornblende-bearing, dioritic intrusions normally less than 2 m wide, that in the least deformed parts of the central gneisses are steeply inclined. They commonly have irregular, cuspate margins, suggesting that they were plutonic dikes. There are several bands of coarse-grained, clinopyroxene-bearing mafic amphibolite that are up to 100 m wide and are generally heavily agmatized by pale gneisses, that may be intra-Amîtsoq mafic-ultramafic intrusions, perhaps related to the Inaluk dikes. The Inaluk dikes are interpreted as being derived from fractionated basic melts of mantle origin.

The white gneisses are a polyphase swarm of anastomosing sheets generally less than 25 m thick that cut the grey gneisses. In the northeast of the central gneisses they coalesce to form a single lens that underlies about 10 km^2, whose center is devoid of grey gneiss inclusions. In contrast, white gneisses are particularly scarce in the northeast of the central gneisses. Overall, the white gneisses form about 30% of the central gneisses and a lower percentage of the gneisses south of the Isua supracrustal belt. The white gneisses are medium to coarse biotite, muscovite granites that grade into potassic granodiorite locally (Figure 3; Table 3). There are some pegmatite veins that preceded intrusion of the large volumes of granitic white gneisses, and pegmatite also occurs as selvages to granitic white gneiss sheets. Biotite is less than 10% modal and forms a crude gneissosity, accentuated in some cases by elongate biotite-rich smears up to 5 mm thick.

Table 3. Representative analyses of Amîtsoq gneisses

Sample	237000	236991	236966	236955	236949	229472	292192	236961	236928
SiO_2	64.12	68.02	71.72	72.64	47.45	74.16	67.10	69.31	71.70
TiO_2	0.47	0.41	0.27	0.17	0.95	0.01	0.39	0.35	0.24
Al_2O_3	14.76	15.22	14.60	14.40	11.31	14.25	15.94	15.50	14.40
Fe_2O_3	2.22	1.29	0.40	0.25	3.42	n.d.	0.80	0.67	0.42
FeO	5.12	2.66	1.46	0.99	8.90	0.44	2.69	3.01	2.36
MnO	0.08	0.04	0.03	0.02	0.23	0.01	0.06	0.06	0.04
MgO	1.25	1.17	0.45	0.25	10.64	0.01	0.99	0.75	2.81
CaO	4.51	3.66	1.86	1.45	9.60	0.85	2.52	2.98	2.36
Na_2O	3.77	4.62	4.02	3.94	1.65	2.24	4.65	4.87	4.34
K_2O	1.92	1.41	3.74	4.73	2.77	6.30	2.88	1.47	2.21
LOI	0.92	0.71	0.71	0.54	1.26	0.15	0.86		
CO_2									
P_2O_5	0.21	0.14	0.08	0.06	0.51	0.1	0.13	0.11	0.07
Total	99.35	99.35	99.34	99.44	98.69	98.42	99.01	99.08	100.88
Rb	64	87	141	116	69	225	154	192	119
Sr	267	263	224	118	189	70	340	191	195
Ba	334	199	626	567	2054	270	551		
Y	26	20	6	7	28	n.d.	10	12	9
Zr	158	169	212	151	89	18	160	167	129
Pb	12	17	27	28	11	110	31	18	24
Th	1	4	16	18	6	4	5	5	11
Cu	29	16	6	2	26	n.d.		8	
V	46	35	20	12	223	1	33		
Ni	6	2	n.d.	n.d.	126	2	10		
Cr	15	14	4	3	598	7	21		
La	19.2	16.9	45.2	39.6	37.2				
Ce	40.0	38.6	91.7	56.7	83.7				
Nd			20.1	16.2					
Sm	4.92	4.24	3.64	3.12	10.20				
Eu	1.65	0.926	0.728	0.580	2.73				
Gd									
Tb	0.754	0.436	0.251	0.179	0.844				
Dy									
Er									
Yb	1.80	1.33	0.205	0.336	1.400				
Lu	0.242	0.187	0.092		0.200				
Hf	4.12	4.35	5.63	4.13	3.61				

237000 - Mafic grey gneiss, southern central gneisses; 236991 - typical grey gneiss, southern central gneisses; 236966 and 236955 - typical white gneisses, northern central gneisses; 236949 - Inaluk dike, northern central gneisses; 229472 - banded gneiss, ca. 5 km south of the Isua supracrustal belt; Grey gneiss inclusions in white gneisses, 236961 - distinct margins; 236928 - blurred margins

In the core of the central gneisses (where deformation is least), the white gneisses are predominantly gently inclined and commonly break up the grey gneisses into lozenge-shaped rafts. It is likely that in this low deformation area the white gneiss sheets have not been significantly rotated since their intrusion. Inaluk dikes are commonly displaced laterally across white gneiss sheets, and where least deformed, a schlieric flow fabric is preserved in the white gneisses that is not seen in the grey gneisses. The characteristics of the white gneisses described above suggest that they were intruded at the present level of exposure as inclined sheets (dipping less than 40°), synchronous with lateral displacements. Commonly grey-white gneiss contacts are slightly blurred with a thin biotite-rich selvage. Grey gneisses that occur as inclusions in or close to very large units of white gneisses are coarsely recrystallized. In extreme cases, inclusions take on a ghost-like appearance. Some chemical changes to the grey gneisses during intrusion of the white gneisses include LREE enrichment, HREE depletion, and enrichment of Pb, Th, and Rb (Nutman and Bridgwater, unpublished data). The composition of the white gneisses shows that they could be early stage, low temperature melts. The host of the white gneisses is ~80% grey gneisses and ~20% supracrustal rocks consisting of amphibolites with subordinate ultramafic rocks, felsic gneisses, mica schists, metaquartzites, and banded iron formation. Thus a possible origin for the white gneisses is partial melting (at depth) of predominantly grey gneisses, with a minor contribution from supracrustal felsic rocks and mica schists.

The pegmatitic gneisses are leucocratic, muscovite- and biotite-bearing quartzofeldspathic sheets ranging from granite to quartz-albitite in composition. Although generally coarse grained, some sheets contain garnetiferous micrograinite that grades into the more typical pegmatite material. They are a volumetrically unimportant component of the gneiss complex and generally occur as sheets less than a few meters thick. Thicker units occur along some lithological boundaries, such as the borders of the Isua supracrustal belt, where they commonly have a flaser texture. It is possible that the pegmatitic gneisses were intruded during a period of deformation, with movement concentrated into certain zones, such as the boundaries of supracrustal units (*Nutman*, 1984). The pegmatitic gneisses may have originated from granitic magma, which interacted with alkali-bearing fluid and country rocks during crystallization, to give rise to the Na-enrichment trend. Rb-Sr isotopic studies of separate units of pegmatitic gneisses from the Isua supracrustal belt (*Baadsgaard et al.,* in preparation) show that they have the same age within error (ca. 3400 Ma) but markedly different initial $^{87}Sr/^{86}Sr$ values (in one case, more than 0.8!).

Banded gneisses with a well-developed biotite foliation are the dominant gneiss lithology adjacent to and south of the Isua supracrustal belt. They are generally finer grained than their less deformed white and grey gneiss equivalents in the central gneisses, probably due to their greater degree of deformation during recrystallization under amphibolite facies. The banding of these gneisses comes from two main sources. First, a large scale (generally over 50 mm) banding is caused by intense deformation that has reduced the grey and white components to more or less parallel bands, with obliteration of intrusive relations. Second, there is a smaller scale banding and lensoid structure in the grey gneiss components. This is a partial separation into biotite-rich melanosome and quartzofeldspathic leucosome, probably the result of recrystallization under upper amphibolite facies metamorphism.

Strongly banded gneisses from early studies in the area (mostly Bridgwater, unpublished) have a wider spread of composition than the grey gneiss samples from areas of lower deformation (Figure 3), and form a "calc alkali" tonalite-granite variation trend (see also *McGregor*, 1979). There are now more than 60 samples of single-phase grey and white gneisses from the area. None of these samples fall in the 'granodiorite gap' of Figure 3, where many banded gneisses plot. This suggests that the variation trend of the banded gneisses could be due to mechanical mixing of grey gneisses veined by white gneisses and by metamorphic segregation, during early and late Archean amphibolite facies metamorphism. These processes allow samples of a few kilograms to contain several bands of grey and white gneisses or to be heterogeneous due to some degree of segregation into granitic leucosome and mafic melanosome.

The early Archean gneiss complex of the Isukasia area demonstrates that the oldest known continental crust is of polyphase, polygenetic igneous origin. The grey gneisses show that at the start of the geological record the juvenile 'continental' crust was of typical Archean common tonalite composition. It is possible that the white gneisses formed by partial melting of sialic crust dominated by rocks resembling the presently exposed grey gneisses. High heat production from radioactive decay in the early Archean, tectonic uplift of crustal segments, or increase in H_2O content in the source region are all possible contributary factors to initiate partial melting deep in the crust, generating the white gneisses. The white gneisses are ca. 100 Ma younger than the grey gneisses. They are probably products of reworking of early Archean sialic crust by partial melting. The somewhat younger pegmatitic gneisses probably record further purging upwards of low temperature melting fractions of the crust, and their wide variation in composition is attributed to modification of granitic melts by interaction with their country rocks and with fluids. The grey gneisses, white gneisses, and pegmatitic gneisses were intruded over a span of ca. 400 Ma. There is no compelling evidence that their formation should be grouped together as a single protracted 'super-event.'

ISUKASIA AREA LOCALITY DESCRIPTIONS

The amount that can be seen in the Isukasia area in mid-June is highly dependent on how much winter snow is left lying. For this reason, several localities of interest that are on NW-facing slopes are omitted since there is almost 100% chance that they are under snowdrifts. Furthermore, restrictions are imposed by the landing requirements of the large helicopter used on this excursion. Several localities demonstrate rocks of the Isua supracrustal belt. The Amîtsoq gneisses are shown where they are virtually undeformed and then traced out into areas where they are progressively modified by early and late Archean tectonometamorphic events. Rocks very strongly affected by Proterozoic metasomatism close to the Ataneq fault are shown, and Akilia association rocks are visited.

Stop A (short stop)

The main lithology at this stop is the garbenschiefer amphibolite unit—a high Al-Mg metagabbro that intrudes the interlayered metavolcanics and metasediments of the Isua supracrustal belt. The garbenschiefer here is a chlorite-bearing rock with a moderately well-defined S fabric. Within it are lenses and pods of rusty weathering garnet-biotite schist. These are probably modified inclusions of pelite. Cutting these rocks is a superficially well-preserved Tarssartôq dike. It is virtually undeformed and has large plagioclase megacrysts concentrated near its eastern side. However, petrographic, geochemical, and isotopic data (*Wagner*, 1982) show the dike to be recrystallized and altered. Very little plagioclase is left in the groundmass of the dike, but scapolite is abundant, with associated strong enrichment of the dike in Cl. The Rb-Sr and Pb-Pb isotopic characters of the dike are somewhat different in two traverses across it, less than 100 m apart (*Wagner*, 1982). The data point to recrystallization and alteration of the dike in the Proterozoic. This story of Proterozoic alteration has been well documented in this part of the Isua supracrustal belt by field, petrographic, and isotopic studies of the garbenschiefer unit by *Rosing* (1983). Looking east from this locality, the western part of the central gneisses can be seen. Note the large, warped, in places slightly podded, Tarssartôq dikes.

Stop B (short stop)

This stop shows strongly altered rocks just above the southeasterly-dipping mid-Proterozoic Ataneq fault. Basic rocks are transformed into (locally crenulated) chlorite-amphibole-albite schists. Alteration is so intense that it can be hard to distinguish between the garbenschiefer unit, banded supracrustal amphibolites, and Tarssartôq dikes. An ultramafic unit in the vicinity has been altered in places to soapstone. Carbonate-bearing veins are common. The strong alteration here is correlated with movement on the Ataneq fault. Alteration of this type (although generally not so severe) is noted throughout the area. For example, the banded iron formation outcrop at Isukasia and the rocks immediately to the southwest overlie a Proterozoic fault of lesser displacement than the Ataneq fault. Retrogression under uppermost greenschist facies, carbonate, and quartz-veining are common close to these faults. Even where faulting is not apparent (e.g., Stop A), partial retrogression under lowest amphibolite to uppermost greenschist facies is common, with associated changes of trace element and isotopic chemistry.

Stop C (long stop)

At this locality in the northern part of the central gneisses we see some of the best preserved Amîtsoq gneisses. Polyphase (3750–3700 Ma), grey metatonalites with a gneissose fabric are cut through by numerous sheets of (3650–3600 Ma) metagranite and associated pegmatite (white gneisses), which have shallow to moderate inclinations to the north. Steeply dipping Inaluk dikes, cut by the white granite and pegmatite sheets occur. Due to the low degree of deformation in the area since ca. 3600 Ma, intrusive relations between the Amîtsoq phases are well preserved and local interaction between the grey tonalites and the white granites can be seen. The gneisses in this general area are virtually free of supracrustal inclusions. Tarssartôq (Ameralik) dikes in this area are undeformed and retain igneous textures.

Stop D (long stop)

This stop is a traverse over sequence B of the Isua supracrustal belt (Figure 1), from its contact with the central gneisses in the west to its contact with sequence A in the east. A garbenschiefer amphibolite unit occurs at the western edge of the felsic formation. Sequence B, particularly its western margin, is intruded by pegmatitic sheets. Some of these have been dated at ca. 3400 Ma (Baadsgaard et al., in preparation). Except for these sheets, the contact between the central gneisses and sequence B is sharp and cuts across the stratigraphy of the sequence (Figure 1); grey gneiss sheets in the supracrustal rocks are rare.

B1 felsic formation consists of generally fine-grained felsic rocks layered on a 20–100 mm scale. Graded beds are locally preserved. Garnetiferous mica schist units occur throughout the formation, increasing in frequency eastwards. To the east, B2 mica schist formation outcrops, forming a scarp. Predominant are chlorite + biotite + garnet + quartz schists that locally contain staurolite, kyanite, carbonate, graphite, and tourmaline. The schists have a faint, but regular layering on all scales. Interlayered are some units of magnetite banded iron formation, graphite schist, amphibolite, and ultramafic schist.

The contact between sequences A and B is a fault with the same orientation as the Ataneq fault in the west of the area. Alteration is common in its vicinity. For example, rocks of B2 mica schist formation show chloritization of garnet and development of a crenulated schistosity of muscovite locally overgrown by tourmaline.

Stop E (short stop)

This locality shows somewhat more deformed Amîtsoq gneisses than at locality (C). Strain is mostly early Archean, but with an added component since the Tarssartôq dikes were intruded. Note the 'steepening-up' of layering in the gneisses and rotation toward parallelism of originally strongly discordant Inaluk dikes. Clinopyroxenic amphibolite with subordinate banded grey amphibolite occurs as a train of inclusions, enshrouded in pegmatitic gneiss. These amphibolites are probably of supracrustal origin. Note textures in the grey gneisses locally, which suggest a small degree of metamorphic segregation during or prior to intrusion of the white gneisses. The Tarssartôq dikes at this locality commonly retain igneous textures but are slightly deformed and commonly have altered margins.

Stop F (long stop)

The purpose of this stop is to show a broad selection of lithologies present in sequence A of the Isua supracrustal belt. Formations upper A3 to A6 (Figure 2) are present as are strongly deformed garbenschiefer and ultramafic units. Pegmatite and grey gneiss sheets are locally present. The sequence of lithologies is corrugated by numerous (2700–2600 Ma) steeply plunging 'Z' folds with a strong fold-axial lineation and is disrupted locally by tectonic slides. A6 is dominated by the felsic nodule lithology. This is most spectacularly developed in the core of a fold on a headland and superficially resembles deformed conglomerate. However, following this unit onto the southern limb of the fold, the pods are seen to be disrupted layers in the sedimentary protolith (this is best seen when the level of the lake is low). Also well displayed here is the carbonate-rich facies of A5, finely laminated A4 banded iron formation, and A5 amphibolites with horizons of quartz-garnet-staurolite rock (A5 being partly included within the garbenschiefer unit). These outcrops show the supracrustal rocks with a fairly typical state of preservation, demonstrating how deformed and recrystallized they are. The Tarssartôq dikes are folded or podded and consist of hornblende-amphibolites that in some cases contain garnet. This shows the extent of late Archean recrystallization in the Isua supracrustal belt, which, taken as a whole, seems to have been a zone of high strain in the late Archean, relative to the adjacent gneisses.

Stop G (medium stop)

At this stop we look at Amîtsoq gneisses and Tarssartôq dikes, a Proterozoic fault, and a unit of Akilia association rocks. The Amîsoq gneisses and Tarssartôq dikes have been so strongly affected by late Archean deformation that the dikes are everywhere subconcordant to the layering of the gneisses. Note that there are also units of deformed, post-dike granitoid in the vicinity. As yet it is unknown if these are 3050–2900 Ma in age or younger. The Proterozoic fault is parallel to the Ataneq fault, about 1 km to the west, and dips at ~45° to the southeast. Note retrogression and discoloration of the gneisses in the fault. Total movement is reverse, with a dextral component. A unit of Akilia supracrustal rocks is truncated by the fault. Lithologies include layered amphibolite gneisses, banded amphibolite, banded iron formation, ultramafic lenses, and a unit of chloritic amphibolite that bears strong resemblance to the garbenschiefer unit of the Isua supracrustal belt. As a package, this supracrustal unit may represent upper A1 to A3 formations of the Isua supracrustal belt, inclusive of the garbenschiefer unit. The western margin of the unit and the gneisses adjacent to it have been affected by very strong, pre-Proterozoic-faulting ductile deformation. Banded amphibolites veined by late Archean granitoids that form the western half of the unit are transformed into mica schists containing granitic nodules that superficially resemble deformed conglomerates in places.

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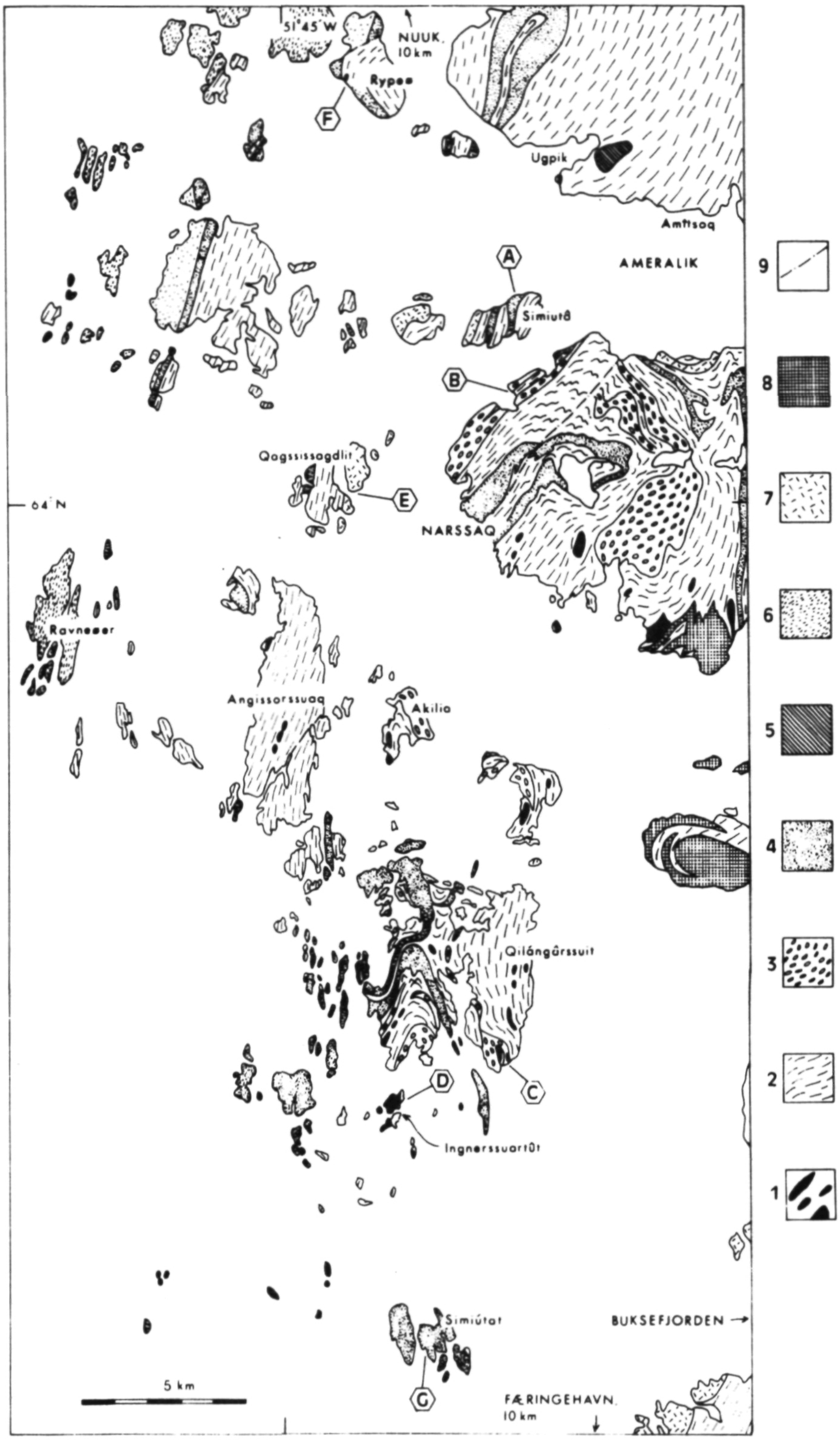

Fig. 4. Geological sketchmap of the outer Ameralik, northwestern Buksefjorden area. A to G, localities described in the text; (1) Akilia association; (2) Amitsôq banded grey gneisses; (3) Amitsôq iron-rich suite, mostly granodiorite; (4) Malene supracrustal rocks; (5) Ugpik metadolerite; (6) Nûk gneiss; (7) late Archean deformed granitoids; (8) late Archean undeformed granitoids, probably correlating with the ca. 2550 m.y. Qôrqut granite complex; and (9) Proterozoic fault.

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