Early Archaean Isua supracrustal belt, West Greenland: pilot study of the Isua Multidisciplinary Research Project

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The Isua belt of 3.8–3.7 Ga metavolcanic and metasedimentary rocks, is located 150 km north-east of Nuuk, within the Archaean gneiss complex of West Greenland. Most of this gneiss complex consists of late Archaean rocks with a minor component of early Archaean age, including the oldest known supracrustal rocks on Earth. The Isua belt contains the best preserved of the oldest supracrustal components and is therefore of vital importance in providing information on the oldest known terrestrial environments and a prospective locality in which to search for the earliest traces of life on Earth (Mojzsis *et al.* 1996). The Isua Multidisciplinary Research Project (IMRP) aims to coordinate a reinvestigation of the geology of the Isua belt and adjacent tonalitic gneisses with a broad-based, diversely skilled, international research team. IMRP is supported by the Danish Natural Science Research Council, the Commission for Scientific Research in Greenland and the Minerals Office of the Greenland Government (from 1998, the Bureau of Minerals and Petroleum).

The project began in 1997 with a pilot study of the north-east sector of the Isua belt to test the feasibility of reinvestigating the early Archaean geology on the basis of new mapping. Five weeks of field work were carried out by a core of four geologists (P.W.U.A, C.M.F., S.M., J.S.M.) augmented by visits of shorter duration by G. Arrhenius, A. Hofmann, V.R. McGregor, S. Mojzsis, R.K. O'Nions and H.K. Schønwandt. This report outlines the geological background to the current study and the results of the 1997 pilot project.

Previous work

The region was first explored geologically by the Kryolitselskabet Øresund A/S during the 1960s (Keto 1998) who discovered the Isua belt of metavolcanic and metasedimentary rocks, including the major banded iron formation at Isukasia. This company made the first geological map of the region and drilled the iron formation.

The great antiquity of these rocks was first established by Moorbath *et al.* (1972, 1973) who obtained a Pb/Pb whole-rock age of 3710 ± 70 Ma on the iron formation at Isukasia, and a Rb/Sr whole-rock age of 3700 ± 140 Ma from the adjacent tonalitic gneiss. The main features of the Precambrian geology were first described by Bridgwater & McGregor (1974) on the basis of 14 days reconnaissance. They compared the tonalitic gneiss to the Amîtsoq gneiss of the Godthåb (Nuuk) region, and the dykes that cut both the gneiss and the supracrustal rocks to Ameralik dykes. They surmised that some quartzofeldspathic and ultramafic units could have been derived from volcanic rocks, and they recognised a distinctive conglomeratic unit that they traced for over 14 km along strike. Near the lake 678 (Fig. 1) the conglomeratic unit was found to comprise deformed "cobs and boulders ranging from a few centimetres to 2 metres in diameter, set in a fine-grained, carbonate-bearing matrix" (Bridgwater & McGregor 1974, p. 51). This was the first discovery of deformed primary depositional features in the Isua belt. A search was made, both in the field and amongst the samples collected, for granitic fragments that could have been derived from an older basement. Analyses of samples indicated that both the clasts and the matrix had a similar granitic composition. Ignimbritic textures were discovered in some of the least deformed fine-grained matrix (D. Bridgwater, personal communication 1975) and it was concluded that this unit was derived from acid volcanic and volcanogenic sedimentary rocks. Geochemical and isotopic studies of both the clasts and matrix confirmed that both had similar REE compositions and ages (Moorbath *et al.* 1975). U-Pb analyses of single zircons from acid volcanic clasts gave a more precise age of $3770^{+0.012}_{-0.009}$ Ga, the oldest age then reported from any terrestrial rock (Michard-Vitrac *et al.* 1977). The 1975 statement by Moorbath *et al.* (p. 238) that "the Isua

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supracrustal succession is thus at present the oldest dated greenstone belt on the earth" is still valid in 1998.

The supracrustal rocks were mapped by J. H. Allaart in 1974–75 for the Geological Survey of Greenland (GGU, now incorporated in the Geological Survey of Denmark and Greenland, GEUS). Allaart delineated the extent of the major belt of metasedimentary and meta-igneous rocks, and presented an outline of the geology (Allaart 1976). He discussed various interpretations of the quartzofeldspathic schists with quartzofeldspathic fragments and concluded that they were derived from acid volcanic rocks. The geology was also described and interpreted by Bridgwater *et al.* (1976) in the context of the regional geology of the Godthåbsfjord region. Both Allaart (1976) and Bridgwater *et al.* (1976) suggested that the Isua belt of supracrustal rocks was probably a fragment of a more extensive sequence, and Bridgwater *et al.* (1976) noted the similarity with younger greenstone belts. The contacts of the Isua supracrustal rocks with the adjacent tonalitic gneisses are strongly deformed, but all these authors considered that the tonalitic gneisses were younger than the supracrustal rocks.

There was a surge of research activity during the late 1970s to early 1980s on a variety of topics including: stratigraphy and sedimentology (Dimroth 1982; Nutman *et al.* 1984); structure (James 1976); petrology, mineralogy and geochemistry (Appel & Jagoutz 1978; Appel 1979a, b, 1980; Schidlowski *et al.* 1979; Gill *et al.* 1981; Boak *et al.* 1983); metamorphism (Boak & Dymek 1982); geochronology (Moorbath *et al.* 1975; Baadsgaard 1976; Michard-Vitrac *et al.* 1977; Hamilton *et al.* 1978), lead, sulphur and oxygen isotope studies (Oskvarek & Perry 1976; Oehler & Smith 1977; Perry & Ahmad 1977; Appel *et al.* 1978; Monster *et al.* 1979), and organic chemistry (Nagy *et al.* 1975, 1977). The Isua belt was remapped by A.P. Nutman in 1980–82 at a scale of 1:10 000, and the mapping was extended across the adjacent gneisses. This work was published with more detailed accounts of the supracrustal rocks by Nutman *et al.* (1983) and Nutman (1986).

Subsequent work at Isua has been carried out intermittently by three independent groups: D. Bridgwater, M.T. Rosing and colleagues at the Geological Museum in Copenhagen; P.W.U. Appel (GEUS), S. Moorbath (Oxford University) and colleagues; and A.P. Nutman (Australian National University) and C.R.L. Friend (Oxford Brookes University). These studies have led to overviews by Nutman *et al.* (1997), a reinterpretation of the metacarbonate rocks (Rose *et al.* 1996), and a substantial reappraisal of the Isua supracrustal belt by Rosing *et al.* (1996). Economic interest in the area was renewed in the 1990s with drilling of the iron formation by Rio Tinto Ltd., and prospecting for gold and base metals by Nunaoil A/S.

Isua Multidisciplinary Research Project

Aims

The Isua Multidisciplinary Research Project (IMRP) aims to provide a new phase of broadly-based, detailed field and laboratory research on the Isua supracrustal belt, based on new detailed mapping of the whole belt and adjacent gneisses. A major aim of the project is to determine the surface conditions on the Earth and the main geological processes current between *c.* 3800 and 3700 Ma. The project includes a search for some of the oldest traces of life on Earth by Stephen Mojzsis, and the broad multidisciplinary nature of the new project, building on previous studies, provides a firmer foundation for this kind of study than did its predecessors.

Achievements of 1997 pilot project

The pilot study involved preliminary remapping of the north-eastern part of the Isua belt at a scale of 1:20 000, and concurrent detailed studies of some of the metasedimentary rocks. The region was found to comprise three fault-bounded tectonic domains (Fig. 1). Two of these domains (NW and SE) consist of intensely deformed schists, whereas strain was relatively low throughout a central domain (CD) in which primary volcanic features are relatively well preserved. This central zone largely consists of metamorphosed and moderately deformed basaltic pillow lavas, pillow breccias, and heterogeneous volcanic breccias, interbedded with minor metamorphosed chert and conglomerate, and a major unit of banded iron formation. These rocks are described in detail by Appel *et al.* (1998), and are here only illustrated by photographs of typical examples (Figs 2–6). The discovery and delineation of this fault-bounded zone of relatively low total strain (Fig. 1, domain CD) was the most significant achievement of the 1997 pilot project, and has important regional implications. This low strain domain (CD) provides the best, and largest known, region in which to investigate the oldest known surface environments on Earth, as well as the geochemistry of contemporaneous basaltic magmas. The rocks in this domain make up a relatively intact stratigraphic sequence that is probably one of the best preserved, oldest terrestrial stratigraphic records.

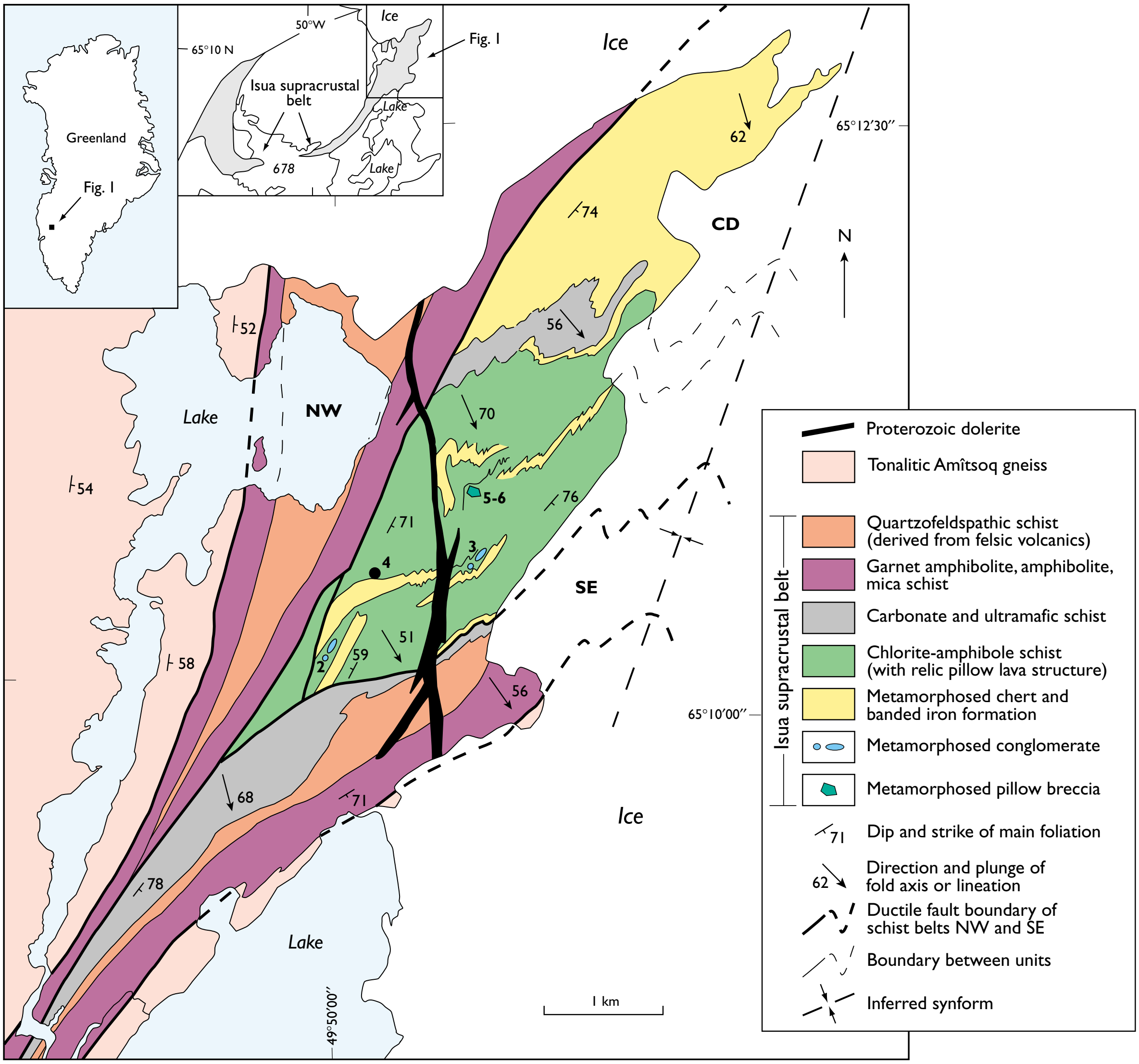

Fig. 1. Simplified geological map of the north-eastern part of the Isua supracrustal belt. Arrows show the direction and plunge of fold axes and lineations related to the major synform. Dips and strikes relate to the main schistosity folded by the major synform. The letters NW, CD and SE indicate the north-west, central and south-east tectonic domains respectively. Numbers 2 to 6 locate outcrops shown on Figures 2 to 6. The dashed boundaries over the ice are postulated from the structure of the adjacent rock outcrops.

The sequence largely consists of basaltic pillow lava and associated breccias, interbedded with chert and banded iron formation. All the other components of the Isua belt in the region studied are intensely deformed schists in which primary statigraphy has been severely modified, and almost obliterated, by tectonic transposition. Elsewhere in the Isua belt primary depositional features have only been found locally in very small areas of relatively low strain in generally schistose units derived from acid volcanic and volcanoclastic sedimentary rocks, such as the locality discovered by Bridgwater & McGregor (1974). Pillow lava structures have not been described before, although they have been mentioned from two localities (within the newly-mapped domain CD) by Allaart (1976), Komiya & Maruyama (1995) and Nutman *et. al.* (1996), and as personal communication from L. Keto (1975).

The main stratigraphic unit of pillow lava extends over an area of 6 km^2 in the central domain (Fig. 1). This rock was previously mapped as 'garbenschiefer amphibolite', a unit that was traced along the whole length of the Isua belt and which formed the largest single component (25%) of the belt (Nutman 1986). This 'garbenschiefer unit' was interpreted as a "gabbroic, possibly sill-like intrusion(s)" by Nutman (1986, p. 15; 1997). However, Rosing *et al.* (1996, p. 43) referred to "sedimentary units with well-preserved Bouma sequence structures that are interbedded with, and grade into, garbenschiefer-textured magnesian schists", and suggested that the 'garbenschiefer unit' was derived from a volcano-sedimentary pile rather than an intrusion. The new field work supports the interpretation of Rosing *et al.* (1996). We found that in the north-eastern part of the Isua belt the so called 'garbenschiefer unit' was predominantly derived from basaltic pillow lava and, although thoroughly recrystallised, still largely preserves deformed pillow lava structure. A brief reconnaissance of a section across the thickest part of the 'garbenschiefer unit' to the west of lake 'Imarsuaq' found that this section also mainly consists of deformed pillow lava, and this may be the dominant protolith. The geochemistry of the 'garbenschiefer unit' was discussed by Gill *et al.* (1981) who showed that the composition of the samples they studied was generally that of high-Mg basalt, rich in Al_2O_3 (15–20%) and low in CaO (8–19%).

The new work of 1997 supports previous suggestions (such as Bridgwater *et al.* 1976, p. 24) that "the original stratigraphy has been disturbed by thrusting", and that the Isua belt may comprise a number of tectonic slices rather than a single stratigraphic sequence or 'coherent stratigraphy' as described by Nutman (1984). However, the new mapping of 1997 does not substantiate the location of major 'tectonic breaks' described by Nutman (1997) and Nutman *et al.* (1997).

In 1986 Nutman proposed that the Isua belt could be divided into two stratigraphic sequences that he called A and B, separated by a fault, and each sequence was divided into a number of formations. Nutman *et al.* (1997) determined different U-Pb SHRIMP ages of zircons from rocks of similar appearance and acid volcanic or volcaniclastic origin in the two sequences. The sample from sequence B gave an age of *c.* 3710 Ma whereas a sample from sequence A gave an age of > 3790 Ma. On this basis Nutman *et al.* (1997, p. 271) concluded that 'sequences A and B' represented "unrelated supracrustal packages of different ages (> 3790 Ma and ~ 3710 Ma), that were juxtaposed in the early Archaean". The dated sample from 'sequence B' came from within the unit of quartzofeldspathic schist in the north-west domain (NW in Fig. 1). The sample from 'sequence A' came from a unit of similar quartzofeldspathic schist at a locality

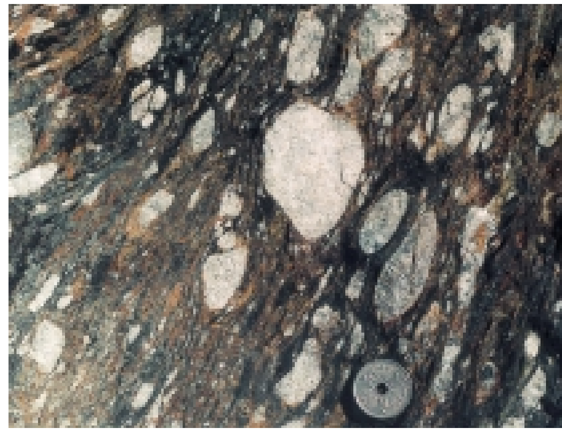

Fig. 2. Metaconglomerate with quartz pebbles of diverse size in a siliceous schistose matrix. All rocks shown in Figures 2–6 are deformed and are viewed perpendicular to the stretching lineation. The coin is 2.5 cm in diameter.

Fig. 3. Polymictic metaconglomerate with pebbles of quartz and quartz-epidote (E).

Fig. 4. Metabasalt pillow lavas with dark rims, in a matrix of chert.

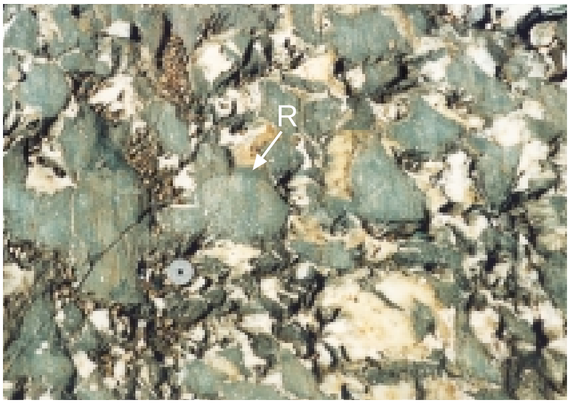

Fig. 5. Recrystallised pillow breccia with angular fragments of amygdaloidal pillow basalt in a matrix of chert. The arrow (R) points to a fine-grained pillow rim.

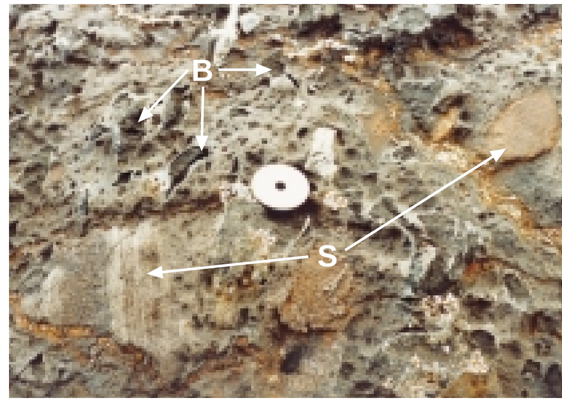

Fig. 6. Recrystallised volcanic breccia with fragments of metamorphosed amygdaloidal basalt (B) and volcanogenic sedimentary rocks (S).

7 km along strike to the south-west of the south-east domain (SE in Fig. 1). However the tectonic contacts shown by Nutman (1986, 1997) and Nutman *et al.* (1997) between 'sequences A and B' do not match the tectonic boundaries between the three tectonic domains (NW, CD, SE) shown on Figure 1. Nutman (1997) describes the fault between 'sequences A and B' as a 'Proterozoic reverse fault', but neither this nor the location of 'early Archaean tectonic breaks' shown on his map in the north-east part of the Isua belt were substantiated by the new mapping in 1997, and none of these faults coincide with the boundaries of the tectonic domains shown on Figure 1.

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