ARCHAEAN GNEISS TERRANES AND PLATE TECTONICS: HOW FAR BACK?

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Understanding how Archaean continental crust evolved draws on evidence from both low- and high-grade terrains. Over the years there has been oscillation between the view that the two environments were either related or completely different. Currently, it is suggested that some high-grade terrains may be depth-related to low-grade terrains, for example parts of the Limpopo Belt (van Reenen et al. 1992), though some seem to be different. There is presently, therefore, no certainty that the evidence from these two different types of terrain relates to the same processes. Because of the greater preservation of primary features and, to a certain extent their greater economic potential, we probably know more about the contents and structure of granite-greenstone and associated meta-sedimentary belts. It is understood that the Canadian greenstone belts of the Superior Province represent sequentially accreted volcano-sedimentary arcs (e.g. Card 1990; Jackson et al. 1994). Similarly, the Barberton belt is now explained as the product of the accretion of different blocks or arcs as the result of a form of plate tectonics (e.g. Lowe, 1994; De Wit, 1998). However, that plate tectonic processes of any form operated is still hotly debated by a minority (e.g. Hamilton 1998).

The major problem in understanding the oldest rocks is that they are preserved in high-grade complexes. These have suffered considerably from tectono-thermal events that destroyed most of the primary textures and structures that were once undoubtedly present. None the less, unravelling how these high-grade complexes were constructed is critical to the understanding of the processes of formation and evolution of early Archaean continental crust. An important question is how far back in Earth's history can evidence of a mechanism akin to plate tectonics be recognised? It is now accepted that in high-grade gneiss terrains the dominant grey gneisses are of broadly tonalitic composition (e.g. Martin 1994) and were juvenile additions to the crust derived from the mantle by a two-stage evolution (e.g. Moorbath 1976). This style of derivation has long been attractive in suggesting that some form of subduction of mafic oceanic crust operated (e.g. Burke et al. 1976). This process must have taken place from the time of the oldest grey gneisses, presently the ~4000 Ma Acasta gneisses. In a modern plate tectonic setting, the chemistry of rocks is only one of the main signatures that are sought. An important result recognised in many areas is the accretion of thrust-bound slices that usually have very different contents and evolutionary histories – the suspect terranes of Coney at al. (1980).

The North Atlantic craton has been one of the type localities for understanding early crustal processes. Within this craton the Archaean high-grade gneiss terrain of West Greenland has been particularly important. This is despite the intense polyphase metamorphism and tectonism that has invariably obliterated much of the primary features of the rocks. Essentially, there are rare areas of low strain that preserve enough evidence with which to interpret the rest of the rocks. Since 1985 new structural, metamorphic and geochronological studies have produced evidence that has allowed working models to be formulated at several scales (e.g. Friend et al. 1988; McGregor et al. 1991).

First, on a craton scale, the best understood part of the West Greenland Archaean is the central area that comprises four different terranes dominated by different TTG lithologies and separated by tectonic contacts. The early Archaean components are contained within the Færingehavn terrane which was intercalated with the ~2820 Ma Tre Brødre terrane and event that occurred under amphibolite facies conditions between 2820-2720 Ma. This composite crustal block was then overridden by another late Archaean terrane, the ~2900 Ma Tasiusarsuaq terrane which had attained granulite facies conditions in its lowermost parts at ~2820 Ma. This complex of three terranes was then abutted against the Akia terrane, a mid-Archaean gneiss complex which had undergone a granulite facies metamorphic event at ~3000 Ma (Friend et al. 1996). To the north of the Akia terrane there is another late Archaean block, the Tuno terrane that underwent a granulite facies event at *c*. 2740 Ma. The contact with the 3000 Ma granulites facies rocks was obscured during deformation and amphibolite facies metamorphism at *c*. 2500 Ma. The southern part of the Archaean craton has been examined more cursorily, but, the crust here can be divided into at least three late Archaean TTG-dominated blocks each separated by tectonic contacts and displaying varying metamorphic histories. The available dates of the TTG components and later granitoids indicate that the assembly occurred in the late Archaean. The precise details for the whole of the craton have not been worked out but the underlying principle is that it was constructed in two main stages. Firstly, individual plutonic arcs were repeatedly formed throughout Archaean times that secondly, some time later, were swept together to form a successively larger and larger piece of continental crust. This continual accretion and enlargement of continental crust appears to refute the ideas of Armstrong (1991) that crust did not grow with time.

Second, within the early Archaean Færingehavn terrane there is tectonic and geochronological evidence suggesting that it was itself assembled from several discrete blocks, each composed of different TTG components associated with a supracrustal sequence (e.g. Nutman et al. 1993, 1996). These blocks of different protolith ages and different metamorphic history were juxtaposed along early Archaean shear zones which could represent transform structures and be interpreted to indicate that they were swept together by an early form of terrane tectonics.

On a larger scale still, evidence from the whole of the North Atlantic craton can be considered. In the case of Greenland a long tectono-thermal history is demonstrated from the early Archaean to the Mesoproterozoic. Around the Archaean craton mobile belts have reworked large portions of the older material, for example the Nagsugtoqidian/ Ammassalikian mobile belt, as well as adding small proportions of juvenile material to form a progressively larger volume of continental crust (e.g. Chadwick et al. 1989; Whitehouse et al. 1998). This type of collisional reworking links west in to Labrador and eastwards to the portion represented by basement rocks in northwest Scotland. This latter portion is interesting because it has previously been explained as a contiguous portion of crust that has been continually reworked over a long period of time (e.g. Park et al. 1994). However, recent studies have shown that this is not the case, with blocks of Archaean TTG gneisses being brought together along tectonic contacts that are Proterozoic in age (Kinny and Friend 1997). The tectonic assembly of the North Atlantic region can be shown to have started in the early Archaean and continued into the Mesoproterozoic. Therefore, there are both chemical and structural signatures within Archaean gneiss complexes that could be attributed to plate tectonic processes and the next stage is to formulate a model that explains the observations.

It is proposed that a plausible model for the initial stages of the generation of very early Archaean sialic crust is ocean-ocean subduction and/or obduction, as proposed by de Wit et al. (1992) where thrust stacks that can partially melt in their lower portions are created. These initial volcanic arcs could accrete in a manner similar to that demonstrated by the Fiji region over the last ~25 Ma. The rapidity of the evolution of this region means that hot, young oceanic crust is subducted which gives geochemical signatures similar to Archaean rocks (c.f. Martin 1994) and so, together with the isolation from known contiental crust, makes it a suitable for use as an analogue for the early Archaean. In the Fiji region relatively young oceanic crust, <10 Ma old, has been subducted to produce tonalitic plutons that equate to first generation continental crust. Given the rapidity of crustal evolution in the Fijian region it is readily understood that even the resolution of SHRIMP dating is presently not sufficient when applied to the Archaean. An uncertainty of 10 Ma could hide the formation and amalgamation of a series of arcs, as demonstrated in the Fiji region. The arcs form in different places and become active at different times. Eventually, due to the rapid spreading arcs may collide and accrete. This accretion could have been accomplished along a combination of transform faults or arc collision through subduction, as seen in the evolution of the Fiji region. Such processes could have allowed attainment of high-grade metamorphism in the lower parts of over-ridden arcs by crustal thickening. This thickening in turn could led to the first generation of crustally-derived granitoids through partial melting of the quartzo-feldspathic component (e.g. as seen in the Itsaq Gneiss Complex). As a consequence the associated sediments preserved at in younger arc complexes would reflect an increasingly complex source, as also shown in the Itsaq Gneiss Complex. By the time of the mid- to late Archaean continental crust is firmly established as growing and it is possible that subduction could take place underneath it because of its inherent bouyant properties relative to oceanic crust. At the same time, with larger pieces of continental crust formed fragments can be rifted off and moved about on transform structures and amalgamated against other fragments to provide a mosaic, a process that can be followed on into the Proterozoic and then the Phanerozoic.

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