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Preface to the special issue of Precambrian Research on the understanding of gneiss complexes, in honour of Clark R.L. Friend

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Abstract

Gneiss complexes are the world's most horrendously complexrocks to understand (see cover of this issue), yet they form a largeamount of the continents, albeit they are normally hidden fromview by sedimentary sequences. The last half century has seenenormous advances in understanding these rocks, which form notonly a large amount of the continental crust, but also hold much ofEarth's oldest rock record – the Archaean.

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Preface to the Special Issue of Precambrian Research on the Understanding of Gneiss Complexes, in Honour of Clark R.L. Friend

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Gneiss complexes are the world's most horrendously complex rocks to understand (see cover of this issue), yet they form a large amount of the continents, albeit they are normally hidden from view by sedimentary sequences. The last half century has seen enormous advances in understanding these rocks, which form not only a large amount of the continental crust, but also hold much of Earth's oldest rock record – the Archaean.

These advances in understanding of gneiss complexes have come from many disciplines, particularly micro-scale U-Pb zircon geochronology (development of large ion microprobe and laser ablation ICPMS technologies), together with advances in understanding of the geochemistry of these rocks and of their field relationships. Advances have been most robust when all these disciplines have been applied in an integrated fashion.

Clark R. L. Friend, whom this issue honours, has had a distinguished career spanning 5 decades, focussing largely on Precambrian gneiss complexes, and his contributions to the field have come from this integrated approach. However, to readers of Clark's work on gneiss complexes, it might come as a surprise that he has published a diversity of other scholarly articles, such as on cave science (Friend and Gooding, 2001) and archaeology (Friend et al., 2007)! Clark started his career in the early 1970s in Greenland, which is arguably the world's best playground for the study Precambrian gneiss complexes. The early 1970s was a watershed for the study of Precambrian Gneiss Complexes, because from the Nuuk region of Greenland the first reliable geochronological data was emerging to show that at >3600 Ma some of the gneisses were extremely ancient, and that superficially similar gneisses in the same region could have much younger ages (Black et al., 1971; Moorbath, 1975). This was integrated with two field-based discoveries by the late Vic

McGregor, who showed that the vastly different radiometric ages agreed with the relative chronology acquired from field relationships, and also that most Archaean gneisses were derived from plutonic granitic (*sensu lato*) rocks, rather than ‘arkosic’ sediment rocks (McGregor, 1973). The latter corrected a misconception held since the early 1900s. These developments indicated that information could be extracted from Earth’s first billion years, to understand early planetary development.

Clark started work as a Ph.D. student on the Archaean rocks in the Fiskenæsset region of West Greenland – developing his considerable skills as a basement geologist during long field seasons of contract mapping for the Geological Survey of Greenland (now incorporated into the Geological Survey of Denmark and Greenland – GEUS). His long association with Greenland basement geology has continued until now – first working as a contract geologist for the survey, and subsequently working as an independent researcher, particularly with the late Vic McGregor, Vickie Bennett and myself. Clark has also worked extensively in other terranes of high grade gneisses, particularly in the Dharwar craton of southern India, the North China Craton and the Lewisian Gneiss Complex of Scotland.

Clark was one of the key players in the 1980s recognition of tectonostratigraphic terranes within gneiss complexes, whereby detailed structural and metamorphic field evidence integrated with geological mapping and following copious U-Pb zircon geochronology shows that the Nuuk region gneiss complex contains cryptic folded tectonic boundaries which separate unrelated blocks of juvenile crust brought together laterally in collisional orogenic episodes (Friend et al., 1987). This structural and geochronological evidence, combined with the igneous petrology and isotope geochemistry of these rocks, demonstrate plate tectonic cycles stretching back to the start of the Archaean (Friend et al., 1988; Nutman et al., 1989; McGregor et al., 1991). The tectonostratigraphic terrane principle has been found to be applicable the world over, and shows that Precambrian gneiss complexes do not represent laterally-extensive welts of crust formation formed by non-uniformitarian processes, but instead consist of strips and blocks formed in different crust formation events that were assembled together in their present configurations by processes resembling (but not necessarily exactly the same in detail) Phanerozoic plate tectonics. Recognition of transient high pressure metamorphism with a clockwise P,T,t path coeval with assembly events (e.g., Nutman et al., 1989; Nutman and Friend, 2007; Dziggel et al., 2014), has reinforced the notion that Precambrian terrane assembly may involve convergence leading to collisional orogeny. Clark applied these principles with great success in an integrated field and zircon geochronological reappraisal of the Lewisian Gneiss Complex – revealing cryptic tectonic boundaries separating blocks of different protolith age and metamorphic history (Friend and Kinny, 2001). The advances in the understanding of Precambrian gneiss complexes over the past 5 decades, in which Clark Friend has played a leading role, has led to the understanding of ancient geological processes in a quasi-uniformitarian framework.

Clark lost his academic job in the early 2000s when the whole of the Department of Geology where he worked (Oxford Brookes University) was closed. Since then he has worked part time for a geophysics company, which specialises in assessing risks of likely unexploded ordnance and other hazards buried in development sites in the U.K. He devotes the rest of his time as a freelance in the pursuit of his other interests such as Archaean geology, scientific archaeology, cave science and ornithology.

The eight papers in this issue explore the deeper understanding of Precambrian gneiss complexes, often with a strong emphasis on the recognition of tectonostratigraphic terranes and application of cutting-edge analytical techniques. These are summarised in alphabetical order of authorship:

Berger et al. (2014; "Exhumation rates in the Archean from pressure-time paths: Example from the Skjoldungen Orogen (SE-Greenland") grapples with the issue of exhumation rates in ancient orogens and the implications this has for the similarity of processes in ancient versus modern orogens. With their Neoarchaean study area in E. Greenland the authors establish that processes were similar to modern collisional orogens, with stiff Mesoarchean continental crust forming a foreland to a collisional orogen, instead of typical accretionary tectonics of weak island arc-like assemblages proposed for granite-greenstone terranes.

Garde et al. (2014; "The Finnefjeld domain, Maniitsoq structure, West Greenland: Differential rheological features and mechanical homogenisation in response to impacting?") presents the most controversial paper in the issue – concerning a new perspective on the impacting record in early Earth history. Generally evidence of impacts is sought via relict crater structures and impact related sedimentary sequences. This requires minimal erosion, thus increasingly back in time through the Precambrian, such features will be rarer, because of overall deeper erosional levels. Garde and co-workers present observations in the late orogenic Finnefjeld (gneiss) domain of W. Greenland of highly unusual, mixed rheological behaviour, whereby plagioclase displays brittle behaviour with cataclasis, whereas quartz was ductilely deformed, and K-feldspar was melted. They propose that the deformation and homogenisation of the Finnefjeld domain was caused by an intense event of heating and deformation, which was co-seismic in nature and which they ascribe to deep-crustal effects of impacting. If correct, then a significant part of Earth's early impact history might be unearthed from mid- to deep-crustal rocks in gneiss terranes.

Kolb (2014; "Structure of the Palaeoproterozoic Nagssugtoqidian Orogen, South-East Greenland: model for the tectonic evolution") gives a detailed synthesis on a Palaeoproterozoic collisional orogen in E. Greenland; extending and revising that given by Nutman et al. (2008). The orogen includes Archaean rocks of Rae Craton to the north and the North Atlantic Craton to the south, and Palaeoproterozoic rocks. The Kuummiut Terrane of Rae Craton rocks is overlain by a ca. 2100–2200 Ma shelf sequence that includes marble, meta-pelite and -psammite. The KuummiutTerrane and its sedimentary cover was probably subducted underneath the SE-trending ca. 1885 Ma Ammassalik Intrusive Complex of arc rocks with a high temperature, moderate pressure metamorphic halo. First tectonic imbrication occurred at ca. 1870 Ma, with transient high pressure metamorphism in the Kuummiut Terrane. The complex structural evolution of the orogen documented by the authors was caused by oblique convergence during WSW-directed subduction and the convergence of irregularly shaped cratons. The scenario presented by the author points to a modern-style of tectonics in the Palaeoproterozoic.

Kröner et al. (2014; "Generation of early Archaean grey gneisses through melting of older crust in the eastern Kaapvaal craton, southern Africa") reports integrated U-Pb and Hf isotopic data from Palaeoarchaean grey gneisses of the Ancient Gneiss Complex of Swaziland, the oldest components of the Kaapvaal craton, southern Africa. The Hf-in-zircon isotopic compositions indicate derivation from older crust. However they suggest that both the Lu-Hf and Sm-Nd whole-rock isotopic systems were disturbed and partly reset during later episodes of partial melting and crustal reworking, most likely during a pervasive 3.2 Ga tectono-metamorphic event. The data support evidence from other Palaeoarchean terranes that crustal recycling, as seen in even the oldest crustal components, played an important role in early continental evolution.

Mora et al. (2014; "Syn-collisional lower continental crust anatexis in the Neoproterozoic Socorro-Guaxupé Nappe System, southern Brasília Orogen, Brazil: constraints from zircon U-Pb dating, Sr-Nd-Hf signatures and whole-rock geochemistry") examines the architecture and development of the southern Brasília Orogen along the southernmost border of the São Francisco Craton (Brazil). It is interpreted as a pile of Ediacaran syn-metamorphic thick-skinned nappes that diachronically migrate towards the cratonic margin. A magmatic arc environment is represented by the Socorro-Guaxupé Nappe, which is a thick segment of partially molten lower to middle continental crust. Detailed U-Pb zircon dating established a history of arc development at ca. 670 Ma, with superimposed tectonothermal events at ca. 621 and 608 Ma. Along with results on older Precambrian orogens presented in this issue, this Neoproterozoic example illustrates the continuity of tectonic processes throughout the Precambrian.

Wan et al. (2014a; “Middle Neoarchean magmatism in western Shandong, North China Craton: SHRIMP zircon dating and LA-ICP-MS Hf isotope analysis”) in this contribution, the timing of crust formation is examined in a portion of the North China Craton. Several previous contributions (e.g., Wan et al., 2014b) have summarised the U-Pb and Hf zircon isotopic data that shows that a massive ca. 2.5 Ga magmatic-thermal event ‘masks’ a significant crust-forming event at ca. 2.7 Ga in the craton. Their contribution reinforces the evidence for this.

Wu et al. (2014; “Geochemistry and Sm-Nd isotopes of Archean granitoid gneisses in the Jiaodong Terrane: Constraints on petrogenesis and tectonic evolution of the Eastern Block, North China Craton”) examine Neoarchaean crustal evolution in part of the North China Craton, via whole rock geochemical data from the Jiaodong terrane. They suggest that late Neoarchaean granitoids were derived by recycling of somewhat older continental crust, with the heat source being a mantle plume.

Yi et al. (2014; “Tracing Archaean terranes under Greenland's Icecap: U-Th-Pb-Hf isotopic study of zircons from melt-water rivers in the Isua area”) look at modern glacial sedimentary provenance to ‘see’ under Greenland’s Ice cap in the Isukasia area. They establish from detrital zircons that Eoarchaean crust exposed along the ice edge continues under the ice, with no components >4.0 Ga recognised. There is also a terrane under the ice dominated by late Mesoarchaean rocks. This information is used to improve Archaean tectonostratigraphic terrane synthesis models for the North Atlantic Craton in West Greenland.

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Figure captions

Figure 1. Clark Friend in the field: Nuuk region, Greenland

Caption for front cover image: Typical orthogneiss from the Eoarchaean Itsaq Gneiss Complex of Greenland. A complex of tonalitic rocks (predominantly ~3800 Ma at this outcrop) had been partially melted under granulite facies at ~3650 Ma to produce granitic patches and veins and then folded prior to intrusion of mafic dykes at ~3500 Ma (now preserved as amphibolite strips – running from left to top centre). Subsequent pegmatite veining was emplaced in superimposed amphibolite facies events at ~2700 Ma. This outcrop indicates the complexity of unravelling the geology of such rocks – a combination of regional fieldwork, understanding of detailed field relationships, application of modern micro-analytical techniques plus patience!


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