



Introduction: Initial investigations of a Neoproterozoic shelf margin-basin transition (Transvaal Supergroup, South Africa)

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ABSTRACT

The late Archean to earliest Paleoproterozoic Transvaal Supergroup preserves both thick platform carbonates and basinal successions rich in iron formation. Two new drill cores, sponsored by the Agouron Institute, document the platform-basin transition, thus facilitating the reconstruction of both late Archean basin development and biogeochemical processes at play just before the Great Oxidation Event. Interpreted in light of previous outcrop and subsurface studies, the new cores provide an unusually detailed framework of time and environment for sedimentological, paleomagnetic, and geochemical analyses. The papers in this special issue constitute the first fruits of research on the Agouron cores, but undoubtedly not the last.

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1. Introduction

Oxygen has been a major pacemaker in the long-term evolution of life on Earth. In particular, redox transformation at the beginning of the Proterozoic and again near its end altered the environmental framework within which evolution takes place, facilitating the evolution of aerobic heterotrophs as the eon began and large animals as it ended. While the general nature and timing of these events has emerged through research over the past decade, debate continues on their causes and consequences. Moreover, the state of the Earth system preceding and following these major events remains to be elaborated in the kind of detail that might facilitate an improved understanding of geobiological processes.

To elucidate the relationship between evolution and environmental change in Earth history, paleobiological and geochemical data must be collected and interpreted in the context of carefully measured stratigraphy. Carbonate platform successions are ideally suited for such studies because they are known to record the interplay of life, ocean chemistry, sea level and basin subsidence through Earth history (e.g., Grotzinger and James, 2000; Sumner and Beukes, 2006). And, as many key analyses of organic and inorganic geochemistry are sensitive to alteration and contamination in the surface environment, an increasing fraction of continuing research will be carried out on fresh drill core samples.

With this in mind, a research consortium supported by the Agouron Institute diamond-drilled two cores, one 1500 m and the other 1300 m deep, in carefully targeted sites along the shelf margin-basin transition within the Neoproterozoic Campbellrand carbonate platform succession of the Transvaal Supergroup in Griqualand West, South Africa (Fig. 1). The cores enable us to sample the physical and chemical features of a Neoproterozoic ocean basin through a bathymetric depth gradient conservatively estimated at several hundred meters. Such data help to reconstruct the state of the Earth system on the eve of what has been called the Great Oxidation Event (GOE).

2. Key geobiological issues

Increasingly, consensus holds that the Earth's surface developed a stably oxic atmosphere and surface ocean for the first time 2.45–2.32 Ga (Bekker et al., 2004; Holland, 2006). Oxygenic photosynthesis carried out by cyanobacteria must have played an important role in this transition, but what role, if any, did cyanobacteria play in pre-GOE ecosystems? Conventional wisdom has long held that oxygenic photosynthesis evolved hundreds of millions of years before oxygen began to accumulate in the atmosphere, requiring some mechanism to prevent oxygen accumulation. In contrast, Kopp et al. (2005) have proposed that the evolutionary origin of water-splitting, oxygen-producing photoautotrophs led directly to the GOE. The two hypotheses are starkly different, but geobiological tests have proven elusive.

Carbon isotopes certainly suggest a carbon cycle in which photoautotrophs fixed CO₂ via the Calvin cycle, but in the modern

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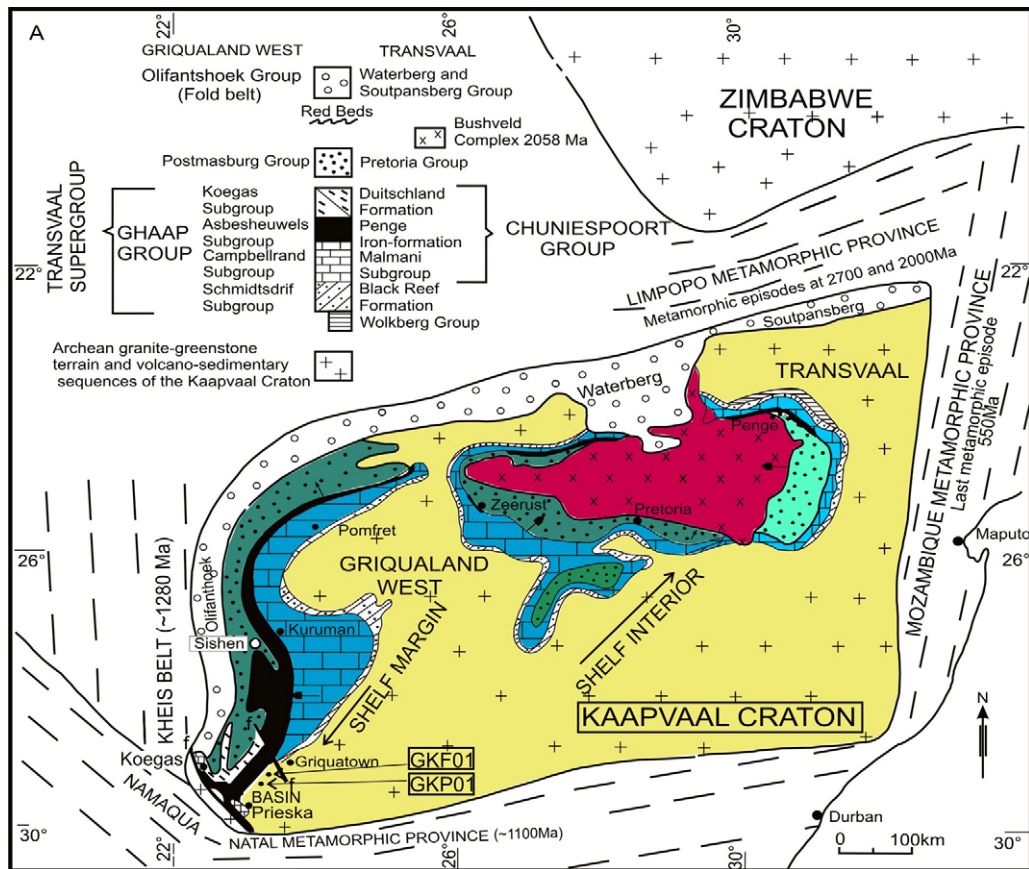


Fig. 1. Map of the Kaapvaal craton showing the distribution of the major rock stratigraphic units of the Transvaal Supergroup in the Griqualand West and Transvaal areas, the location of the basin-shelf facies of the Campbellrand–Malmani carbonate platform, and the position of the two Agouron drill cores (GKP01 and GKF01) immediately off the shelf in the slope to basin transition. Note that between Griquatown and Prieska the slope and basin facies of the Campbellrand carbonate platform and the underlying mixed siliciclastic-carbonate succession of the Schmidtsdrif succession is not exposed.

world, anoxygenic photosynthetic bacteria, as well as cyanobacteria and their chloroplast descendants, fix carbon in ways that can account for the isotopic data (Hayes and Waldbauer, 2006). Late Archean microfossils from Transvaal cherts (Altermann and Schopf, 1995) could easily be cyanobacterial, but preservation is relatively poor, making it difficult to pick out characters that are *diagnostically* cyanobacterial, and the trail grows cold in older rocks. The same is true of molecular fossils. 2Me-hopanoids long interpreted as cyanobacterial biomarkers are now known to be synthesized by certain proteobacteria (Rashby et al., 2007). Steranes isolated from late Archean black shales (Brocks et al., 2003a,b) provide presumptive evidence for at least local oxygen, given that plausible anaerobic paths to sterol synthesis have not yet been elucidated. However, both the extremely low sterane concentrations and distinct C-isotopic compositions of extractable hydrocarbons in late Archean rocks from Australia have kindled concerns about contamination (Rasmussen et al., 2008; see Waldbauer et al., this issue).

At least some of the stromatolites in late Archean carbonates accreted by trapping and binding, just as cyanobacterial mats do today. Buick (1992) has further argued that lacustrine stromatolites in the 2.7 Ga Tumbiana Formation, northwestern Australia, record cyanobacterial growth for the simple reason that alternative electron sources were in short supply. Once again, consistency arguments are strong, but *diagnostic* evidence is harder to come by. And if cyanobacteria did hold sway in some lakes, does it follow that they were comparably successful in the oceans, where Fe^{2+} , H_2 , and H_2S were arguably more abundant?

Evidence from the mass independent fractionation of sulfur isotopes indicates that prior to the GOE atmospheric oxygen levels

were exceedingly low, perhaps below 10^{-5} atm (Pavlov and Kasting, 2002; Farquhar and Wing, 2003). This is consistent with the long recognized evidence of Archean iron formations for ferrous iron transport through anoxic deep oceans, although hematite in many iron formations also requires a means of oxidizing iron. Cyanobacterial photosynthesis provides one possible source of oxidants, but not the only one (e.g., Konhauser et al., 2002). Recent papers, however, argue for a “whiff of oxygen” in the latest Archean surface ocean, based on transient changes in Mo abundances and isotopes, as well as S-isotopic chemistry (Anbar et al., 2007; Kaufman et al., 2007; Wille et al., 2007—note that the last mentioned paper includes data from the Agouron drillcores). If correctly interpreted, such data imply that cyanobacteria existed at 2.5 Ga. Can we document this better, and is dioxygen strictly necessary to explain the geochemical data? If cyanobacteria were present, what prevented them from producing oxygen sufficient to raise P_{O_2} and limit alternative electron donors in the oceans? Only new geochemical and paleobiological data, meticulously collected from clean samples, will answer these questions.

3. The Agouron drill cores: location and geological setting

3.1. Rationale

The Neoarchean–Paleoproterozoic Transvaal Supergroup, with a total stratigraphic thickness of up to 11 km (Button, 1976a), covers a large part of the Paleoproterozoic Kaapvaal craton (Fig. 1). Post-depositional deformation and erosion limits the distribution of preserved strata to two regions: (a) the so-called Transvaal area

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