BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

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RECORD

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5-6 NOVEMBER, 1984

THE BMR MODEL - A DISCUSSION PAPER

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INTRODUCTION

The exposed Early to Middle Proterozoic domains of northern Australia display an areally extensive, ensialic type of orogeny. As such, it differs significantly from the time-transgressive, lateral accretion models of modern orogeny, and may be specific to this period of the Earth's evolution. In this paper and the workshop, we present for discussion a model of Proterozoic basin evolution, magmatism and orogeny that involves vertical accretion, both by underplating and overplating, during discrete, areally extensive events related to continent-wide or even global mantle processes. We will emphasize the similarity of process and timing between terrains in developing this model, which we hope will provide a useful working framework for mineral exploration and evaluation of Early to Middle Proterozoic provinces.

CHRONOTECTONIC FRAMEWORK

It is now well established in Precambrian Shield areas that a major tectono-thermal episode occurred around 1800 Ma. There is a wide spread of isotopic "ages" which purport to date this episode in different terrains (1920-1730 Ma). However, the chronological framework for this time period has been substantially refined in the last 10 years by the application of the zircon U/Pb technique, and by closer collaboration between geochronologists, petrologists and structural geologists in the application of Rb/Sr techniques to rocks with complex deformational and metamorphic histories. In their recent summary, Page, McCulloch & Black (1984, Proc. 27th IGC-vol 5) have critically assessed the available data for the Australian Precambrian on the basis of this experience.

A striking result of this reassessment is that a widespread orogenic event can be well bracketed between about 1820 & 1920 Ma over the whole of northern Australia; and there is increasing evidence for a further narrowing of that range to 1850 to 1880 Ma, especially in the Mt Isa and Pine Creek provinces. As will be discussed later, this orogeny was marked, especially at its close, by a distinctive felsic igneous event of large magnitude and remarkably consistent chemistry, which has been recognized in the Halls Creek, Pine Creek, Arunta, Tennant Creek, Gawler and Mt Isa provinces. Thus, a major orogenic/magmatic event affected virtually all of the Early Proterozoic domains of Australia within a period of 30-60 Ma.

This orogenic/magmatic episode separates two sedimentary cycles corresponding broadly to the Nullaginian and Carpentarian of Dunn et al (1966). The younger of these two cycles was variably deformed and metamorphosed between about 1650 & 1550 Ma.

TECTONOSTRATIGRAPHIC HISTORY

Each of the two cycles is itself divided into three sequences of differing tectonostratigraphic character.

1.) A lower clastic sequence, quartz-rich and commonly demonstrably fluviatile, containing more or less extensive bimodal vulcanism. This sequence probably represents an initial phase of crustal extension and rifting which initiated each cycle.

2.) A middle finer grained clastic sequence, commonly carbonaceous, and with abundant carbonates and some iron formations. This apparently represents a phase of transgression associated with post-extension subsidence, and is of wide lateral extent.

3.) An upper turbidite or molasse facies, which may mark the beginning of the orogenic phase.

The best examples of the earlier of the two cycles are found in the Pine Creek and Halls Creek provinces, and the younger cycle is best represented in the Mt Isa province.

IGNEOUS HISTORY AND GEOCHEMISTRY

There are significant differences between the igneous rocks of the two cycles. The older contains fewer igneous rocks, with mafic compositions dominant throughout. The younger contains abundant igneous rocks, with mafic rocks concentrated in the lower half and felsic rocks, most of which are anorogenic, occurring throughout. Layered mafic complexes appear to be restricted to the older cycle, whereas alkaline mafic rocks have only been found near the top of the younger cycle. Throughout the Early to Middle Proterozoic, igneous compositions are bimodal, with SiO_2 contents between 56 and 63% rare.

The igneous rocks which overlap the orogenic event that separates the two cycles are dominantly felsic, and form a compositionally distinctive suite occupying over 30,000 sq km. They are almost exclusively I-type, with high LIL and LREE concentrations (eg, K_2O, Rb, Ba, Th, U, Sn, La, Ce), and low MgO, CaO, Ni, and Cr relative to Phanerozoic and many Archean granitoids. They also have high Rb/Sr ratios and low initial $^{87}Sr/^{86}Sr$. Isotopic modelling implies a short pre-history, with a mantle source age of 2000 to 2200 Ma. These granitoids provide a mechanism for substantially enriching the upper crust in K, Th, U, Sn and possibly W.

The anorogenic felsic intrusives and extrusives of the younger cycle seem to be concentrated in three age groups - 1800 to 1780 Ma, 1760 to 1740 Ma, and 1670 to 1640 Ma. These suites can be distinguished from the orogenic rocks on the basis of higher K_2O, TiO_2, Th, U, Zr, Nb, Y, La and Ce contents. Again, the felsic igneous rocks of these suites are best modelled as having been derived by partial melting of deep crustal mafic parents with short crustal residence times.

Deformation and metamorphism of the second cycle was followed by an extensive sequence of felsic igneous intrusives and extrusives. These are also largely I-type, but their chemistry is not well characterized in detail.

DEFORMATIONAL STYLE

In northern Australia, the older cycle is everywhere at least moderately deformed, with a structural style and history that is consistent in all provinces. An early nappe-style event was followed by a regionally developed upright fold episode that dominates most of the published map patterns. Sub-vertical shear zones, commonly in several strike sets with steep movement directions, may be superimposed on the folded terrains. These zones may have a long history of reactivation.

Where the younger sequence is deformed, a very similar style sequence is observed. However, in neither sequence do the nappe events produce widespread inversions of facing, and stratigraphic duplications are limited in thickness. Basement involvement in the thrusting is also rare. Further, in spite of the shortening apparently associated with the upright folding, there is little evidence of substantial crustal thickening or of the consequential uplift and erosion in any of the terrains.

METAMORPHISM AND P-T-t PATHS

The high pressure metamorphism and paired metamorphic belts characteristic of modern orogenesis are absent in Early to Middle Proterozoic terrains. Low to rarely medium pressure metamorphic facies are ubiquitous in this time period. Peak metamorphic grade commonly occurred during or prior to the main upright folding episode. Most importantly, this peak is generally followed by a period of isobaric cooling, giving rise to a P-T-t path that is quite different from that typical of modern collisional orogens. It is incompatible with rapid crustal thickening and consequent isostatic uplift. The widespread andalusite and sillimanite-bearing assemblages suggest heating by addition of mantle-derived melts to the lower crust.

A MODEL

The main elements of a distinctive tectonic model for the Early to Middle Proterozoic are:

- Two cycles of crustal (?lithospheric) stretching and consequent basin formation are separated by a major orogenic/magmatic event. The timing and character of these events are remarkably similar across northern Australia, and even in other continents.

- The lithospheric stretching and the substantial mantle-derived magmatism throughout this period are related to small-scale mantle convection that began about 2200 to 2000 Ma. The roughly polygonal pattern of Proterozoic extensional terrains around Archean nuclei is analogous to the modern pattern of rifts and swells in Africa, in that it is ascribed to small scale mantle convection beneath a stationary or slow-moving plate.

- Initially, the bulk of the mantle melt was underplated at the base of the crust, only reaching the surface as the first cycle extension began. Underplating would have been restricted to the regions above upwelling mantle that then evolved into Early Proterozoic rifts and basins. The mafic material underplated at about 2000 Ma formed the source for the extensive felsic magmatism from 1900 to 1750 Ma. In particular it formed a uniform source for the widespread and voluminous granitoids and volcanics of the distinctive and homogeneous 1880 to 1820 Ma Kalkadoon-type event.

- There is no evidence that crust of modern oceanic character was formed during either extensional event. The style of sedimentation is consistent with basin formation by limited (50 to 100%) stretching of a pre-existing continental lithosphere, followed by thermal subsidence, analogous to that envisaged for a number of modern ensialic basins (e.g., North Sea, Aegean Sea, Bass Basin). Likewise, there is no evidence for subduction and island arc-style magmatism. The orogenic magmatism is distinctly bimodal, with an absence of andesitic compositions.

- The contemporaneous and widespread onset of orogenesis throughout the basins of the first cycle contrasts strongly with the progressive lateral accretion of terrains typical of younger tectonism. It may have been due to a sudden change in mantle convection pattern, with deformation restricted to the "weaker" areas that had undergone extension and rifting. Whatever its cause, it was characterized by high heat flow and absence of evidence for significant crustal overthickening. We infer that any crustal shortening associated with orogenesis simply restored the pre-rift crustal thickness.

- The second basin-forming cycle was initiated 20 to 50 Ma after the orogeny by a further phase of stretching and rifting. The distribution of second cycle terrains is less regular, although they are apparently generally developed on a first-cycle basement, commonly where the basement is at higher metamorphic grade. Orogenesis was more patchy and differed significantly in age from province to province, perhaps reflecting a breakdown of the regular, small-scale convection pattern.

- We therefore regard the crust beneath Early to Middle Proterozoic provinces to comprise 1) an upper layer of Proterozoic rocks of one or both cycles, 2) a fairly thin upper to middle crustal layer of stretched Archean protolith, and 3) a substantially mafic lower crustal layer largely underplated about 2000 Ma.

IMPLICATIONS FOR METALLOGENESIS

A major control on metallogenesis at this period is clearly the composition of the evolving atmosphere and hydrosphere, which is superimposed on the controls exerted by aspects of the tectonic model outlined here. The major implications of the tectonic model for metallogenesis are:

- The average crustal composition beneath the Proterozoic provinces underwent substantial change between about 2200 Ma and 1800 Ma, as a result of massive underplating. Fractionation of this underplated material to the upper crust by partial melting during basin formation and orogenesis gave rise to an upper crust of quite different chemical character to its Archean basement and hinterland. In particular, there is little evidence for significant reworking by igneous processes of the Archean into the Early to Middle Proterozoic terrains.

- Felsic magmas of this period are largely derived by partial melting of a dry mafic underplated layer, giving rise to hot, relatively anhydrous melts. The melts rarely fractionated at high levels, and do not evolve a significant hydrous phase, reducing the potential for a range of magmatic hydrothermal deposit styles.

- The first cycle is remarkably devoid of significant mineral concentrations, except those resulting from post-1850 Ma overprints. Atmosphere and hydrosphere compositions are probably particularly important influences at this time, but other factors probably include the paucity of felsic magmatism, the predominance of fairly conventional tholeiitic mafic rocks, and the likely reduced, low salinity character of hydrothermal fluids.

- In contrast, the post 1850 Ma period was one of rich and varied mineralization, with an abnormal concentration of very large deposits. We regard the development of extensive evaporitic carbonate sequences and their influence on basinal and metamorphic hydrothermal fluid compositions to be a key element in this mineralization. The high heat flow throughout the second cycle would have encouraged large scale convective circulation of these fluids, both during basin evolution and regional metamorphism.

- The most important of the zones of reactivated faulting commonly control the distribution of mineralization. In particular, they may play an important role in locating the deep-seated mantle magmatism associated with diamonds.