BIOTIC OR ABIOTIC MINERALISATION OF FERRUGINOUS PISOLITHS IN TERTIARY PALAEOCHANNEL SEDIMENTS, YILGARN CRATON?

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INTRODUCTION

Ferruginous concentric pisoliths have been of interest due to their economic importance and mode of formation. Concentric pisoliths are typically developed in Tertiary palaeochannels, and various inorganic mechanisms (accretionary or concretionary) of their formation and Fe enrichment have been suggested (e.g., Nahon *et al*., 1977; Anand and Paine, 2002). Similar spherical pisoliths have been reported to occur on Mars where biotic mechanisms have been proposed to account for their formation. This paper will summarise (a) the petrography, geochemistry, morphology and dimensions of the Fe-mineralised structures in ferruginous pisoliths and (b) present mechanisms of their formation.

Ferruginous pisoliths and nodules were collected from palaeochannels at Rose Dam, Paddington, Kanowna, Sundowner and Madoonga and analysed by a variety of macro and micro-analytical techniques. Pisoliths occur in a grey matrix of kaolinite and smectite with minor amounts of quartz. Pisoliths make up 15-25% of the clay unit and are overlain by 5-20 m of Tertiary mottled clays and Quaternary colluvium and alluvium. The pisoliths and ooliths are typically yellow to brown, spherical and range in size from 1 to 10 mm. The nodules (5-15 mm) are minor component and are typically irregularly shaped.

Petrography of pisoliths

The pisoliths have high sphericity and typically have well-developed concentric laminated cutans and a variety of cores. Petrographic examination of pisoliths and nodules show the following characteristic features:

(i) Pisoliths nuclei comprise either: (a) older hematite-maghemite nodule; (b) ferruginous clay; (c) fragments of older goethite pisoliths; or most commonly, (d) goethite or hematite-replaced fragments of wood. Most nuclei, are situated at the centre, or slightly offset from the centre, of pisolith boundaries. Radial desiccation cracks are common within many of the hematite cores and cutans, suggesting hematite formation resulted from dehydration of goethite.

(ii) Some pisoliths lack a discernible nucleus.

(iii) Most nodules have large nuclei of sandy clay, in which small goethitic pisoliths and fragments, and an earlier generation of dark red hematitic nodules are embedded. Cutans of goethite are generally well developed, but thin.

(iv) Cutans comprise at least one third of the total pisolith diameter and are mostly fully concentric, with innermost cutan increasing in thickness so as to fill and smooth out depressions in the nucleus surface. The external shape of composite pisoliths appears to be circular regardless of nucleus shape. Cutans show different levels of dehydration.

(v) In places, there are two sets of cutans; broken hematitic cutans are encased by *in situ* concentric goethitic cutans.

Mineralogy and geochronology of pisoliths

Cutans are low (4-10 mole %) Al-substituted goethite with very small amounts of kaolinite and quartz. In general, the cutans show increasing ferruginisation and dehydration (maturity) towards the nucleus, as indicated by the increase in Fe and decrease in Al and Si contents. This relationship suggests replacement of kaolinite by goethite and dehydration of goethite to hematite. Low to moderate values of Al substitution in goethite are typical of hydromorphic environments, such as those associated with bog iron ores (Fitzpatrick and Schwertmann, 1982). Mineralogy of cores is highly variable ranging from goethite through hematite-maghemite to kaolinite-quartz. (U-Th)/He dating of goethites from cutans of concentric pisoliths range from 22-24.4 Ma in the Rose Dam palaeochannel (Dr Mark Paine written communication, 2006).

Scanning electron microscopy of pisoliths

Scanning electron micrographs (SEM) analyses of fresh broken surfaces of concentric pisoliths reveal several morphologies:

Goethitised wood fragment core: Core of fossilised wood reveal longitudinal channels, which on the basis of their lateral continuity, oval to circular cross section, and small (10-20 µm) diameter are likely to be the xylem vessels of angiosperms. Wood fragments were ferruginised *in situ* within palaeochannel sediments. Most of the xylem vessels appear to have been partly or wholly infilled or covered by rod shaped and spherical growths of goethite. The consistently small size of the fossilised wood fragments suggest they are derived from shrubs, rather than tress (de Broekert, 2002). However, it is possible that this reflects preferential preservation, with larger wood fragments forming unsuitable nuclei for pisolith development, and hence fossilisation by goethite. Fossilised wood fragments in the goethitic pisolith nuclei indicate the existence of woody vegetation covering the palaeochannel filling.

Older hematite–maghemite-rich core: Two types of biostructures were identified in hematite and maghemite cores derived from the older weathering profiles : (i) Globular bodies, 1-3 µm in diameter, preserved as perfect spheres covered with small (<0.1 µm) hematite spherical crystals and (ii) rods, straight or curved, up to 1 µm long that vary in diameter from 0.1 to 0.2 µm. An EDAX spectrum from a rod-shaped structure and clusters shows Fe as the main constituent. Rods were observed on many magnetic grains. They do not occur on the surface, but they fill cavities. Such cavities are absent on neighbouring rod-free magnetic grain surfaces which are covered by platy or spherical-shaped hematite crystals.

Concentric cutans: Spherical (0.1-0.3 µm) nanocrystals are the most common in the cutans and are grouped in clusters, chains or rods. The clusters are associated with biological filaments that are 0.5 to 1 µm wide and tens of micrometres long.

Origin of pisoliths

Pisoliths from a number of sites have distinct cores which in some cases can be identified as fragments of earlier pisoliths whereas others were derived from sandy clay sediments and wood fragments deposited within the palaeochannel. Laminated cutans grew around the cores. Disconformable contacts between sets of cortical laminae, sometimes including thin layers of quartz, indicate the laminae formed by accretion. This mode of pisolith formation is different to that proposed by Nahon *et al*., (1977), in which cortical laminae develop by the progressive inwards ferruginisation of a progenitor particle. Reworking of pisoliths took place as is clearly attested by the presence of abundant compound goethitic pisoliths.

Morphology and dimensions of the iron mineralised structures of both cutans and cores in the pisoliths show they may be of biological origin. Laminations appear to have formed sub-aqueous through the activity of microorganisms. Nanometre-scale spherical and rod–shaped structures represent mineralised bacterial cells as suggested by their shape and relatively small dimensions (Preat *et al*., 2000; Gradzinski *et al*., 2004; Chan *et al*., 2004; Tazaki *et al*., 2006). The complex interaction between biotic and abiotic processes in the weathered environments may also help in providing a model for the formation of the Martian pisoliths. The role of biotic and non-biotic processes in the formation of pisoliths as well as implications of this work will be discussed at the meeting.

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