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The origin of terrestrial pisoliths and pisolitic iron ore deposits: Raindrops and sheetwash in a semi-arid environment

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ABSTRACT

Ooliths evidently form by chemical precipitation in limnic, paralic, fluvial and marine environments, pisoliths, however, appear to be restricted to terrestrial environments. Typically composed of iron, aluminium and manganese sesquioxides with minor admixtures of quartz and kaolinite, they are widely distributed in tropical to subtropical regions overlying deeply weathered soil profiles. Although iron-, aluminium- and manganese-rich end members are important sources of these metals, their genesis is still enigmatic; their formation has never been observed or produced experimentally and current models for their origin are little more than guesses.

A new model is presented based on a unique personal observation in which pisoliths are formed by the action of charged raindrops during thunderstorms impacting on dry deeply weathered powdery soils. The pisoliths are transported across pediments by sheetwash, accumulating as thick deposits in the valley floors. Pisolites are characteristically unfossiliferous and typically clearly pedogenic. The absence of fine depositional layering, fossil seeds, leaves and pollen in pisolites is explained by bioturbation and the action of soil organisms during extended pedogenesis while the major coarse bedding features derive from erosional and depositional events in the evolution of the pediment.

Pisolitic iron ores (aka channel iron deposits, CID) are a special case of transported pisolitic ferricrust that form an important resource of medium grade iron ore (57–60 wt% Fe) in the Pilbara Region of Western Australia. Apart from minor deposits in the northern Yilgarn Province of Western Australia, they have not been found elsewhere. They differ from normal transported ferricrust and terrestrial pisolites not only in the exceptionally high iron and low alumina and silica content but also in containing abundant fossilised wood particles.

1. Introduction

Pisoliths are abundant in terrigenous deposits and soil profiles in many parts of Australia and overseas (Adeleye, 1973; Anand and Paine, 2002; Firman, 2006; Glassford and Semeniuk, 1995; Nahon et al., 1980), ranging from unconsolidated beds of pisolitic gravel to cemented ferricrete and may form major components of soils and colluvium associated with "lateritic" deep weathering. Pisoliths are also abundant in undoubtedly colluvial deposits of cemented scree such as canga and also form minor to major components of soils, colluvial gravels and detrital ores but are uncommon and typically fragmented in alluvial sediments. Terrestrial pisoliths have a wide range of compositions consisting principally of oxides and/or sesquioxides of iron, aluminium and manganese with variable admixtures of kaolinite, titanium oxide, quartz and other weathering-resistant minerals. The iron, aluminium and manganese-rich end members of terrestrial pisolites are less common but have considerable economic importance as major components of many world class ore deposits and they have been extensively studied during research into laterite formation (Mather et al., 2014; Nahon et al., 1980; Nahon and Tardy, 1992), in connection with bauxite deposits (Anand et al., 1991; Brimhall and Lewis, 1992; Loughnan and Bayliss, 1961; Taylor et al., 1992; Taylor and Eggleton, 2008) and pisolitic iron ores (Adair, 1975; Danišik et al., 2011, 2013; Hall and Kneeshaw, 1990; Harms and Morgan, 1964; Heim et al., 2006; Morris, 1988, 1994; Morris et al., 1993; Morris and Ramanaidou, 2007; Ramanaidou et al., 1991, 2003), and for their potential in geochemical exploration in deeply weathered terrains (Anand and Paine, 2002; Anand and Butt, 2010). High manganese varieties may be important constituents of manganese ore deposits (Bolton et al., 1988). Pisolitic gravel is also widely used as a road-making material, with minor decorative use in horticulture.

Typically occurring near or on the surface in deeply weathered terrains, pisoliths are spheroidal soil components, ranging up to 5 mm in diameter and consist of a core containing aggregated soil particles, mineral particles such as quartz, hematite, or lithic fragments, surrounded by one or more concentric layers forming a distinct cortex. The concentric layers of the cortex are typically colloform with abundant inclusions of quartz suggesting accretion of colloidal particles rather than precipitation from solution which would form radiating crystalline layers.

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Ferruginous pisolites are abundant globally but ferruginous pisolites of the richness and purity of the Pilbara pisolitic iron ore deposits have rarely been recorded elsewhere (Butt, 1979; Lascelles, 2014). These iron-rich pisolites with very low silica and alumina are important as medium grade iron ore resources (Morris, 1988; Ramanaidou et al., 2003). Previous models of the genesis of the pisolitic iron ore deposits have generally concentrated on the ore deposits without considering the characteristics of the widespread uneconomic pisolite deposits, e.g. pea gravel, and how they might relate to the origin of the ore deposits. It was previously suggested that the spheroidal shape was formed by the rolling action of moving water in streams and rivers (Pettijohn, 1957) and although high energy flows such as streams and rivers are generally destructive of pisoliths and the pisolites show no evidence of fluvial deposition. The generally accepted model considers pisoliths to form by modification of sesquioxide-rich concretions within the soil or saprolite of deeply weathered terrains and the layers of cortex acquired either in situ or during subsequent erosion and to be either in situ or transported locally by low energy flows such as sheetwash (Eggleton and Taylor, 2006; Morris, 1994). Nahon et al. (1980) described ooliths and pisoliths derived from “glauconite” grains in greensands by replacement and successive centripetal deposition of iron oxides and Schwann (2009) suggested that the Robe River deposits derived from alteration of the Mardie Greensand Formation. Morris and Ramanaidou (2007) considered pisolitic iron ore to be fluvial deposits and the term channel iron deposits (CID) has come into general use throughout the industry.

The precise mechanism by which pisoliths form in the soil has never been observed and their current genesis model is purely hypothetical. None of the current models explain the sphericity of pisoliths or the process by which successive coatings are accreted. Normal sesquioxide-rich concretions can form in any shape and typically have gradational boundaries with the enclosing soil and saprolite and rarely, if ever, form the main constituent of stratigraphic horizons. Internal layering is also poorly defined and similar to Liesegang rings In striking contrast, pisoliths are typically spheroidal with well-defined internal and external boundaries and may comprise widespread clast supported stratigraphic units from ~1 to ~100 m thick, commonly with little or no matrix. Also pisoliths are only found in transported deposits and not in basement saprolite. The rings in concretions are precipitated from solution whereas the cortical rings in pisoliths are accreted. A new model for the formation of pisoliths is proposed that was conceived after a unique and totally unexpected observation of the initiation of pisolith formation by the impact of raindrops on dry soil during a sudden thunderstorm. The proposed new model explains many of the unique characteristics of pisoliths and pisolites but being based on a single uncorroborated observation remains hypothetical until supported by further independent observations.

This paper falls into two parts: (A) the origin of terrestrial pisoliths in general and (B) the origin of the ore grade fossiliferous iron pisolites. Part A is based on numerous observations of pisoliths throughout the Hamersley Province, Yilgarn Province, southwest Western Australia, and at Fifield in New South Wales (Fig. 1), and Part B is based on examination of diamond drill core from pisolitic iron ore at Yandi and Hope Downs, and mapping and RC drilling of the Mindy Mindy prospect. It is intended to highlight inconsistencies in current genesis models and provide a new model that more closely fits the known characteristics of pisolitic iron ore deposits and may enhance exploration targeting and the discovery of high-grade iron pisolite deposits in other parts of the world.

2. Part A: Terrestrial pisoliths

Beds of unfossiliferous, unconsolidated to locally cemented aluminous/ferruginous pisoliths (pea gravel) commonly occur in close proximity to outcrops of BIF in both the Pilbara and Yilgarn regions but are also widespread throughout Western Australia, commonly forming widespread sheets on the plateau areas of southwest Australia (Wilde and Low, 1978), and also in Queensland (Klenowski, 2015) where they are an important source of road-making material, as well as architectural and horticultural feature gravels. Sheets of typically

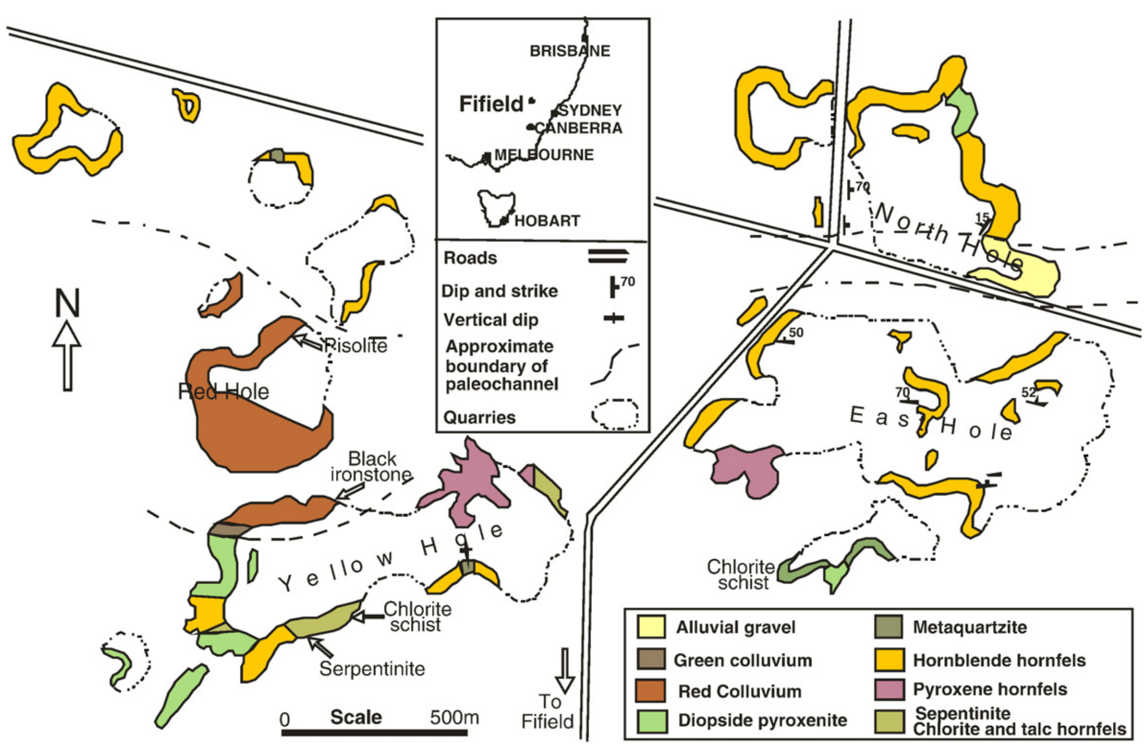

Fig. 1. Geological map of the Fifield magnesite deposits (inset: map of southwest Australia showing location of Fifield magnesite deposits).