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Climatic and geochemical implications of Archean pedogenic gypsum in the Moodies Group (~3.2 Ga), Barberton Greenstone Belt, South Africa

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ABSTRACT

Lithic sandstones of braided-fluvial to supratidal facies in the Paleoarchean Moodies Group (~3.22 Ga, Barberton Greenstone Belt, South Africa) include several regionally traceable units with common to abundant, in places rock-forming, nodular concretions of megaquartz pseudomorphs after gypsum, barite and calcite. Concretionary accumulations are stratiform and commonly associated with aqueously reworked, fine-grained, tuffaceous sediment of originally rhyodacitic composition and can grow to fist-sized agglomerates in crusts tens of m in lateral extent. Weathering of tuffaceous material and feldspar delivered alkali cations such as Ca, Ba, and K, while carbonates were likely supplied by silicate weathering of mafic to ultramafic volcanic rocks during exposure to a CO_2-rich atmosphere. Sulfate ions were partly delivered by oxidative pyrite dissolution which may have included microbial and abiotic disproportionation of volcanic S or SO_2. Concretionary growth apparently took place under pedogenic to early diagenetic conditions within unconsolidated granular sediment in the vadose zone, dominated by seasonal fluctuations of the groundwater level under evaporitic conditions. The concretions likely represent the oldest terrestrial evaporites known to date and form part of the oldest known compound paleosols. Their formation and composition constrain the local occurrence of sulfate in the Archean atmo- and hydrosphere, their interaction with the emerging biosphere, Archean weathering regime, local climate, and vadose-zone hydrodynamics.

1. Introduction

Composition and facies associations of numerous Archean units worldwide suggest deposition in terrestrial settings and thus provide a record of Earth's earliest non-marine environments (Grandstaff et al., 1986; Mueller and Dimroth, 1987; Macfarlane et al., 1994; Eriksson et al., 1998; Heubeck and Lowe, 1999; Watanabe et al., 2000; Eriksson et al., 2004; Awramik and Buchheim, 2009). However, surprisingly little is known about the interaction of these sediments with the atmosphere and the emerging biosphere, thereby constraining terrestrial weathering conditions and early diagenetic processes. This is mostly due to the poor preservation potential of such features but certainly also due to the lack of suitable fresh outcrops permitting unambiguous identification of relevant details. A high degree of post-depositional alteration, pervasive deformation and metamorphism, and perhaps also a general lack of awareness of paleo-weathering and early diagenetic features in Archean sedimentary strata complicate the identification and analysis of the relevant rock record.

Here we describe the widespread, mappable occurrence of early diagenetic nodular concretions that formed in unconsolidated sandy sediments in fluvial and coastal settings of the Archean Moodies Group, South Africa (ca. 3.22 Ga; Tegtmeyer and Kröner, 1987; Kröner et al., 1991; Heubeck and Lowe, 1994b; Kamo and Davis, 1994; Heubeck et al., 2013). Although their original composition has largely (but not entirely) been metasomatically replaced by silica, the excellent outcrop conditions and the low degree of penetrative deformation of the Moodies Group allow reconstruction of facies and paleo-hydrological parameters. The objective of this contribution thus is to provide a detailed description of these strata at regional, outcrop, and hand-sample scale as well as a petrographic

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characterization of the concretions to infer Archean terrestrial weathering and pedogenic processes. Isotopic constraints will be treated in a forthcoming manuscript.

2. Geological setting

The Barberton Greenstone Belt (BGB) is located in northeastern South Africa and forms part of the Archean Kaapvaal Craton. Its stratigraphic fill is known as the Barberton Supergroup which is subdivided (from base to top) in the Onverwacht, Fig Tree and Moodies Groups (Fig. 1). The lowermost, ca. 8–10 km thick, 3.57–3.30 Ga-old Onverwacht Group is mainly composed of mafic to ultramafic volcanics, such as komatiites and basalts; cherts are subordinate. Its setting is thought to represent an oceanic plateau or a hot-spot volcanic complex (Viljoen and Viljoen, 1969; Anhaeusser, 1976; Lowe, 1994; Lowe and Byerly, 2007; De Wit et al., 2011). The overlying, up to 3 km thick Fig Tree Group is 3.26–3.225 Ga old and consists mainly of epiclastic, volcaniclastic, and chemical sedimentary rocks including thick turbidites, banded-iron formation, chert, some stratiform barite, and felsic to intermediate volcanic and subvolcanic rocks (Heinrichs and Reimer, 1977; Reimer, 1980; Condie, 1997; Lowe et al., 1999; Hofmann, 2005). The uppermost unit in the BGB, the Moodies Group, reaches a thickness of up to 3.7 km and consists mainly of quartz-rich sandstones, polymict conglomerates and argillaceous siltstones deposited in terrestrial to shallow-marine environments including alluvial, fluvial, deltaic and tidal settings (Anhaeusser, 1976; Eriksson, 1977, 1978, 1979, 1980; Heubeck and Lowe, 1994a, 1994b, 1999; Eriksson and Simpson, 2000; Eriksson et al., 2006; Simpson et al., 2012; Heubeck et al., 2013). The greenstone belt is approximately divided axially by the Inyoka Fault into northern and southern domains which show differences in their stratigraphy, lithology, petrographic composition, tectonic history and age at formation level (Heinrichs and Reimer, 1977; De Wit et al., 1992; De Ronde and de Wit, 1994; Heubeck and Lowe, 1994a, 1994b, 1999). Moodies strata generally occupy large synclines separated by tightly folded and faulted anticlinal zones. Most strata dip subvertically. However, undeformed conglomerate clasts, the lack of foliation and mica reorientation on hand sample and thin-section scale as well as the near-absence of shear or strain indicators show that Moodies strata have experienced only minor strain. Strain was significantly higher near major fault zones, the sheared intrusive greenstone belt margin, or in fold hinges (Gay, 1969; Anhaeusser, 1969a, b; Lamb, 1984; Heubeck and Lowe, 1994b). The central part of the BGB has experienced lower-greenschist-facies regional metamorphism while contact metamorphism is important near its margins (Heubeck et al., 2015). Widespread early silicification of Moodies Group rocks strongly reduced mechanical compactability and allowed excellent preservation of original sedimentary textures and structures. Silicifiaction further led to preservation of delicate details such as microbial mats, desiccation cracks, volcanic lapilli, etc.

This study focuses on Moodies strata north of the Inyoka Fault and includes strata exposed in the Stolzburg, Dycedale and the Eureka Synclines (Fig. 1). The age of the Moodies Group in this part of the greenstone belt is well constrained by detrital zircons, stratiform tuff beds and several cross-cutting dikes (Zeh et al., 2013; Heubeck et al., 2013). Deposition started between 3225 and 3218 Ma (Tegtmeyer and Kröner, 1987; Kröner and Todt, 1988; Kröner et al., 1991; Heubeck and Lowe, 1994b; Kamo and Davis, 1994; Byerly et al., 1996; Layer et al., 1996; Sanchez-Garrido et al., 2011; Heubeck et al., 2013) and ended prior to 3219 ± 9 Ma, the age of a felsic dike crosscutting the uppermost Moodies Group in the Moodies Hills Block (Heubeck et al., 2013). Thus, Moodies

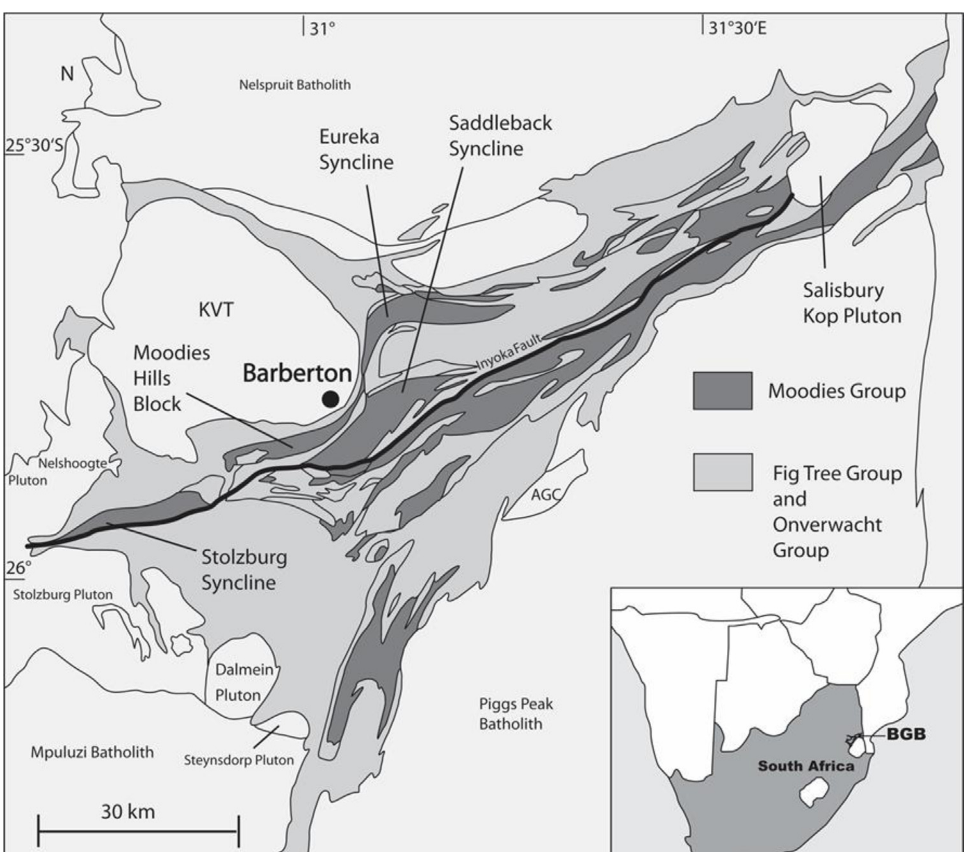

Fig. 1. Generalized geological map of the Barberton Greenstone Belt (modified after Anhaeusser, 1969).