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Nature and origin of the protolith succession to the Paleoproterozoic Serra do Navio manganese deposit, Amapa Province, Brazil

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ABSTRACT

Until its closure in 1997, the Serra do Navio deposit, located in Amapá Province, Brazil, was one of the most important sources of high-grade manganese ore to the North American market. The high-grade manganese oxide ores were derived by lateritic weathering from metasedimentary manganese protoliths of the Serra do Navio Formation. The local geological context and nature of this protolith succession are not well understood, due to poor surface outcrop conditions, and intense deformation. However, based on similar age, regional tectonic setting and lithology the Paleoproterozoic volcanosedimentary succession that includes the Serra do Navio Formation is widely believed to be similar in origin and laterally equivalent to the Birimian Supergroup in West Africa. For the present investigation several diamond drill cores intersecting the protolith succession were studied. Detailed petrographic and whole rock geochemical studies permit distinction of two fundamental lithological groups comprising of a total of five lithotypes. Biotite schist and graphitic schist lithotypes are interpreted as former metapelites. A greywacke or pyroclastic protolith cannot be excluded for the biotite schist, whereas the graphitic schist certainly originated as a sulfide-rich carbonaceous mudstone. Rhodochrosite marble, Mn-calcite marble and Mn-silicate rock are grouped together as manganiferous carbonate rocks. Manganese lutite constitutes the most probable protolith for rhodochrosite marble, whereas Mn-calcite marble was derived from Mn-rich marl and Mn-silicate rock from variable mixtures of Mn-rich marl and chert.

The sedimentary succession at the Serra do Navio deposit is similar to that encountered at many other black shale and chert-hosted Mn carbonate deposits. A metallogenetic model is proposed, predicting deposition of manganese and closely associated chert in intra-arc basins, in environments that were bypassed by distal siliciclastic (carbonaceous mud) and proximal pyroclastic/siliciclastic detritus. Positive Ce anomalies and $\delta^{13}C_{VPDB}$ values of −4.3 to −9.4 per mill suggest that manganiferous carbonates derived during suboxic diagenesis from sedimentary Mn^{4+} oxyhydroxide precipitates. Metamorphic alteration of manganese carbonate–chert assemblages resulted in the formation of Mn-silicates, most importantly rhodonite and tephroite; porphyroblastic spessartine formed where Mn-carbonate reacted with aluminous clay minerals. Microthermometric studies of fluid inclusions in spessartine porphyroblasts suggests that peak metamorphic conditions reached the upper greenschist facies (1–2 kbars and 400–500 °C). Retrograde metamorphism is marked by partial re-carbonation, expressed by the formation of small volumes of rhodochrosite, and Mn-calcite that are closely associated with quartz, chlorite and minor amounts of sulfides related to post-metamorphic veinlets. It is this metamorphosed succession that sourced the high-grade manganese oxide ores during prolonged lateritic weathering.

1. Introduction

The Serra do Navio manganese deposit is located in the Amazonian rainforest, 235 km northwest of the regional capital of Macapá, in the Province of Amapa, northwestern Brazil. With proven reserves of over 43 million tons of manganese, the exploitation of the Serra do Navio deposit by the Brazilian company *Indústria e Comércio de Minérios S.A* (ICOMI) began early in 1957. During its early years of production, Serra do Navio was the single most important source of high-grade manganese ore to the North American market. The operation was finally closed in 1997, due to depletion of the mineable ore resource.

Despite its considerable economic importance there are remarkably few published contributions on the geological setting of the Serra

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do Navio manganese deposit. All authors agree that high-grade manganese ores formed by supergene residual enrichment, at the expense of a manganese carbonate-rich protolith (Costa, 1997; Gebert, 1989; Holtrop, 1965; Rodrigues et al., 1986; Scarpelli, 1968, 1973). The nature and origin of this protolith has, however, received surprisingly little attention (Scarpelli, 1973). Based on the available published data Roy (2006) recently proposed a tentative genetic model for the Serra do Navio deposit.

This contribution provides the first comprehensive description of the lithostratigraphy of the manganiferous protolith succession and associated host rocks at the Serra do Navio deposit, based on the study of selected diamond drill core samples. The mineralogy, petrology and whole rock geochemistry of the different metamorphic lithotypes is described. Microthermometric studies of fluid inclusions in peak metamorphic garnet are used to constrain P–T conditions of metamorphism. Furthermore, this study reports the first stable isotope data for the manganiferous carbonates from the Serra do Navio deposit. Data are used to invoke a metallogenetic model consistent with the one previously proposed for chemical and siliciclastic sediments of the West African Birimian Supergroup (Leube et al., 1990). Further, this study demonstrates that detailed geochemical, mineralogical, petrographic analyses permit significant constraints to be placed upon possible sedimentary protoliths of a metamorphosed and strongly deformed succession. These constraints are consistent with a metallogenetic model proposed for the purportedly coeval Birimian deposits.

2. Geological setting

The Serra do Navio deposit is hosted by metamorphosed and strongly deformed Paleoproterozoic rocks forming part of the Guiana Craton of the Amazonian Craton (Fig. 1a). The Amazonian Craton comprises of two main nuclei that expose suites of Archean and Paleoproterozoic rocks. These are the Guiana Craton and the Central Brazil Craton (Zhao et al., 2002). The Guiana Craton, with a surface area of nearly 900,000 km^2, constitutes the northern part of the Amazonian Craton (Fig. 1b). It is composed of both Archean and Paleoproterozoic intrusives and supracrustal rock suites that formed during protracted periods of intense magmatism, metamorphism and deformation culminating in the Trans-Amazonian tectonothermal event, bracketed at 1.9–2.1 Ga (Voicu et al., 2001; Zhao et al., 2002). The Trans-Amazonian tectonothermal event did not only rework the Archean basement, but also affected volcanic and volcano-sedimentary successions that have been dated at 2.11 Ga (Voicu et al., 2001). Today, these can be traced through discontinuous exposures as tightly folded and variably metamorphosed fold belts, surrounded by coeval granitoids (Fig. 1a). This assemblage is similar in age and composition to the Birimian Supergroup of West Africa (Dantas et al., 2004; Zhao et al., 2002). Accordingly, the assemblage is interpreted as a series of volcanic island arcs and intermittent sedimentary basins, with closely associated granitoid intrusions (Ledru et al., 1994).

The protolith succession to the Serra do Navio manganese deposit constitutes part of such a Paleoproterozoic volcanosedimentary succession that is exposed in the south western part of the Amapa Province. The succession forms a poorly exposed NW–SE striking fold belt constituted by the Vila Nova Group and surrounded by granitic gneiss domes (Fig. 2). The relation between these deformed granitic intrusions and the Vila Nova Group remains poorly constrained. Scarpelli (1973) suggested that the Vila Nova Group unconformably overlies the granitic intrusions, whereas more recent regional studies prefer a coeval relationship between granitic gneisses and metamorphosed volcanosedimentary successions (Voicu et al., 2001).

The Vila Nova Group has been subdivided into the volcanic Jornal Formation and the metasedimentary Serra do Navio Formation (Fig. 2). The Jornal Formation of the Vila Nova Group is a thick succession of basaltic amphibolites (Dorr, 1973). The metasedimentary Serra do Navio Formation, host to the Serra do Navio manganese deposit, appears

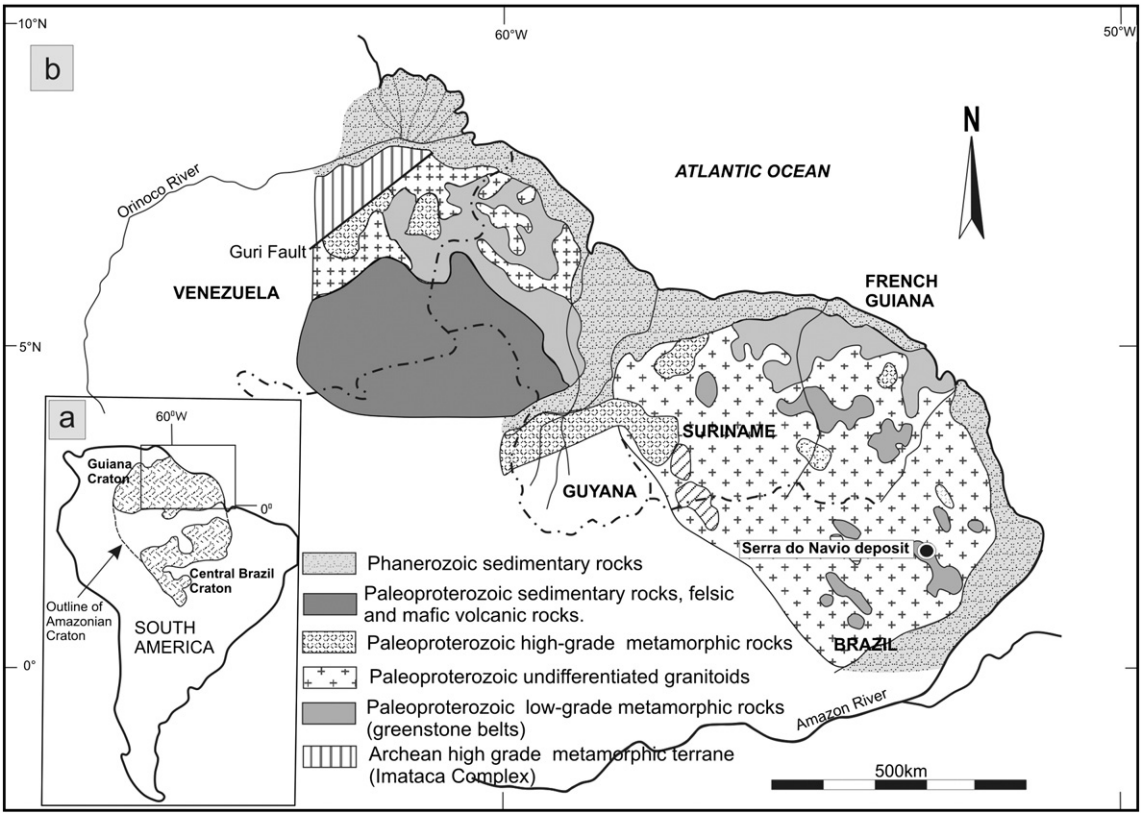

Fig. 1. a: Geology of the northern part of the Guiana Craton, showing the location of the Serra do Navio deposit (modified after Voicu et al., 2001); b: Position and extent of the Guiana Craton and the Central Brazil Craton as part of the Amazonian Craton.