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Nanhuan manganese deposits within restricted basins of the southeastern Yangtze Platform, China: Constraints from geological and geochemical evidence

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ABSTRACT

The Nanhuan manganese deposits in the southeastern Yangtze Platform occur in the black shale series in the lower part of the Datangpo Formation. In order to constrain the genesis of the deposits, a detailed study was undertaken that involved field observations, major and trace element analyses, organic carbon analyses, and isotope analyses (C, O, S). The major findings are as follows. (1) The ore-bearing rock series, morphology of the ore bodies, and characteristics of ores in several deposits are similar. The ore minerals are rhodochrosite and manganocalcite. The gangue minerals are mainly quartz, feldspar, dolomite, and illite. Minor apatite and bastnaesite occur in the manganese ores. (2) The ores are enriched in Ca and Mg, whereas they are depleted in Si, Al, K, and Ti compared to wall rocks. The ores normalized to average Post-Archean Australian shale (PAAS) are enriched in Co, Mo, and Sr. The chondrite-normalized rare earth element (REE) patterns for ores and wall rocks are between those of typical hydrogenous and hydrothermal type manganese deposits. Additionally, the ores have positive Ce anomalies with an average Ce/Ce* of 1.23 and positive Eu anomalies with an average Eu/Eu* of 1.18 (normalized to PAAS). (3) The average content of organic carbon is 2.21% in the samples, and the average organic carbon isotopic value ($\delta^{13}C_{V\text{-}PDB}$) is −33.44‰. The average inorganic carbon isotopic value ($\delta^{13}C_{V\text{-}PDB}$) of carbonates in Gucheng is −3.07‰, while the values are similar in the other deposits with an average of −8.36‰. The oxygen isotopic compositions ($\delta^{18}O_{V\text{-}PDB}$) are similar in different deposits with an average of −7.72‰. (4) The sulfur isotopic values ($\delta^{34}S_{V\text{-}CDT}$) of pyrite are very high and range from +37.9‰ to +62.6‰ (average of 52.7‰), which suggests that the pyrite was formed in restricted basins where sulfate replenishment was limited. The sulfate concentrations in the restricted basins were extremely low and enriched in $\delta^{34}S$, which resulted in the very high $\delta^{34}S$ values for the pyrite that formed in the manganese deposits. Therefore, a terrigenous weathering origin for manganese can be excluded; otherwise, the sulfate would have been introduced into the basins together with terrigenous manganese, which would have decreased the $\delta^{34}S$ values of pyrites. The manganese, which originated from hydrothermal processes, was enriched in the restricted and anoxic basins, and then, it was oxidized to manganese oxyhydroxide in the overlying oxic waters whereby the products precipitated into the sediments. The manganese oxyhydroxide in the sediment was then reduced to Mn^{2+} and released to the pore waters during the process of diagenesis. Some organic carbon was oxidized to CO_3^{2-}, which made the depletion of ^{13}C in manganese carbonates. Therefore, we suggest that the Nanhuan manganese deposits are hydrothermal–sedimentary/diagenetic type deposits.

1. Introduction

The Nanhuan manganese deposits, which are located in the southeastern Yangtze Platform, China, occur in the black shale series in the lower part of the Datangpo Formation (Fan and Yang, 1999; Liu et al., 1989). Typical deposits include the Yanglizhang, Dawu, Datangpo, Daotuo, and Xixibao deposits in Guizhou Province, the Xiushan deposit in Chongqing City, the Minle, Xiangtan, and Guzhang deposits in Hunan Province, and the Gucheng deposit in Hubei Province (Fig. 1). The Daotuo (with a reserve of 142 Mt (million tonnes)) and Xixibao (with a reserve of 20 Mt) deposits were discovered during recent explorations, and these new discoveries have increased estimates of manganese resources in the study area to ~400 Mt (Zhou et al., 2013). The average grade of manganese ranges from 15.4% to 22.1% in the study area (Table 1).

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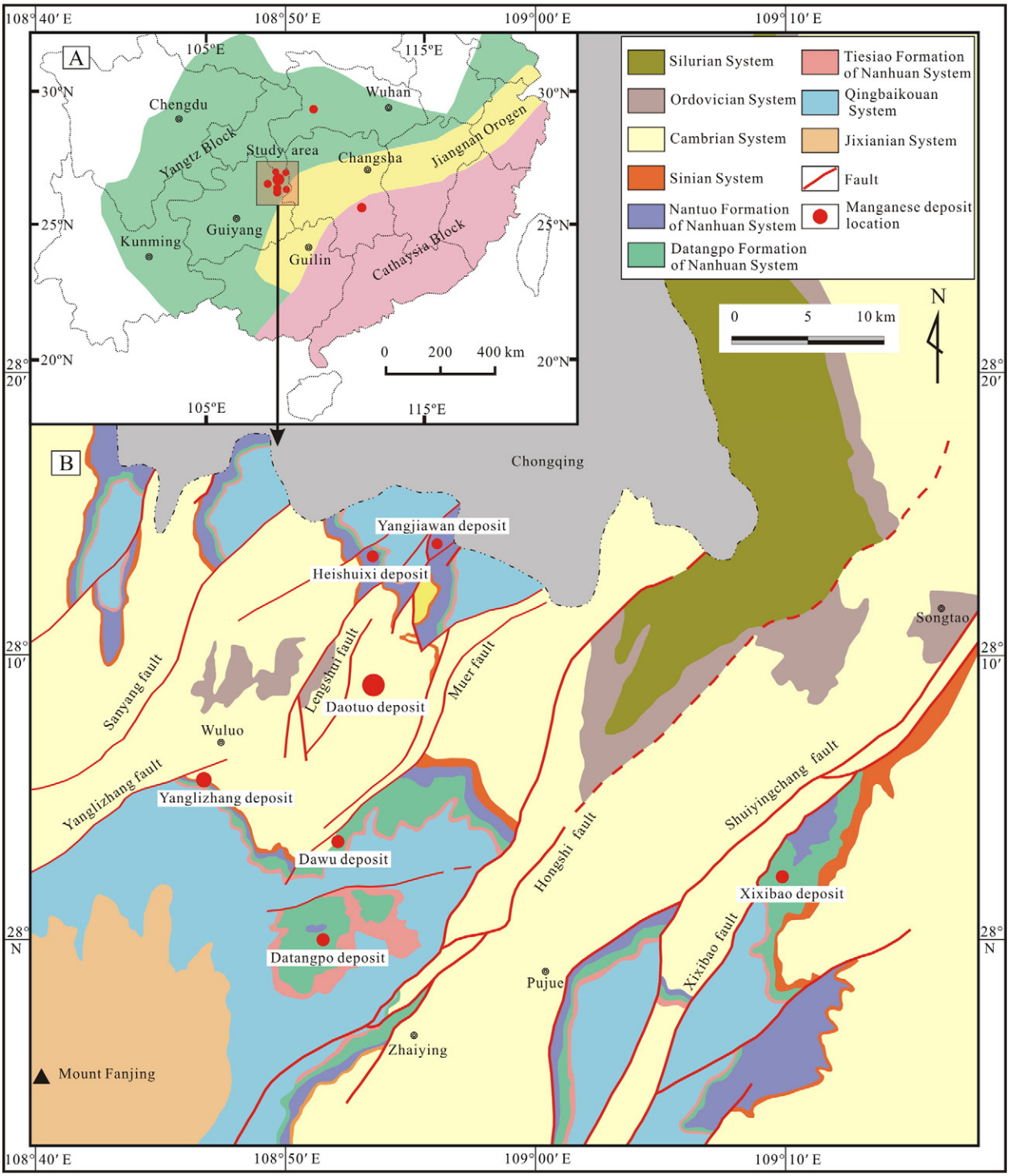

Fig. 1. (A) Tectonic sketch map of South China and the location of the study area. (B) Geological sketch map of the Nanhuan manganese deposits in eastern Guizhou, China. Modified after Zhu et al. (2013).

Many researchers (Chen and Chen, 1992; He et al., 2014; Kuang et al., 2014; Liu et al., 1989; Yang et al., 2002; Yang and Lao, 2006; Zhou et al., 2013) have investigated the mineralization mechanism. However, there are two main unresolved arguments regarding the ore genesis, and views put forth about the ore genesis have been inconsistent. The first one involves the manganese source, and the second one involves the formation of manganese carbonates. There have been controversies about the sources of the manganese in the deposits, and proposed models have included terrigenous weathering (Tang and Liu, 1999), submarine hydrothermal processes (Chen and Chen, 1992; He et al., 2014; Xie et al., 1999), and submarine volcanic activities (Kuang et al., 2014; Yang and Lao, 2006). Regarding the formation of manganese carbonates, some researchers have suggested that they precipitated directly from seawater (Zhou, 2008; Zhou et al., 2013), while others have proposed that they were formed from the reduction of Mn-oxyhydroxides in the sediments (Wang et al., 1985; Zhang, 2014; Zhang et al., 2013a,b). Therefore, different genetic processes for these deposits have been suggested, such as biogenesis (Liu et al., 1989),