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Origin of early Cambrian black-shale-hosted barite deposits in South China: Mineralogical and geochemical studies

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ABSTRACT

The barite deposits hosted in early Cambrian black shales in South China are a classic example of sediment-hosted stratiform barite deposits, and their origin is controversial. In this paper, we address the origin of these deposits by a comprehensive integrated study of mineralogy and geochemistry, based on a case study of the Dahebian deposit in Tianzhu County, Guizhou Province, which contains the largest global reserve of barite. Particular attention was paid to a comparison between ore and non-ore horizons, as this has not been fully addressed previously. The results indicate that the ore horizon is dominated by barite with intergrown hyalophane, quartz and pyrite. The hyalophane is zoned, implying hydrothermal activity. In contrast, the non-ore horizons contain minor amounts of granular barite and are free of hyalophane, suggesting that these horizons experienced weaker hydrothermal activity. The contrasting trace and rare earth element compositions of the ore and non-ore samples indicate dilution of complex geochemistry with multiple ore-forming processes and materials during barite mineralization. The barite mineralization was rapid, as demonstrated by the relatively low terrigenous input in the ore samples compared with the non-ore samples. The ore samples have positive Eu anomalies (>3.0), indicative of hydrothermal activity during mineralization. Organic geochemical analyses provide evidence of the development of abundant organic matter and hydrothermal activity. The sulphur isotopic values ($\delta^{34}S$) of the ore samples show an enrichment relative to contemporaneous early Cambrian seawater and substantial variation (+36.7‰ to +43.8‰), indicative of sulphur derived from seawater that was affected by sulphate-reducing bacteria and hydrothermal activity in a restricted marine environment. To summarize, the barite deposit in the Dahebian site was most likely formed in a generally restricted and reducing marine basin environment with rapid sedimentation during a period of hydrothermal activity. These results have general implications for the future study of other black-shale-hosted deposits worldwide.

1. Introduction

Black-shale-hosted barite deposits are an important type of sediment-hosted stratiform mineral deposit and are the main source of barite globally (Clark et al., 2004). As such, these deposits have been a research focus for decades; however, the origin of these deposits remains debated. The majority of researchers considers that these deposits were formed as a result of submarine hydrothermal activity (Lydon et al., 1985; Poole, 1988; Clark et al., 1991). Some studies have suggested that the ore mineralization is related to marine biological activity, because the black shales that host these deposits are commonly organic-rich with total organic carbon (TOC) levels generally exceeding 1.0% (Jewell and Stallard, 1991; Gao, 1998; Elmas et al., 2012). Others have suggested that these deposits have a terrigenous chemical sedimentary origin (Chu, 1989). These uncertainties limit our understanding of the nature of these deposits and hinder future exploration.

Black-shale-hosted barite deposits occur widely across the world, including in South China, the Qinling Mountains of central China, Nevada (USA) and Mangampeta, India (Clark et al., 2004). Of these deposits, the Dahebian barite deposit in Tianzhu County, Guizhou Province, South China is the largest known barite mineral reserve globally (Yang et al., 2008), and thus has been the subject of many previous studies (Chu, 1989; Gao, 1998; Wu et al., 1999; Yang et al., 2008). The origin of this deposit is controversial. It is generally believed to have formed by submarine exhalative hydrothermal activity (Wu et al., 1999; Xia et al., 2004, 2005a, 2005b; Yang et al., 2007, 2008), although terrigenous chemical

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sedimentary (Chu, 1989) and biological (Gao, 1998) origins have also been proposed.

The formation of a mineral deposit is a complex process, and comparison of mineralized ore and non-ore units in an ore-bearing sequence can provide valuable insights into the origin of the deposit. For instance, a study of the Ni–Mo deposits in the Zunyi and Zhangjiajie areas of South China by Kříbek et al. (2007) revealed that the mineralized ore horizon contains three different types of organic matter, whereas the surrounding barren black shales contain only one type. This suggests that a certain type of organic matter is necessary for the formation of the Ni–Mo deposits in this area (Cao et al., 2013), demonstrating the utility of this research approach (Greenwood et al., 2013). For the Dahebian barite deposit, the majority of research has been focused on the mineralized ore horizon itself, and the non-ore horizons have been neglected.

In this study, we examine the mineralogical and geochemical differences between mineralized ore and barren horizons of the Dahebian barite deposit, and use these data to provide a more comprehensive understanding of its origin.

2. Geological setting

The Dahebian barite deposit is located on the southeastern margin of the Yangtze Craton, South China, which is bounded to the north and southeast by the North China Craton and the South China fold belt, respectively (Fig. 1). During the late Sinian (Neoproterozoic) to the early Cambrian, the studied area was generally a passive continental margin, developed in the Jiangnan–Longsheng island arc and a subsequent back-arc basin (Yang et al., 2007; Wang et al., 2012). The area was part of the Hunan–Guizhou–Guangxi rift basin on the continental margin, and thus deposition within the area took place in an uncompensated marine basin environment on the continental slope within deep water (Liu et al., 1993; Yang et al., 2007). The area contains a number of E–W- and NE–SW-trending extensional faults that were active during the early Palaeozoic, leading to the formation of graben in some regions (Li and Yu, 1991; Liu et al., 1993). Barite deposits in this area generally crop out in parallel zones along these deep-seated faults and are concentrated in areas between oceanic rises and secondary hollows or depressions sandwiched between rises (Li and Yu, 1991; Fang et al., 2002).

Folds and faults are common throughout the study area, including NE–SW-trending Caledonian folds and faults, and the NNE–SSW-trending Yanshanian thrust-fold belt (Fig. 2). The area is characterized by a >7000 m cumulative thickness of exposed sediments, including the Proterozoic Xiajiang Group, and Sinian, Cambrian, Ordovician and Silurian deposits. Of the sediments, the Cambrian units account for approximately 30% of the tortal sediments, while the Sinian, Ordovician and Silurian units occur only locally. The Lower Cambrian Niutitang Formation is the main stratigraphic interval hosting barite ore mineralization in the study area. This formation crops out continuously in belts of between several kilometres and several tens of kilometres in length along a NE–SW stratigraphic strike. The mineralized ore units dip at 20–40° to the northwest and southeast in the northwestern and southeastern sections of the formation, respectively. The ore horizon generally has a thickness of 3–5 m, with a maximum of 10.2 m.

The barite ore horizon is underlain by thin-bedded black siliceous rocks that locally contain lenticular and radial barite nodules and black shale, and is overlain by black shales containing pyrite and granular, needle-shaped, banded and lenticular barite. The ore horizon is layered and relatively continuously distributed. A few late-stage well-crystallized barite veins occur in both the ore-bearing and non-ore-bearing horizons. As these veins are rarely present, they are not the main focus of this study.

3. Samples and methods

The samples analysed in this study were collected from both ore and non-ore horizons (Fig. 3), to conduct a comparative analysis as outlined above. As shown in Fig. 3, the ore samples are sandwiched

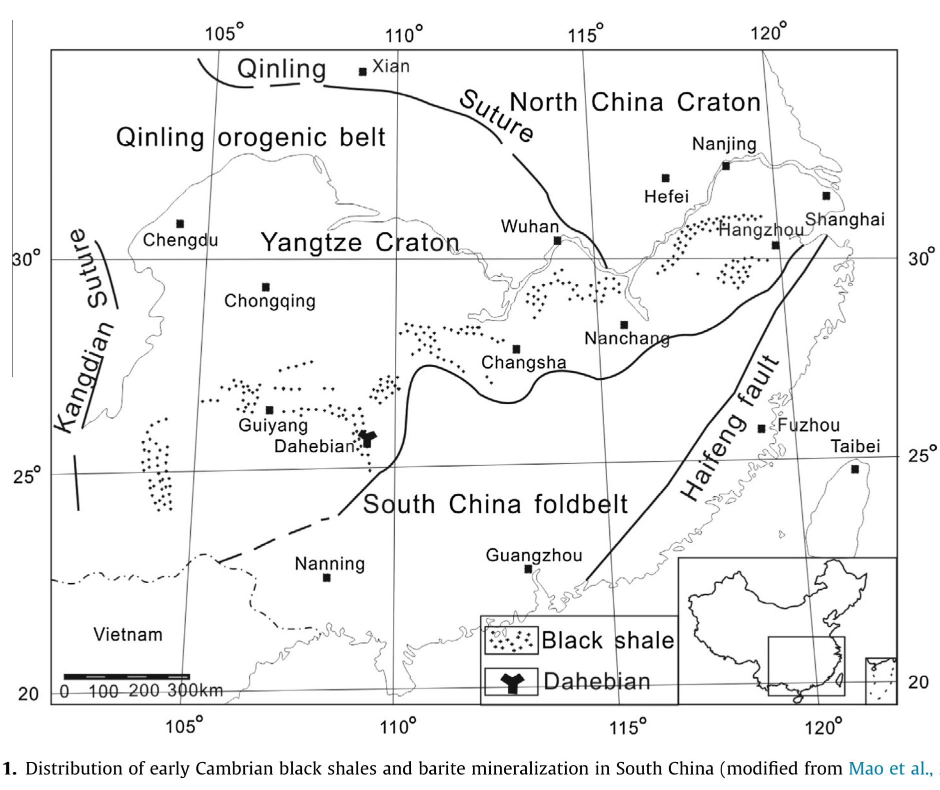

Fig. 1. Distribution of early Cambrian black shales and barite mineralization in South China (modified from Mao et al., 2002).