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Discovery of hydrothermal venting community at the base of Cambrian barite in Guizhou Province, Western China: Implication for the Cambrian biological explosion

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Abstract

The barite deposit in the Niutitang Formation of Lower Cambrian, in Tianzhu County, Guizhou Province, western China, is a super-large barite deposit with about 2×10^9 tons of reserves. Mineral, petrological and geochemical studies reveal that this barite deposit belongs to a hydrothermal sedimentary deposit. Microscopic observations indicate that a lot of algae, sponge spicules and tube-type fossils are well-preserved in this barite section, and moreover, those fossils share most characteristics of the deep-sea hydrothermal venting community in the modern Pacific. We suggest that the hydrothermal venting community was thriving in hydrothermal vent in early Cambrian, and it is of great significance for elucidating the geological background of the ''Cambrian explosion''.

Keywords: Hydrothermal community; Barite; Cambrian; Guizhou

1. Introduction

Barite deposits are widely distributed at the Lower Cambrian in Tianzhu County, eastern Guizhou, and Xinhuang County, western Hunan, which covers the Dahebian-Dagongtang barite deposit with about 2×10^9 tons of reserves. The barite ore-layer occurs at the base of Niutitang Formation of Lower Cambrian, and parallel to the sedimentary lane. The ore-layer extends 20 km long, 1–3 m in thickness, up to 5 m in maximum, in the forms of bedding, bands, lens, pillar, discus and nodules. The ore is black, black–grey, and white–grey in color. The content of $BaSO_4$ is generally 85–95%, and rich in carbon [1].

The investigated area is located at Dahebian-Dagongtang barite deposit, Tianzhu County (Fig. 1), along the southern side of Yichang-Douyun syn-faulting. The lithofacies, strata thickness, tectonic evolution and fossil assemblage were all different on the two sides of the syn-faulting in Sinian and Early Paleozoic. Thus, sedimentary basin was controlled by syn-fault. The barite deposits are distributed along the Sangzhi-Jishou-Xinhuang-Tianzhu deep fault, and the largest hydrothermal venting cloud is located at Dahebian region, Tianzhu County, forming a super-large barite deposit in this region.

Previous studies on the deposits [2–4] proposed three original types, i.e. biogenesis barite [5], terrestrial-chemical sediment barite [6], and hydrothermal venting barite on the seafloor [1,7–14] to account for the origin of barite. Crustal evolution led to continent extension in early Cambrian and the hydrothermal deposit was widely distributed in Lower Cambrian in the world. On the other hand, since the ''Cambrian explosion'' took place in early Cambrian, how do the hydrothermal biota thrive in hydrothermal vent

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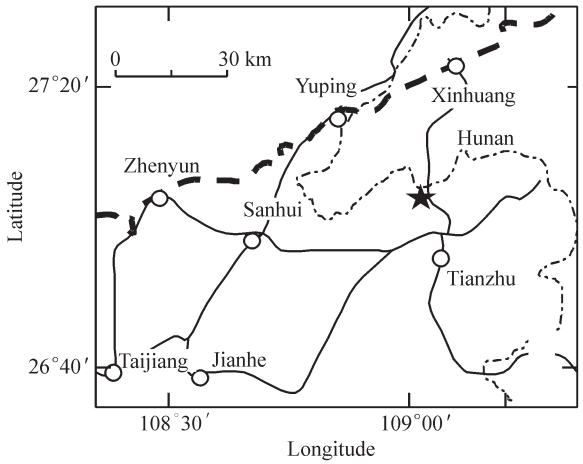

Fig. 1. Geographical location of the study area (★).

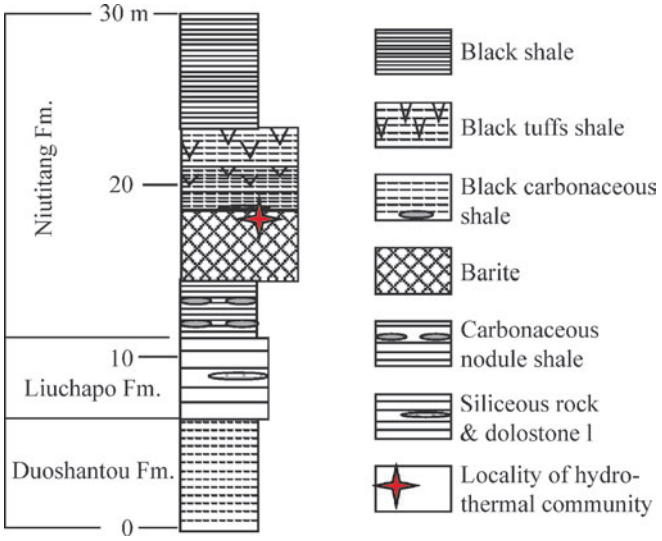

Fig. 2. Horizon of hydrothermal community in the barite deposit in the Lower Cambrian.

in early Cambrian? And how do the hydrothermal communities preserve in Lower Cambrian? These are important problems that need to be solved by geologists recently. Ecological environment study is one of the important subjects in studying ''Cambrian explosion''. Ecological environment of hydrothermal biota could provide a new path for exploring ecological background of ''Cambrian explosion''. Therefore, in this paper, we studied a typical hydrothermal vent barite deposit at Dahebian-Dagongtang, Tianzhu County, Guizhou Province in Lower Cambrian (Fig. 2), aiming to find hydrothermal vent community in typical hydrothermal vent barite deposit.

2. Evidences of the hydrothermal sediment of the barite deposit in Cambrian Niutitang formation

The barite deposits in eastern Guizhou Province and western Hunan Province in Lower Cambrian were considered to be hydrothermal origin [1,7–14]. The main evidences are as follows:

(1) *Sedimentary feature:* The barite deposit shows typical hydrothermal vent sediment feature [14], including vein structure (Fig. 3(d) and (e)), erode structure (Fig. 3(g)), discus structure (Fig. 3(c)), pillar structure (Fig. 3(b)), bedding structure (Fig. 3(a)), and spotted structure (Fig. 3(f)). These hydrothermal venting sediment features were discovered in both the modern hydrothermal venting sediment [15] and the ancient hydrothermal venting sediment rocks [16].

(2) *Mineral petrology:* Sphalerite, galena, chalcopyrite, pyrite and siderite hydrothermal mineral occurred in the barite ore layer [8]. Importantly, hyalophane, a typical submarine hydrothermal mineral, was found in the barite [12,17–19].

(3) *Temperature of fluid inclusion:* Studies of the fluid inclusions indicate that the temperature of the mineralization fluids generally ranges from 105 to 192 °C, and most within 150–180 °C [8,9].

(4) *Isotopic composition:* Strontium isotopic compositions of the barite deposit is comparable with that of Cambrian seawater with $^{87}Sr/^{86}Sr$ ratios ranging from 0.708310 to 0.708967. Nevertheless, vein barite and pyrite-bearing barite have relatively high $^{87}Sr/^{86}Sr$ ratios, (0.709585 and 0.709537, respectively), similar to that of hydrothermal brine. Additionally, lead isotopic compositions of barites indicate a mixing sources of the lead, including the upper crust, the upper crust-mantle mixed subduction zone, and the submarine hydrothermal sediments [11,13].

(5) *Trace elements and rare earth elements composition:* The Th/U ratios of the barite ore layer are low (~0.2), which indicates the addition of the mantle materials (through hydrothermal fluid) during the mineralization of the barite [10]. Additionally, the wall rocks, black shales at the upper and lower barite ore layers are enriched in V, Co, Ni, Cu, Sr, U, and Mo elements, and these elements were possibly insolated and extracted from deep basic and ultrabasic rocks by hydrothermal fluid.

The barite exhibits negative Ce but positive Eu abnormalies, which demonstrates that the barite mineralization was affected by hydrothermal fluid [10]. At the same horizon, the Ni–Mo–sulphide layer in black shales at the base Cambrian of Zunyi County was interpreted to be hydrothermal origin [20,21].

The above-mentioned evidences strongly suggest that the barite of the base Cambrian in Tianzhu County, Guizhou Province belongs to hydrothermal sediment.

3. Characteristics of the hydrothermal community in the barite

A lot of algae, spongia, tube-type fossils and global-type fossils were discovered by light microscope in the barite section in this study (Fig. 4). These fossils are described as follows:

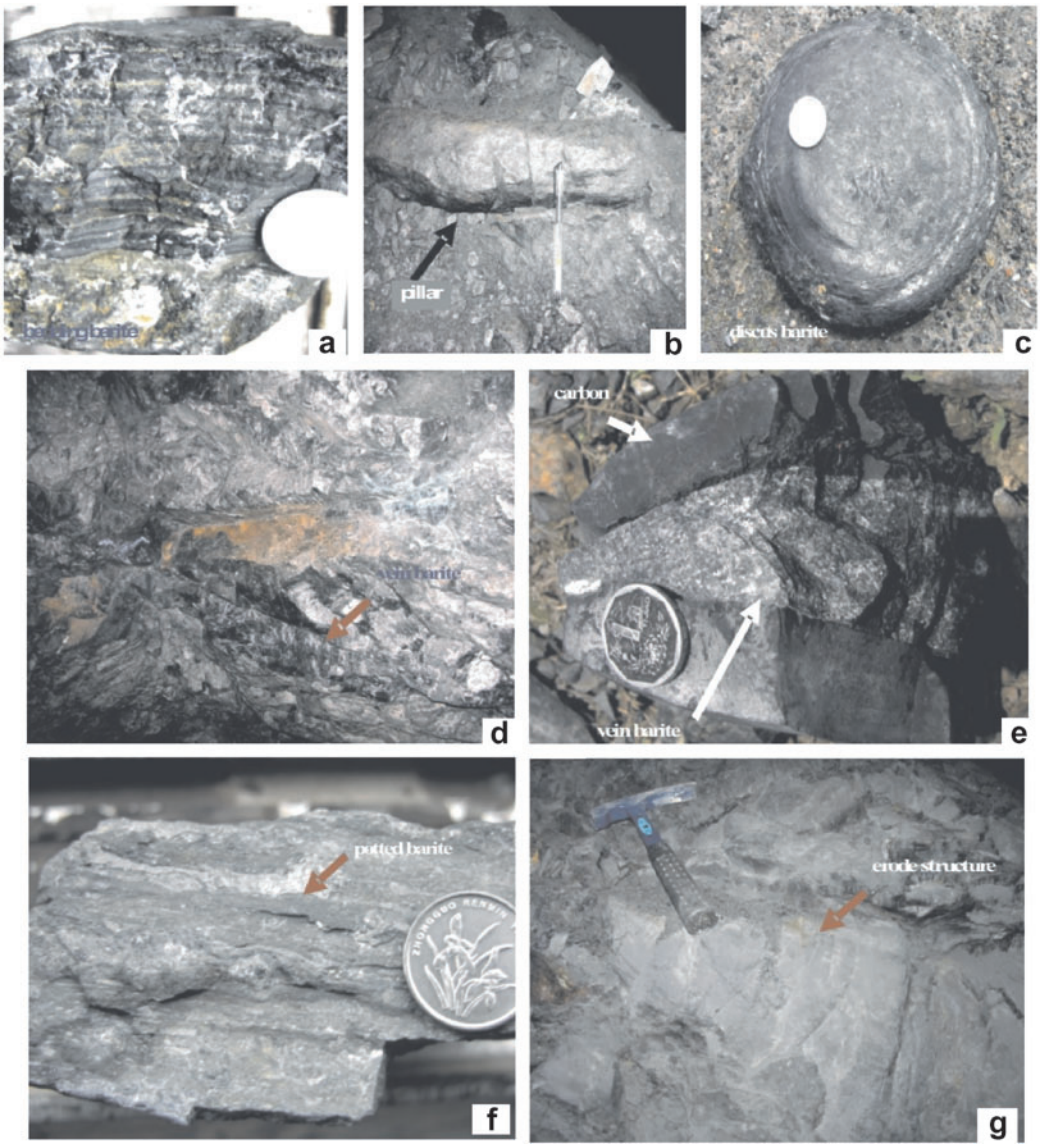

Fig. 3. The structure and feature of the barite deposit. (a) Bedding structure; (b) pillar structure; (c) discus structure; (d) and (e) vein structure; (f) spotted structure; (g) erode structure.

3.1. Algae fossils

A lot of algae fossils in filamentous shape were found in the bedding pyrite layer and the bedding barite layer. The interbed of filamentous algae layer and fine grain pyrite layer and the fine grain pyrite twined by filamentous algae can be seen under light microscope (Fig. 4(a)). The algae fossils are confirmed as Cyanophyta or Chlorophyta, formed 0.2–0.5 mm in layer thickness. The algae fossil was preserved only in a filamentous shape in the barite ore (Fig. 4(b) and (f)). The bedding pyrite layer and the bedding barite layer are rich in the filamentous algae fossils. Nevertheless, the pillar barite ore and discus barite ore are poor in the filamentous algae fossils. The filamentous algae fossils are very rich in carbon body (Fig. 4(g)). The above-mentioned distribution of algae fossils indicates that the algae fossils are mostly preserved in barite deposit, especially pyrite layer.

The content of algae fossil in the studied geological section (barite deposit layer) is low in the lower part of the barite deposit, high in the middle part of the barite deposit, and then low in the upper part of the barite deposit. The hydrothermal venting process is weaker in the early hydrothermal venting stage. Therefore, the bedding barite ore layer, pillar and discus carbon body were formed at the hydrothermal vent. Abundant alga was thriving at the hydrothermal vent under the lower temperature and weak venting environment, similar to the pillar of alga formed by hydrothermal venting matter and life body (main algae) at east Pacific ridge 13°N (Fig. 4(h)) [22].

The block barite ore indicated that the sedimentation speed is rapid, and the venting temperature is high. The block barite ore is poor in algae fossil, resulting from rapid sediment of $BaSO_4$ at hydrothermal vent during the middle venting stage.

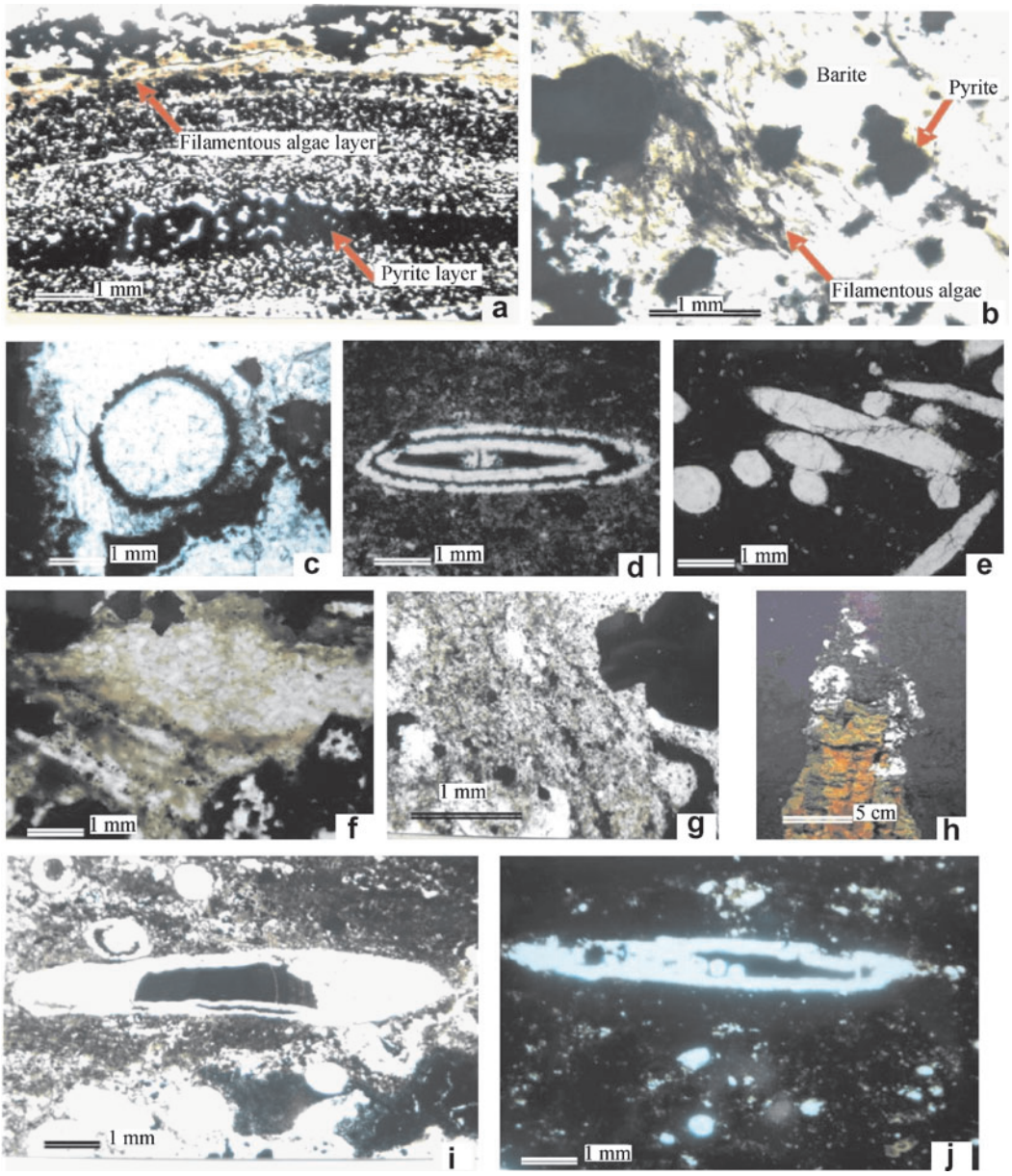

Fig. 4. Main fossils of the hydrothermal community in the barite deposit. (a) Filamentous algae layer; (b) filamentous algae fossils; (c) global fossil; (d) tube-type fossils; (e) sponge spicules fossils; (f) and (g) filamentous algae fossils; (h) black smoker in the Pacific; (i) and (j) tube-type fossils.

Until the late venting stage, the bedding pyrite layer and the bedding barite layer were formed under weak hydrothermal venting and low $BaSO_4$ sediment. The sediment speed of clastic matter is low; and abundant sulphide on the submarine floor creates reducing condition, and leads to precipitate lots of pyrite. Nevertheless, the algae still thrives strongly under this condition, so a lot of filamentous algae formed the interbed of filamentous algae, pyrite, or barite.

3.2. Sponge fossils

Abundant and well-preserved siliceous sponge spicules were discovered in carbon body in the barite deposit. The siliceous sponge spicules are similar to that of the black shale in Lower Cambrian [23]. The cross-section and vertical section of sponge spicules can be seen by light microscope (Fig. 4(e)). It is characterized by single axis. The modern submarine investigation discovered that much more sponge animals thrive at the hydrothermal vent [15,22,24,25], and abundant sponge fossils were found in hydrothermal sediment rocks [23], which indicates that sponge animal is the main hydrothermal vent animal.

3.3. Tube-type fossils

The tube-type fossils were found in carbonaceous barite (Fig. 4(d) (i) and (j)). The cross-section is similar to the fossil *Conotheca* with many rings. The fossils have two rings, two shell walls, calcium shell wall, and carbon within shell

wall. The tube worm animal in the modern hydrothermal vent was reported [24] and was considered to be mainly hydrothermal vent animal. The feature of the fossil in this study is closely related to tube worm animal, and thus we consider the fossils may be tube worm animal. Nevertheless, the cross-section of fossils in the carbonaceous barite ore was reported only in this study. To confirm that the fossil is the tube worm animal, further work will be needed to extract fossil from barite by chemical method.

3.4. Global fossils

The fossils were preserved in carbonaceous shell wall in the barite ore. The cross-section of the fossil is circle (Fig. 4(c)). The fossil is similar to large acritarch feature such as polygonal reticulation. If the fossil is to be conformed, further work needs to be done.

4. Scientific significance of discovering hydrothermal community in early Cambrian

The Early Cambrian biological evolution is one of the most important events in the geological time. The small shell animal appeared and ''Cambrian explosion'' took place in the early Cambrian. The intra-continental extension was intensive in the early Cambrian, which led to hydrothermal activity in submarine [26]. The multi-metal beds were formed and black shale was deposited at the base of Cambrian in the world due to hydrothermal activity in submarine. However, the relationships between the ''Cambrian explosion'', hydrothermal and black shale events and crustal evolution are hotly debated among geologists all over the world.

The hydrothermal vent community in the barite deposit of Tianzhu County, Guizhou Province lives at ~180 °C. It consists of high abundant algae (Cyanophyta or Chlorophyta) and few submarine animals. Nevertheless, the hydrothermal vent community with high abundance and low diversity was discovered at the same stratum (in the Mo–Ni sulphide ore bed at the base Cambrian) in Xioazhu, Zunyi County, Guizhou Province. It consists of large sponge, bivalves fossils, algae and few worm fossils. The ecological temperature of the hydrothermal vent community in Zunyi County is lower than that of the hydrothermal vent community in Tianzhu County [23].

A series of hydrothermal vent community discovered at the base Cambrian black shales indicated that the hydrothermal vent existed in the extensive ecological community in the early Cambrian. The hydrothermal activity spreads widely in the global submarine due to the strong intra-continental extension in the early Cambrian. A lot of hydrothermal vent communities in the early Cambrian are similar to the modern Eastern Pacific hydrothermal vent community. Therefore, the hydrothermal vent communities make up mainly ecological community in the early Cambrian.

Fossils of hydrothermal vent worms from cretaceous sulfide ore of the Samal Ophiolite, Oman, were first reported by Haymon et al. [27]. Silurian hydrothermal vent community from the southern Urals, Russia and Late Cretaceous hydrothermal vent communities from the Troodos ophiolite, Cyprus, were reported by Little et al. [28,29]. The studied early Cambrian hydrothermal vent communities in Guizhou Province, China, might be the oldest hydrothermal vent community ever reported. It is of important significance to investigate the background of the ''Cambrian explosion'', which has supplied a new window for the study of Cambrian ecology.

Additionally, abundant algae (Cyanophyta or Chlorophyta) discovered at the hydrothermal vent indicates that bacterium, Cyanophyta and Chlorophyta take sulfide fractionation in the submarine, which leads to isotope $\delta^{34}S$ of the barite up +41.65‰. Microbial community might have played an important role in the barite metallogenlogenic process [25,30–33]. A lot of hydrothermal vent communities have been reported in the modern submarine, and many new species have been discovered in the communities [34–41]. Therefore, it is suggested that many new species fossils may be found in the barite deposit.

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