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Methane-derived authigenic carbonates of mid-Cretaceous age in southern Tibet: Types of carbonate concretions, carbon sources, and formation processes

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ABSTRACT

Methane-derived authigenic carbonates with distinctive structures and morphologies have been documented worldwide, but they are rarely found from ancient strata in the Eastern Tethys Ocean. The methane-derived authigenic carbonates found in southern Tibet are developed in calcareous or silty shales of mid-Cretaceous age in the Xigaze forearc basin and in the Tethyan Himalaya tectonic zone. The morphology, mineralogy, elemental geochemistry and composition of carbon and oxygen isotopes of these carbonates are studied in detail.

The carbonates have nodular, tubular, and tabular morphologies. They are primarily composed of carbonate cement that binds and partly replaces host sediment grains; host siliciclastic sediments are composed mainly of quartz and plagioclase feldspar; a few foraminifers; and framboidal or subhedral to euhedral pyrite. Carbonate cements dominantly are micritic calcite, with minor contribution of dolomite.

Nodular concretions are characterized by depleted $\delta^{13}C$ values, commonly ranging from −30‰ to −5‰. The $\delta^{13}C$ values show a gradual decrease from the periphery to the center, and the CaO, SiO_2, Fe_2O_3, Al_2O_3, K_2O, and TiO_2 contents generally show a gradual change. These features indicate that the nodular concretions grew from an early-formed center toward the periphery, and that the carbon source of the nodular concretions was derived from a mixture of methane, methanogenic CO_2, and seawater-dissolved inorganic carbon.

The tubular concretions are characterized by $\delta^{13}C$ values of −8.85‰ to −3.47‰ in the Shangba Section, and −27.37‰ to −23.85‰ in the upper Gamba Section. Unlike the nodular concretions, the tubular concretions show central conduits, which are possible pathways of methane-rich fluids, suggesting that the cementation of tubular concretions begins at the periphery and proceeds inward. Moreover, the tubular concretions show morphological similarity with the methane-derived carbonate chimneys, pipes and slabs reported in present-day cold seep settings. We suggest that the carbon source of the tubular concretions was derived from a mixture of seawater-dissolved inorganic carbon and oxidized methane formed by released hydrate.

The tabular concretions are characterized by $\delta^{13}C$ values of −21.87‰ to −6.67‰ in the Xiege Sections. These depleted $\delta^{13}C$ values suggest that the carbon of the tabular concretions was derived at least in part, from AOM. The tabular concretions are characterized by $\delta^{13}C$ values of −28.81‰ to −12.99‰ in the Gamba Section. According to the $\delta^{13}C$ values and field observation, we infer that their carbon source was more likely to be a mixture of the oxidized methane formed by released hydrate and seawater-dissolved inorganic carbon.

1. Introduction

Methane-derived authigenic carbonates (MDACs) are formed by the oxidation of methane, which coupled with sulfate reduction by

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the activity of archaea and bacteria (Greinert et al., 2001; Hovland et al., 1987; Kulm et al., 1986; Michaelis et al., 2002; Ritger et al., 1987). MDACs have been documented worldwide, and a variety of morphologies have been described, including mounds, nodular concretions, slabs, chimneys, and tubular concretions (Aiello et al., 2001; Aloisi et al., 2002, 2000; Campbell, 2006; Clari et al., 2004; Conti and Fontana, 2005; Conti et al., 2004; Dela Pierre et al., 2010; Diaz-del-Rio et al., 2003; Nyman et al., 2010; Peckmann et al., 2001). MDACs are primarily composed of microcrystalline calcite, aragonite, and dolomite (Chen et al., 2006; Lim et al., 2009; Peckmann et al., 2001). Because MDACs are derived from methane, their carbon isotope values typically range from −60‰ to −20‰ VPDB (Aiello et al., 2001; Aloisi et al., 2002, 2000; Campbell, 2006; Clari et al., 2004; Conti and Fontana, 2005; Conti et al., 2004; Dela Pierre et al., 2010; Diaz-del-Rio et al., 2003; Louis-Schmid et al., 2007; Nyman et al., 2010; Peckmann et al., 2001; Peckmann and Thiel, 2004).

Studies of present-day active systems have focused on the seafloor morphological features, rather than on the subseafloor features that form as the result of the upward flow of methane-rich fluids through the sedimentary column (Cavagna et al., 2015). Tong and Chen (2012), who found methane-derived authigenic carbonates in the Xigaze forearc basin, focused on the sources of the methane-rich fluids and the formation conditions associated with them, but they did not perform any detailed research on the formation processes of carbonate concretions in this region. Here, we investigate the characteristics of nodular, tubular, and tabular concretion outcrops in southern Tibet. The carbonate concretions are found in the mid-Cretaceous marine strata of the Xigaze forearc basin and the marine stata of the southern and northern subzones of the Tethyan Himalayas. In addition, we test the hypothesis that these morphologies resulted from growth processes under differing diagenetic conditions.

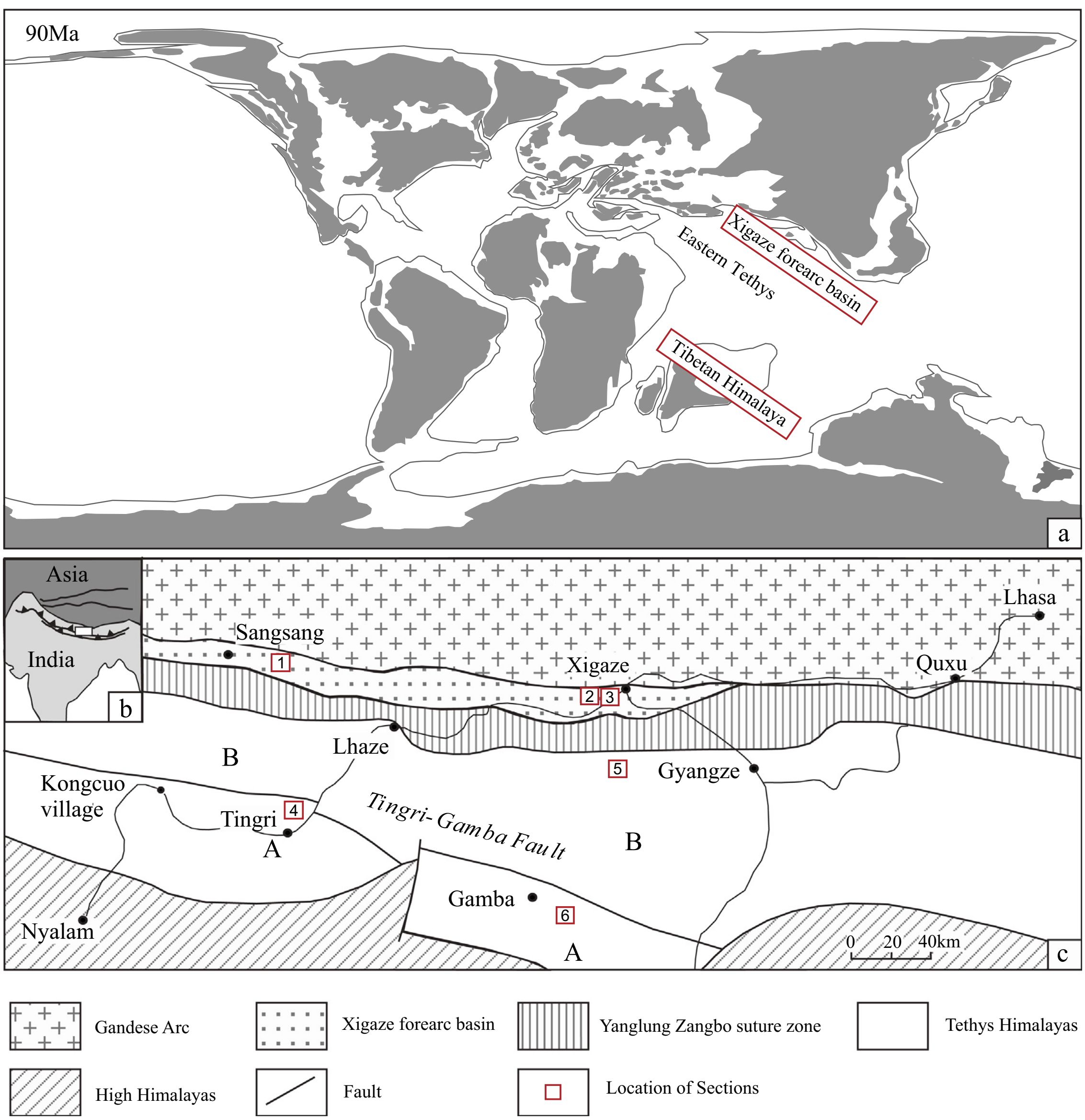

Fig. 1. Paleogeographic reconstruction of the mid-Cretaceous and geological setting of the study area. (a) Paleo-geographic reconstruction at 90 ma (modified from Blakey, R.C. http://jan.ucc.nau.edu/rcb7/globaltext2.html); (b) location of the study area; (c) the tectonic framework of central southern Tibet and the locations of the sections studied (modified from Li et al., 2006). 1, Walie Section; 2, Kadui Section; 3, Jiding Section; 4, Xiege Section; 5, Shangba Section; 6, Gamba Section. (A) The southern subzone of the Tethyan Himalayas. (B) The northern subzone of the Tethyan Himalayas.