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Characteristics of hydrothermal sedimentation process in the Yanchang Formation, south Ordos Basin, China: Evidence from element geochemistry

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ABSTRACT

Hydrothermal sedimentation occurred in the Triassic Yanchang Formation, Ordos Basin, China. However, their macroscopic features at the scale of the stratum and hydrothermal sources still lack correlational research. This paper performed element geochemical study on a large number of core samples collected from the Yanchang Formation of a new drilling well located in the south Ordos Basin. The $SiO_2/(K_2O + Na_2O)$ vs. MnO/TiO_2 crossplot and Fe vs. Mn vs. $(Cu + Co + Ni) \times 10$ ternary diagram demonstrate that the Yanchang stratum in the study area has, in general, hydrothermal components. The Al/(Al + Fe + Mn) and (Fe + Mn)/Ti ratios of the core samples range from 0.34 to 0.84 and 4.81 to 50.54, averaging 0.66 and 10.67, respectively, indicating that the stratum is a set of atypical hydrothermal sedimentation with much terrigenous input. Data analysis shows that the hydrothermal source in the study area was from the deep North Qinling Orogen around the south margin of the basin, where some active tectonic and volcanic activities took place, rather than from the relatively stable internal basin. Early Indosinian movement and volcanic activities activated basement faults around the southern margin of the basin, providing vents for the deep hydrothermal fluid upwelling. The hydrothermal indicators suggest that the study area experienced 4 episodes of relatively stronger hydrothermal activity, namely during the Chang 10, Chang 9–1, Chang 7–3 and Chang 6–2 periods. We also propose a new hydrothermal sedimentation model of hydrothermal fluids overflowing from basin margin faults, for the Yanchang Formation, which is reported here for the first time.

1. Introduction

Hydrothermal sedimentation, sometimes known as exhalative sedimentation, refers to syngenetic sedimentation formed by underground hydrothermal fluids which are ejected through rock fractures or vent channels; they then flow into and mix with terrigenous clastics and the bottom water of a sea or lake. Their lithified sediments are termed as “hydrothermal sedimentary rock” or “exhalative rock” (Boström et al., 1979; Edmond et al., 1982; Dias and Barriga, 2006; Zheng et al., 2006; Zhong et al., 2015). Hydrothermal sedimentation has a long history of study, and currently is still a hot research topic in geology (Dias and Barriga, 2006; Wen et al., 2013; Li et al., 2014; Zhong et al., 2015). Early hydrothermal sedimentation research primarily targeted seafloor regions such as the east Pacific Rise and the Mid-Atlantic Ridge (Boström and Peterson, 1969; Rona et al., 1975; Boström et al., 1979; McMurtry and Yeh, 1981). Subsequently, a large number of hydrothermal sedimentation reports have been published about oceanic island arcs, back-arc basins and marine strata (Crerar et al., 1982; Marchig et al., 1982; Adachi et al., 1986; Lyle et al., 1986; Yamamoto, 1987; Rona, 1988; Cronan et al., 1995; Hodkinson and Cronan, 1995; Chen et al., 2004; Dekov et al., 2011). Most studies have focused on the metallogenic significance of metal deposits, because the sediments are often enriched in metallic elements such as Fe, Mn, Cu, Zn, Au, Ag, Sn, etc. These studies have yielded detailed knowledge of hydrothermal systems and have established a set of indicators for hydrothermal sedimentation, including rock textures, sedimentary structures and geochemical discrimination diagrams. Linked with this marine hydrothermal research, other aspects of hydrothermal sedimentation have also received increasing attention in the last decade: for example, siliceous rocks (Liu et al., 2001; Qi et al., 2004; Grenne and Slack, 2005; Li et al., 2014) and faulted lacustrine basin carbonate rocks originating from continental hydrothermal fluids (Zheng et al., 2006; Wen et al., 2013); and even metalliferous black shales occurred along continental margins (Slack et al., 2015). These findings suggest that hydrothermal sedimentation can take place in various environments,

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and is a relatively common sedimentary type, with important research significance and application value. However, hydrothermal sedimentation often occurred in the tectonically active regions mentioned above, therefore, ones formed in relatively stable depression lake basin have less been noted and reported.

The Ordos Basin in North China is an extensively studied depression lake basin. In recent years, some studies (Zhang et al., 2010; Yang et al., 2010; Qiu et al., 2015) have found mineralogical, petrologic and isotopic evidence for hydrothermal sedimentation in the Upper Triassic Yanchang Formation of the Ordos Basin: for example, siliceous rocks, ankerite laminar deposits, marcasite brassil anhydrite symbiosis systems and authigenetic albite filling in early diagenetic fractures have been discovered in the stratum; abnormally abundant S^{2-} content, high ratios of U to Th, a positive carbon isotopic composition of crystalline ankerite, depleted oxygen isotopic composition, and isotopically enriched ^{34}S sulfur isotopic composition of strawberry-shaped pyrite in the Chang 7–3 interval (Zhang et al., 2010); a notable positive uranium anomaly (Yang et al., 2010) and iridium-rich minerals present in Chang 7–3 oil source rocks, as well as most of the Chang 7–3 hot shales data plotting near to the field of hot springs in the ternary plot of Zn–Ni–Co (Qiu et al., 2015). These studies confirmed the existence of hydrothermal sedimentation in the Yanchang Formation. However, because of the lack of continuously sampling, there is still limited knowledge of the macroscopic characteristics at the scale of the stratum of hydrothermal sedimentation in the Yanchang Formation; especially the hydrothermal source in this relatively tectonic stable depression lake basin. Here we report the macroscopic characteristics at the scale of the stratum of hydrothermal sedimentation in the Yanchang Formation from a large number of samples by element geochemical study, and on the basis of our geochemical data and previous studies, we discuss the possible hydrothermal source of the sedimentation and its sedimentary model.

2. Geological setting

The Ordos Basin, with an area of 320,000 km^2, is situated in the western part of the North China Block and is bordered to the north, east, south and west by the Yin, Luliang, Qinling, Liupan and Helan mountains, respectively (Fig. 1a). The Ordos Basin is a typical multicycle cratonic depression basin developed on Archean granulites and Lower Proterozoic greenschists, with large scale basement faults which acted as the channel for volcanic material upwelling in the Archean–Neoproterozoic. Since the Cambrian, the basin interior has been relatively stable; no volcanic activity has occurred in the rigid basement and no large faults have developed in the sedimentary cover despite squeezing and control by the peripheral orogenic belts. However, tilting has intensified: the whole basin has uplifted in the east and subsided in the west. In the late Paleozoic and Mesozoic, the basin margin underwent a number of volcanic activities, accompanied by the formation of roughly north–south-trending and east–west-trending basement faults in the basin periphery and resulting in the accumulation of large volumes of volcanic materials. Volcanic tuffs from the basin periphery have been discovered in the central basin. Moreover, the peripheral volcanic activities and basement faults provided the necessary conditions for the formation and upwelling of Mesozoic deep hydrothermal fluids (Yang et al., 2005; Zhao, 2005; Li and Gao, 2010).

As a consequence of regional collisional tectonism and related intra-plate deformation in the Middle–late Triassic (Indosinian Movement), the southern Ordos Basin evolved into a foreland basin, and was dominated by lacustrine environments in its center

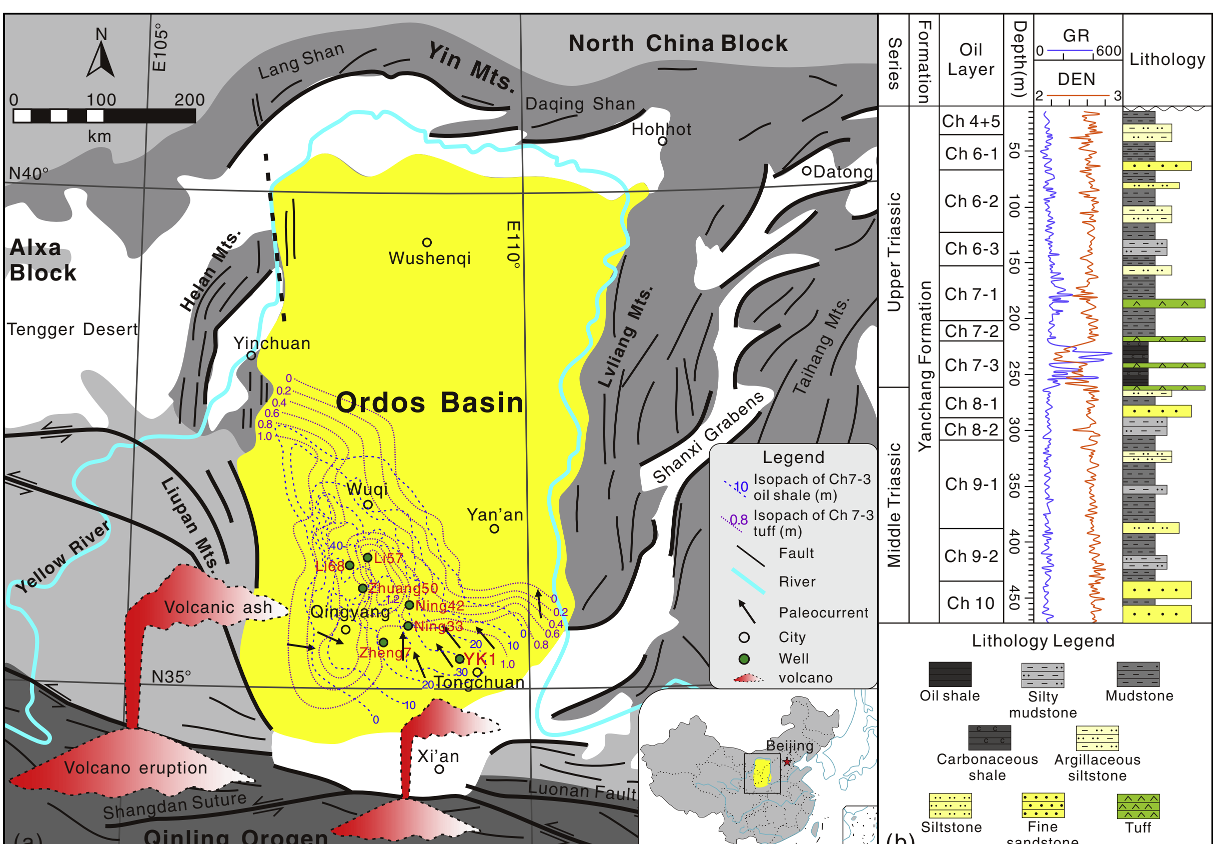

Fig. 1. (a) Simplified geological map of the Ordos Basin and its adjacent regions, modified after Darby and Ritts (2002). The isopach of tuffs and oil shales after Deng et al. (2008). The thickness of Chang 7–3 tuffs tends to be decrease toward northeastern part of the Ordos Basin, suggesting that the volcanic sources could be near to the Qinling Orogen (Qiu et al., 2014). The paleocurrent direction after Wei et al. (2003). (b) The stratigraphic column of Well YK1. Ch = Chang, the same hereinafter.