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Closure time in the East Qilian Ocean and Early Paleozoic ocean–continent configuration in the Helan Mountains and adjacent regions, NW China

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ABSTRACT

Lithofacies and faunal assemblage affinities of the Helan Mountains and its adjacent blocks are explored using field investigations and analysis of previous results. The tectonic affinity between the Alxa Block and the North China Block is analyzed by means of LA-ICP-MS detrital U–Pb zircon age spectrums. The Early Paleozoic stratigraphic framework is constructed and stratigraphic contact relationships between the study area and its adjacent regions are assessed. The ocean–continent configuration during the Caledonian period is discussed and the closure time in the east of North Qilian Ocean is determined. Finally, the basin type and its evolutionary process during the Early Paleozoic are analyzed. The carbonate platform facies of the Alax Block and the abyssal flysch deposition on the margin of the Central Qilian Block, established the coexistence of ocean and continent configuration during the Cambrian. During the early Ordovician, the stable shallow water platform-shelf facies was distributed over all the study area and the biofacies was also unified. The east of the North Qilian Ocean closed at that time. The North Qilian Ocean and the North Qinling Ocean did not affect the study area, but the North China Sea was connected intermittently to the research area. The east Central Qilian Block, the Alax Block, the North China Block and the Qinling Microblock collided together to form a unified megablock, which resulted in the formation of a complex foreland depression during the early Ordovician. The eastern boundary of the basin is the Aselang–Chedao Transform Fault, which lies between the Alax Block and the North China Block. The southern boundary of the basin is marked by the Guyuan–Qingtongxia Fault which is located between the Alax Block and the Central Qilian Block. The western boundary of the basin is an overlapping boundary toward the Alax Block. During the late Ordovician, when the Yangtze Block approached toward the North China Block, the Shangdan Ocean began to influence the study area and the turbidite fans were formed because of the large-scale transgression. Thus, the basin type is a complicated foreland depression influenced by transgression during the late Ordovician.

1. Introduction

The Helan Mountains and its adjacent regions are located at the junction of the Qinling Orogenic Belt and the North Qilian Orogenic Belt. Previous researches on the study area were focused on the stratigraphy, petrology, paleontology and regional tectonics (Li et al., 2010; Huang et al., 2010). There have still been many debates on the ocean–continent configuration during the Early Paleozoic in the study area, which is related to the tectonic affinity of the Alax Block to the North China Block. One academic school suggested that the Alax Block was a part of the Sino-Korea plate and belonged to the western extension of the North China Block. However, with the accumulation of paleomagnetic and geochronological data and the discovery of granitic plutons in the Alax Block over the past twenty years, it is now found that the paleomagnetism, the basement composition and the sedimentary cover of the Alax Block are different from those of the North China Block. Based on those new quantitative data, another viewpoint concluded that the Alax Block has no tectonic affinity to the North China Block before the Caledonian Movement (Huang et al., 2000; Geng et al., 2002;

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Wan et al., 2003; Li et al.,2004, 2009; Zhao et al., 2005; Duan and Ge, 2005; Wang et al., 2005; Geng and Zhou, 2010; Zhang et al., 2011, 2012). A few scholars even considered that the Alax Block was part of the Xing-Meng Orogen and thus has no affinity to the Yangtze Block and the North China Block (Li, 2006).

Even those who held the second point had different opinions about the timing of aggregation of the Alax Block and the North China Block. Zhao et al. (2005) suggested that the Alax Block and the North China Block aggregated during the Mesoproterozoic. Huang et al. (1999) believed that the Alax Block and the North China Block aggregated during the early Ordovician, while Ge and Liu (2000) and Ge et al. (2009) considered that both blocks aggregated during the middle- to late-Triassic. Yuan and Yang (2012, 2015) held that the Alax Block was not part of North China Block by the Late Devonian based on the data of detrital zircon U–Pb geochronology and Hf isotopes. These different opinions on the tectonic affinity of the Alax Block has led to the different suggestions about the basin types during the early Paleozoic in the Helan Mountains and its adjacent regions. Zhang (1992) suggested that the Helan areas is a passive continental margin during middle Ordovician. Lin et al. (1995) believed that the Helan Mountains was an aulacogen of the Qinling–Qilian–Helan triple-armed rift system during the Ordovician. Bai and Yang (2007) believed that the Helan Mountains evolved into a rift basin from the Early Ordovician to the Middle Ordovician. Huang (2009) maintained that the Helan Aulacogen was developed from the Early Ordovician to the Middle Ordovician. The above proposals are based on the premise that the Alax Block had tectonic affinity to the North China Block. Zhang et al. (2011, 2012) pointed out that the basement composition of the Alax Block is different from that of the North China Block, and the two blocks may aggregated to form an under-compensation foreland basin. Di and Xie (2008) believed that the Helan Mountains was a compressed depression. The above two proposals are based on the premise that the Alax Block had no tectonic affinity to the North China Block.

2. The Early Paleozoic rock assemblages between the study area and the North Qilian Orogenic Belt

2.1. The Early Paleozoic igneous rocks between the study area and the North Qilian Orogenic Belt

The North Qilian Orogenic Block is derived from the collision between the Alax Block and the Central Qilian Block. The volcanic rocks of the North Qilian Orogenic Belt are composed of island-arc volcanics in the central zone and residual oceanic crust volcanic rocks (ophiolite mélange) on the northern and southern sides. The large-scale Qingshuigou–Baijingsi subduction-accretionary complex crops out in the north of the Yushigou–Chuancigou ophiolite belt. The age of the ophiolite mélange in the north side of the North Qilian Orogenic Belt is ca. 480–400 Ma, while the age of the south ophiolite mélange is ca. 550–490 Ma (Feng et al., 1994; Pan et al., 2009; Xiao et al., 2009; Shen et al., 2005; Chen et al., 2010; He et al., 2011). The island-arc volcanic formation, the subduction–accretionary complex and ophiolite mélange in the North Qilian Orogenic Belt are fully developed. However, the typical formation of active continental margin in the study area, such as island-arc volcanic formation, the subduction–accretionary complex and ophiolite mélange are not found. In Xiaosongshan of the central study area, only a very small area of gabbros and diabases were found (Huang, 2009).

2.2. The Early Paleozoic sedimentary rocks of the study area

The Lower Paleozoic is developed from the Cambrian Nangao Stage to the Ordovician Qiantangjiang Stage in the study area (Figs. 1 and 2). The thickness of Early Paleozoic strata ranges from 600 m to 5000 m. The Cambrian strata experienced various degrees of metamorphism. For instance, the high-grade metamorphosed strata occur in the south of the Zhongwei subregion in Niushoushan, Miboshan and Xiangshan. The low-grade metamorphosed strata lie to the north of Niushoushan–Miboshan–Xiangshan. The Silurian strata are missing, while the Devonian strata only crop out in the Zhongwei–Zhongning area.

The Cambrian includes carbonates and clastic rocks in the study area. The carbonate rocks are mainly distributed in the north-east in Kexueshan–Guchengzi–Yantongshan–Tongxin, mainly distributed in Guchengzi, Yuanshanzi, Xianggendalai (Figs. 1 and 2). The carbonate rocks comprise mainly of limestone, dolomite, siderite nodule limestone, flint zebra dolomite, oolitic limestone and grainstone. The carbonate rocks are represented by the Abuqiehai, Zhangxia Hulusitai and Taosigou formations in the Zhuozishan subregion; the Abuqiehai, Zhangxia, Hulusitai, Taosigou, Wudaotang and Suyukou formations in the Helan–Lingwu subregion; and by the Abuqiehai, Zhangxia, Mantou, Zhushadong and Xinji formations in the Qinglongshan subregion (Fig. 2). The clastic rocks are mainly distributed in the south-west of Kexueshan–Guchengzi–Yantongshan–Tongxin, mainly cropping out in the Zhongwei area. The clastic rocks are mainly composed of the Xiangshan Group, which was subdivided into 4 subgroups (Fig. 2). Only the third and fourth subgroups of the Xiangshan Group crop out in the study area, which are mainly composed of pebbles, siliceous dolomite, silicolites, feldspar sandstone with celadon slate, and a thinner layer of limestone and oolitic limestone. In addition, phosphoric glutenites, siltstone and feldspar–quartz sandstone crop out in the Suyukou area (Chen et al., 2010; Li et al., 2011).

The Ordovician is divided into four stratigraphic subregions: the Zhuozishan–Lingwu, the Yinchuan–Helan, the Qinglongshan and the Zhongwei subregions. They are represented (from bottom to top), by the Sandaokan, Zhuozishan, Kelimoli, Wulalike, Lashizhong, Gongwusu and Sheshan formations, in the Zhuozishan–Lingwu subregion. In the Yinchuan–Helan subregion the Ordovician is represented (from bottom to top), by the Xialingnangou, Tianjingshan, Miboshan, Pingliang and Yinchuan formations, and by the Machuan, Shuiquanling, Sandaogou, Pingliang and Beiguoshan formations in the Qinglongshan subregion (Xu et al., 2010, 2012) (Fig. 2 and Table 1).

The lower and middle Ordovician rocks include the Xialingnangou and Tianjingshan formations which are composed of carbonate rocks. The Xialingnangou Formation mainly includes gray massive dolomite, medium to thinner dolomite, dolomite limestone, argillaceous limestone and minor limestone and gray green slate at the top. The Tianjingshan Formation, which is a shallow-water carbonate platform deposit with a thickness of nearly 1 km, mainly includes gray thick mesh limestone, flint nodule limestone, chert dolomitized limestone and thick-bedded limestone. The middle and upper Ordovician Miboshan, Pingliang, Wulalike, Lashizhong, Gongwusu and Sheshan formations are mainly composed of deep-sea clastic sediments, such as slate, shale, calcirudite, siltstone, sandstone with thin layer of bioclastic limestone, nodular limestone and silty limestone (Fig. 2 and Table 1).

2.3. The differences in igneous and sedimentary rocks between the study area and the North Qilian Orogenic Belt

The middle Cambrian Gemoergou Group, which is the main unit of the North Qilian Orogenic Belt, mainly includes volcanic and pyroclastic rocks with a small amount of fine-graded clastic rock, silicalite and marlstone. The volcanics comprise of lava, pyroclastic and bimodal volcanic rocks (Xia et al., 1996). The upper Cambrian