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Late Paleozoic paleomagnetism of South Mongolia: Exploring relationships between Siberia, Mongolia and North China

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ABSTRACT

The tectonic evolution of a large region that includes South Siberia, Mongolia and North China is still a matter of fierce debate. This is due, at least in part, to the contentious proposals detailing the kinematics of the major tectonic units in that area. One solution to the problem is the acquisition of better defined paleomagnetic data for the various players in the system. We carried out a paleomagnetic study of Early Carboniferous subduction-related volcanic rocks of the Trans-Altai zone in South Mongolia and successfully isolated a pre-folding and presumably primary component from 22 sites. A critical analysis of Late Paleozoic paleomagnetic data from Mongolia revealed several problematic data sets, while the paleolatitudes derived from more reliable studies agreed well with the expected values for Siberia and were consistently different from those for the North China block. We also found that Late Paleozoic declinations from Mongolia are rotated counterclockwise through various angles with respect to Siberia. In addition, those rotations are widespread in both Inner Mongolia and the North China block. In this paper, we put forward some testable hypotheses and propose a preliminary paleogeographic scheme of the region: 1) Consistent difference in Late Paleozoic paleolatitudes between Siberia and Mongolia on the one hand and the North China block on the other, is largely due to strong inclination shallowing in paleomagnetic data for the latter area, where most data are from sedimentary rocks. 2) Widespread counterclockwise rotations in Mongolia, Inner Mongolia and North China may be accounted for by a wide zone of sinistral transpression that was active in the Early Mesozoic. 3) In the Early Mesozoic, the Mongol-Okhotsk Ocean was much narrower than is usually assumed; 4) There was no large-scale oroclinal bending between Siberia and North China in the Permian–Early Mesozoic.

1. Introduction

The onset of tectonically-oriented paleomagnetic studies may be compared with the first steps of solving a puzzle, where a single new pole can strongly affect the entire picture. Gradually, the data grow in number and the “impact-factor” of each new datum helps to bring the entire puzzle into sharper focus. As an example, global reconstructions for the Cenozoic, Mesozoic and Late Paleozoic differ in details; perhaps important ones, but the general picture is clear. Deeper in time, the ambiguities are more numerous even though, on a broader scale, the first-order paleogeography of the world is adequately known since the Early Ordovician. More recently, the game of reconstructing the global paleogeographic puzzle has moved into the Precambrian.

Other puzzles are focused on reconstructions of major mobile belts, where the evolution of orogenic belts are interwoven with kinematics of key cratonic blocks. One of the favorite playgrounds is central East Asia that includes the Siberian and North China cratons, Precambrian-aged microcontinents and the mobile belts between them. Our limited tectonic understanding of this region is hindered by its complexity and multi-phase history, which is aggravated by insufficiently well defined apparent polar wander paths, APWP's, of Siberia and North China and the paucity of paleomagnetic results from the mobile belts and microcontinents. For instance, the first-order question “Where is the boundary between the “Siberian” and “North China” domains?” is still

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hotly debated even for the Late Paleozoic. Some researchers regard the Late Paleozoic structures (Hercynides) of South Mongolia as an active margin of Siberia (Ruzhentsev et al., 1985, 1989; Ruzhentsev and Pospelov, 1992; Sengör et al., 2014); whereas others attach them to the North China craton (Zhao et al., 2013; Edel et al., 2014; Yuan and Yang, 2015). Still others consider the latter as a part of Eurasia in the Late Permian (ca. 255 Ma; Sengör et al., 2014). Even in the Jurassic, the picture is not clear as a recent reconstruction proposes a rather wide continuous seaway (ocean?) between North China and Siberia (Van der Voo et al., 2015).

In order to address the multiple problems in tectonics of East Asia we carried out a paleomagnetic study of an Early Carboniferous aged subduction-related volcanic complex from the Trans-Altai zone of South Mongolia. We also compile Late Paleozoic paleomagnetic results from the other parts of Mongolia and compare them with those from the Siberian and North China cratonic areas. Finally, an attempt is undertaken to reach a non- controversial pattern from available paleomagnetic and geological pieces of the puzzle.

2. Geological setting and sampling

The eastern half of the Central Asian orogenic belt, CAOB, between the Siberian craton in the north and the Tarim and North China blocks in the south, is a complex collage of structures of various ages and tectonic settings. The cross-section of this belt is almost entirely represented in Mongolia, and several first-order domains, or realms, as well the Mongol-Okhotsk belt in the NE part of the country, can be recognized in this region (Fig. 1).

2.1. Northern realm

This realm is a messy mosaic of pre-Ediacaran microcontinents and Ediacaran-Early Paleozoic island-arc and accretionary complexes (Kuzmichev et al., 2001; Yarmolyuk et al., 2011; Kozakov et al., 2012, 2013; Jian et al., 2014; Kröner et al., 2015). Judging by widespread Early Ordovician metamorphism and coeval granites, the northern realm was consolidated and could have docked to the Siberia continent at that time (Yarmolyuk et al., 2011; Kozakov et al., 2012).

In the Chinese and Mongolian Altai Ranges to the south, the mosaic is a bounded by a band of Late Cambrian to Devonian variably metamorphosed terrigenous sediments and carbonates with subordinate volcanics of diverse composition (Kröner et al., 2007; Demoux et al., 2009; Cai et al., 2011; Wang et al., 2011; Cai et al., 2015). To the east, this band can be traced into Central and East Mongolia (the Gobi Altai terrain of Badarch et al., 2002) and probably, to NE China where it is regarded as a Middle Paleozoic accretionary complex on the margin of the Siberian continent (Dergunov, 2001; Demoux et al., 2009; Cai et al., 2011; Wang et al., 2011; Cai et al., 2015) or as a back-arc basin (Badarch et al., 2002).

2.2. Central realm

The northern and central realms are separated by a slightly curved, southward-convex fault system; which is called the Irtysh (Erqis) strike-slip zone in the west. In Central Mongolia, a set of conjugated faults is collectively named the Main Mongolian Lineament (MML) that passes along the southern foothills of the Gobi and Mongolian Altai ranges, although its further continuation eastward is contentious. In Russian publications this fault system is regarded as the major boundary between the Caledonides in the north and the Hercynides in the south (Dergunov, 2001, and references therein).

South of the MML, Silurian and Devonian, locally earliest Carboniferous, basalt-andesite piles with sub-ordinate acid volcanic rocks stretch from NE Kazakhstan via East Junggar all the way through South Mongolia south of the MML (Trans-Altai zone). This intensely deformed volcanic series is thought to have accumulated in intra-oceanic island arcs and back-arc basins distal from the continental margins (Ruzhentsev and Pospelov, 1992; Dergunov, 2001; Yarmolyuk et al., 2008; Kröner et al., 2010; Xiao et al., 2011; Cai et al., 2014). Accretionary complexes separated by ophiolites of island-arc affinity were also reported (Helo et al., 2006; Huang et al., 2012; Luo et al., 2015).

Throughout South Mongolia and the East Junggar region of the Trans-Altai zone, the Middle Paleozoic complexes are unconformably overlain by Carboniferous continental deposits that are in turn conformably covered with a series of volcanic rocks of bi-modal composition (Dergunov, 2001; Yarmolyuk et al., 2008; Zhang et al., 2015). The Carboniferous sediments and volcanic rocks are much less deformed than the underlying Middle Paleozoic rocks. In South Mongolia, the ages of the upper volcanics range from 354 Ma to 321 Ma (Blight et al., 2010b; Wainwright et al., 2011; Kozlovsky et al., 2015; Yang et al., 2016); similar ages (343–323 Ma) were reported for their counterparts in East Junggar and the Santanghu area (Xiao et al., 2011; Huang et al., 2012; Li et al., 2013; Xu et al., 2015). Volcanism was accompanied by the intrusion of calc-alkaline granites and subordinate mafic rocks with ages of 350–320 Ma. (Yarmolyuk et al., 2008; Blight et al., 2010a, 2010b; Shen et al., 2011; Wainwright et al., 2011; Economos et al., 2012; Cai et al., 2014; Xu et al., 2015).

This volcano-plutonic belt stretches for more than 1800 km from East Junggar to SW Mongolia and is regarded by some (Zhang et al., 2015) as a manifestation of post-collisional magmatism. On the other hand, the dimensions of the belt, its prolonged activity, the up to 2500 m thickness of volcanic series and wide variation in composition of predominantly calc-alkaline volcanic rocks indicate that this belt was formed on an active continental margin of Andean type, most probably of the Siberian continent, with subduction having been directed northward (in present-day coordinates; Dergunov, 2001; Yarmolyuk et al., 2008; Blight et al., 2010a, 2010b). The Early Carboniferous volcanic rocks of this belt were the main target of our paleomagnetic studies (below).

Middle Paleozoic and Early Carboniferous complexes of South Mongolia and East Junggar are unconformably overlain by bi-modal volcanics confined to narrow E-W trending grabens (Kozlovsky et al., 2007; Yarmolyuk et al., 2008). This complex comprises high-alkali rhyolites, pantellerites and komendites, which are geochemically similar to A-type granites, and numerous intrusions of granites and subordinate mafic rocks. Two outbursts of bi-modal magmatism are defined in South Mongolia, at about 318 Ma (mid-Carboniferous time) and 290 Ma (Early Permian time; Yarmolyuk et al., 2008; Kozlovsky et al., 2012; Cai et al., 2014, 2015; Kozlovsky et al., 2015). Comparable 325–280 Ma bi-modal magmatism is also described in the East Junggar region (Shen et al., 2011; Xiao et al., 2011; Liu et al., 2013; Luo et al., 2015).

2.3. Southern realm

This realm has a prevailing E-W structural grain including several blocks of the South Gobi microcontinent, the Eastern Tien and Beishan orogenic collages and is separated from the central realm by the Gobi - Tien-Shan fault in South Mongolia. The Early Neoproterozoic basement is documented in the eastern and central blocks of the microcontinent (Yarmolyuk et al., 2005; Wang et al., 2011). In the western Atas-Bogd block, similar ages of the basement are inferred from inherited Neoproterozoic and Early Paleozoic zircons found in the Permian-aged Gobi-Tien Shan batholith (Dergunov, 2001; Yarmolyuk et al., 2008; Lehmann et al., 2010; Kröner et al., 2010).

In the southeast, the South Gobi microcontinent borders on the late Carboniferous- Permian (324–250 Ma) ophiolites of the Solonker suture zone (Jian et al., 2010). These ophiolites of presumably intra-oceanic origin are usually thought to have been formed in an oceanic basin that separated the CAOB units from the North China margin in the Late Paleozoic.