Journal of Asian Earth Sciences 96 (2014) 108–122

Contents lists available at ScienceDirect

Journal of Asian Earth Sciences

journal homepage: www.elsevier.com/locate/jseaes

Zircon ages and geochemical compositions of the Manlay ophiolite and coeval island arc: Implications for the tectonic evolution of South Mongolia

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ARTICLE INFO

Article history:
Received 1 April 2014
Received in revised form 27 August 2014
Accepted 2 September 2014
Available online 16 September 2014

Keywords:
South Mongolia
Early Paleozoic
Manlay ophiolite
Huree

ABSTRACT

Numerous small dismembered ophiolite fragments occur in South Mongolia, but they are very poorly studied. The lack of age data and geochemical analysis hampers our understanding of the Paleozoic tectonic evolution of the region. We conducted detailed studies on the Manlay ophiolitic complex and Huree volcanic rocks south of the Main Mongolian Lineament (MML) to provide some constraints on these rocks. The Manlay ophiolite consists of dunite, harzburgite, pyroxenite, gabbro, plagiogranite, basalt and chert, locally with chromite mineralization in dunite. The gabbro and plagiogranite yielded SHRIMP zircon weighted mean $^{206}Pb/^{238}U$ ages of 509 ± 5 Ma and 482 ± 4 Ma, respectively. The basalt and dolerite samples of this complex show enrichment in LREE and LILE and negative Nb, Ta and Ti anomalies, and the chrome spinel from the chromitite lens in the dunite is characterized by high $Cr^{\#}$ and low TiO_2 contents. These features suggest a supra-subduction zone (SSZ) origin for the ophiolitic complex. The Huree volcanic rocks, ranging from basalt to dacite, display enrichment in LREE and LILE, weak Eu anomalies and distinctly negative Nb, Ta and Ti anomalies, consistent with those of typical magmas in a subduction environment. An andesite sample from this arc yielded a SHRIMP $^{206}Pb/^{238}U$ zircon age of 487 ± 5 Ma, which is the oldest reliable age for an island arc in South Mongolia. Recognition of an Early Paleozoic ophiolitic complex and a coeval island arc indicates that South Mongolia underwent a period of active volcanism during Late Cambrian to Ordovician. Additionally, the tuff overlying the ophiolitic complex and a granite intruding the ophiolite have SHRIMP zircon U–Pb ages of 391 ± 5 Ma and 304 ± 4 Ma, respectively. Combining the available data, we propose that the Early Paleozoic subduction–accretionary complexes likely constitute the basement of the Late-Paleozoic arc formations and correlate with the Lake Zone in western Mongolia.

1. Introduction

As remnants of oceanic lithosphere that were squeezed into, and preserved within, orogenic belts on the continents, ophiolites are some of the most important indicators of collisional/ accretionary mountain belts (Dilek and Furnes, 2011). Therefore, studies on ophiolites can provide important constraints on the tectonic evolution of the orogenic belts and essential information on the nature of the oceanic lithospheric mantle, oceanic magma processes, and mechanisms of continental growth in accretionary and collisional belts (e.g., Dilek, 2003; Whattam, 2009; Jian et al., 2010). Volcanic arcs are the magmatic expression of sites where one lithospheric plate is subducted beneath another (Macdonald et al., 2000). Research on volcanic arcs may provide important information on plate dynamics, melt generation, and crustal growth (Stern, 2002). Both arcs and ophiolites play important roles in studying orogenic evolution.

Mongolia occupies a central position within the Central Asian Orogenic Belt (CAOB) or the Altaid (Sengör et al., 1993). Traditionally, the territory of Mongolia has been subdivided into two tectonic domains by the Main Mongolian Lineament (MML), namely an Early Paleozoic (“Caledonian” in the Russian and Mongolia literature) domain to the north and a Late Paleozoic (“Hercynian” in the Russian and Mongolia literature) domain to the south (Badarch

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http://dx.doi.org/10.1016/j.jseaes.2014.09.004
1367-9120/

et al., 2002). However, this division appears questionable because, according to this division, the MML should be the suture zone of the two orogenic collages, but there are no geological indicators such as ophiolites or HP rocks within the MML. Instead, the lineament is mostly covered by Mesozoic–Cenozoic sedimentary rocks. If the above tectonic division is correct, the ophiolites and arc complexes exposed south of the MML, such as Manlay, Gurvan Sayhan and Zoolen, should be Late Paleozoic (Hercynian) in age, but there are no relevant age data available to verify it.

During the last few years, especially since the discovery of the world-class Oyu Tolgoi gold-rich porphyry copper deposit in the 1990s (Kirwin et al., 2005), many studies (e.g., Blight et al., 2008; Kröner et al., 2010; Lehmann et al., 2010) were conducted on volcanic arc development and terrane accretion in South Mongolia south of the MML. Some of these studies focused on the mineral deposits and related granites (Blight et al., 2010; Wainwright et al., 2011a), with few studies dealing with ophiolite fragments and associated formations. Although published data confirmed that the arc formations hosting the mineral deposits formed during the Devonian – Carboniferous (Blight et al., 2010; Wainwright et al., 2011a), the tectonic relationship between the ophiolites and the "Hercynian" arcs remains uncertain due to lack of geochronological and geochemical data. Therefore, the tectonic evolution of South Mongolia remains to be properly reconstructed.

This paper presents geochronological and geochemical data for the Manlay ophiolitic complex as well as the related island arc formations in the Manlay area, with aims to: (1) determine the age, origin and type of ophiolite in the region; (2) check the validity of the tectonic division or to explore the presence of Early Paleozoic formations south of the MML; and (3) provide constraints on the tectonic evolution of the CAOB in the South Mongolian segment.

2. Geological setting

The Central Asian Orogenic Belt (CAOB; Jahn et al., 2000; Windley et al., 2007) or the Altaid (Sengör et al., 1993) extends from the Uralides in the west to the Pacific margin in the east and is bounded by the Siberian Craton to the north and the Tarim–North China cratonic blocks to the south (Pirajno et al., 2008). The CAOB, which is a complex collage of fragments of ancient microcontinents, arc terranes, accretionary complexes, oceanic crust (ophiolite), and formations of passive continental margins (Filippova et al., 2001; Windley et al., 2007; Xiao et al., 2008), is thought to be a typical accretion-type orogenic belt. In addition, voluminous granitoids with positive $\varepsilon_{Nd(t)}$ values intruded throughout the CAOB, suggesting vertical growth of crustal materials (Jahn et al., 2004; Wang et al., 2009). Mongolia, which lies in the heart of the CAOB, could shed light on the origin and evolution of this giant orogen.

According to Badarch et al. (2002), the study area is dominated by two island-arc terranes, the Gurvansaykhan in the south and the Mandalovoo in the north. These two terranes were interpreted to originally belong to one contiguous island-arc, and a later dextral strike-slip fault separated them to their current locations (Blight et al., 2008). They have similar components and mainly consist of deformed Ordovician to Carboniferous volcanic and sedimentary rocks. The Ordovician and Silurian formations of the area comprise sandstone, argillite, limestone, chert and volcanoclastic rocks (Lamb and Badarch, 1997). The Devonian and Early-Middle Carboniferous formations consist of conglomerate, sandstone, shallow-marine fossil-rich limestone, felsic tuff, pillow basalt, andesite, volcanoclastic rocks and chert (Badarch et al., 2002). Geochemical data of pillow lavas indicate that the basalts were erupted in a subduction setting (Lamb and Badarch, 2001). Many porphyry copper deposits, such as Tsagaan Suvarga and Oyu Tolgoi, are related to arc formations during this time. There are many small ophiolitic complexes exposed as inliers among the Devonian and Carboniferous formations (Fig. 1). The Late Carboniferous and Permian strata are characterized by a bimodal volcanic suite, with peralkaline granites in the study area and the entire region of South Mongolia (Yarmolyuk et al., 2008). Subsequent to suturing of the ocean, the study area underwent several periods of intercontinental deformations, including Jurassic contractional deformation (Zheng et al., 1996), Jurassic–Cretaceous extension (Meng et al., 2003) and Cretaceous thermal uplift and volcanism (Barry and Kent, 1998). The structure of this area is complex and dominated by imbricate thrust sheets, dismembered blocks, mélanges, and high strain zones (Badarch et al., 2002). During Cenozoic, South Mongolia was reactivated due to the far field effect of the Indo-Eurasia collision (Cunningham, 1998).

There are many small outcrops of dismembered ophiolite in South Mongolia, but no age and geochemical data have been reported so far. Among them, the Manlay ophiolitic complex (Fig. 2) is the largest and best-preserved entity. Near the Huree area, the ophiolite consists mainly of ultramafic rocks, basalts and cherts. Pillow lava is exposed in the Gonus area southeast to Manlay town (Fig. 3a). Along the strike of Ih Ulzit uul Mountain, the lithology varies significantly from west to east. In the western portion, basalt with minor greenish chert crops out as blocks in a matrix, mainly composed of tuffaceous sandstone in the north and dipping to the south. The ultramafic rocks occur as blocks in the middle of the western part. Locally, plagiogranite occurs with gabbro as blocks in fault contact with the ultramafic rocks, but the original relationship between these rock types is not clear. The matrix of the middle part mainly consists of schist and siliceous sedimentary rocks. The southern part of the western side consists mainly of gabbro and pyroxenite which occur as lens in a matrix composed of turbidites intruded by granite (Fig. 3b). In contrast, the eastern portion of Manlay ophiolitic complex is dominated by thick ultramafic rocks (about 1 km in thickness) associated with widespread dolerite intrusions that have experienced strong secondary carbonation. Several thin veins ($\sim$20 cm wide) of chromitite were found intruding the ultramafic rock. In addition, some podiform chromite mineralization is hosted in dunite–harzburgite, concordant with their foliation in this suite (Fig. 3c).

Farther northwest of the Manlay complex, a mélange-type assemblage of arc formations consists mainly of andesite and tuffeous sandstone interlayered with siliceous shale (Fig. 3d). Andesite with a thickness of about 200 m is exposed in the northern part of this section.

3. Analytical methods

3.1. SHRIMP zircon U–Pb geochronology

Zircon crystals were extracted from fresh rock samples by conventional heavy liquid and magnetic separation technique and then hand-picked under a binocular microscope. The zircons were mounted in epoxy resin together with standard TEMORA (417 Ma) and polished so that the zircon interiors were exposed. Optical (transmitting and reflecting lights) photographs and cathodoluminescence (CL) images were prepared to investigate internal texture and origin of the zircons in order to select optimal sites for analysis. Finally, the mounts were gold-coated to enhance the conductivity for SHRIMP U–Pb isotopic analysis.

Zircon U–Pb dating was carried out on SHRIMP II at the Beijing SHRIMP Center, Institute of Geology, Chinese Academy of Geosciences, following the standard procedures described by Jian et al. (2012). The rastering by the primary beam over the analysis site for 3 min prior to each analysis was used to minimize contamination