Lithos 245 (2016) 7–17

Contents lists available at ScienceDirect

Lithos

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

Assembly of the Lhasa and Qiangtang terranes in central Tibet by divergent double subduction

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ARTICLE INFO

Article history:
Received 4 May 2015
Accepted 29 June 2015
Available online 4 July 2015

Keywords:
Multidisciplinary data
Divergent double subduction
Bangong Ocean
"Soft" Lhasa–Qiangtang collision
Central Tibet

ABSTRACT

Integration of lithostratigraphic, magmatic, and metamorphic data from the Lhasa–Qiangtang collision zone in central Tibet (including the Bangong suture zone and adjacent regions of the Lhasa and Qiangtang terranes) indicates assembly through divergent double sided subduction. This collision zone is characterized by the absence of Early Cretaceous high-grade metamorphic rocks and the presence of extensive magmatism with enhanced mantle contributions at ca. 120–110 Ma. Two Jurassic–Cretaceous magmatic arcs are identified from the Caima–Duobuza–Rongma–Kangqiong–Amdo magmatic belt in the western Qiangtang Terrane and from the Along Tso–Yanhu–Daguo–Baingoin–Daru Tso magmatic belt in the northern Lhasa Terrane. These two magmatic arcs reflect northward and southward subduction of the Bangong Ocean lithosphere, respectively. Available multidisciplinary data reconcile that the Bangong Ocean may have closed during the Late Jurassic–Early Cretaceous (most likely ca. 140–130 Ma) through arc–arc "soft" collision rather than continent–continent "hard" collision. Subduction zone retreat associated with convergence beneath the Lhasa Terrane may have driven its rifting and separation from the northern margin of Gondwana leading to its accretion within Asia.

1. Introduction

The Wilson cycle involves the opening and closing of ocean basins and its recognition in the rock record provides a clear manifestation of the process of plate tectonics (e.g., Dewey and Spall, 1975; Wilson, 1966). Closure of ocean basins during the latter stages of the Wilson cycle involves the subduction of oceanic lithosphere and results in arc–continent or continent–continent collision. Two distinct geodynamic frameworks have been proposed for the closure of ocean basins (cf. Frisch et al., 2011). The first involves single-sided oceanic subduction leading to the development of a single magmatic arc on the overriding plate, subduction of the passive continental margin on the down-going plate, and development of large-scale fold and thrust structures and associated high-grade metamorphism in the collision zone. This pattern is exemplified by the Alpine-Himalayan orogen (cf. Leech et al., 2005; Sengör, 1987; Yin and Harrison, 2000). The second mechanism of ocean basin closure involves divergent double-sided oceanic subduction without significant subduction of the opposing continental blocks and leads to the development of two magmatic arcs on the opposing overriding plates, extensional basins, and generally low-grade metamorphism, as well as extensive long-lived granitoid magmatism with a mantle isotopic signature within the collision zone that postdates ocean closure (Soesoo et al., 1997). The modern Molucca Sea in eastern Indonesia (cf. Hinschberger et al., 2005) and the Paleozoic Solonker suture in central Asian Orogenic Belt (Eizenhöfer et al., 2014, 2015a, 2015b; Xiao et al., 2003) are examples of this second mechanism. The distinct tectonic, metamorphic, and petrological consequences of single versus double divergent subduction zones during ocean basin closure (Soesoo et al., 1997; Zhao, 2015) provide a set of testable relationships for evaluating suture zones juxtaposing continental blocks in the geological record. The focus of this paper is to critically evaluate these features for differentiating the assembly of the Lhasa and Qiangtang terranes and intervening Bangong suture in central Tibet, which is ascribed to the Mesozoic closure of the Tethyan Bangong Ocean.

The existence of the Bangong Ocean is inferred from the presence of extensive dismembered ophiolitic fragments within the Bangong suture

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http://dx.doi.org/10.1016/j.lithos.2015.06.023
0024-4937/

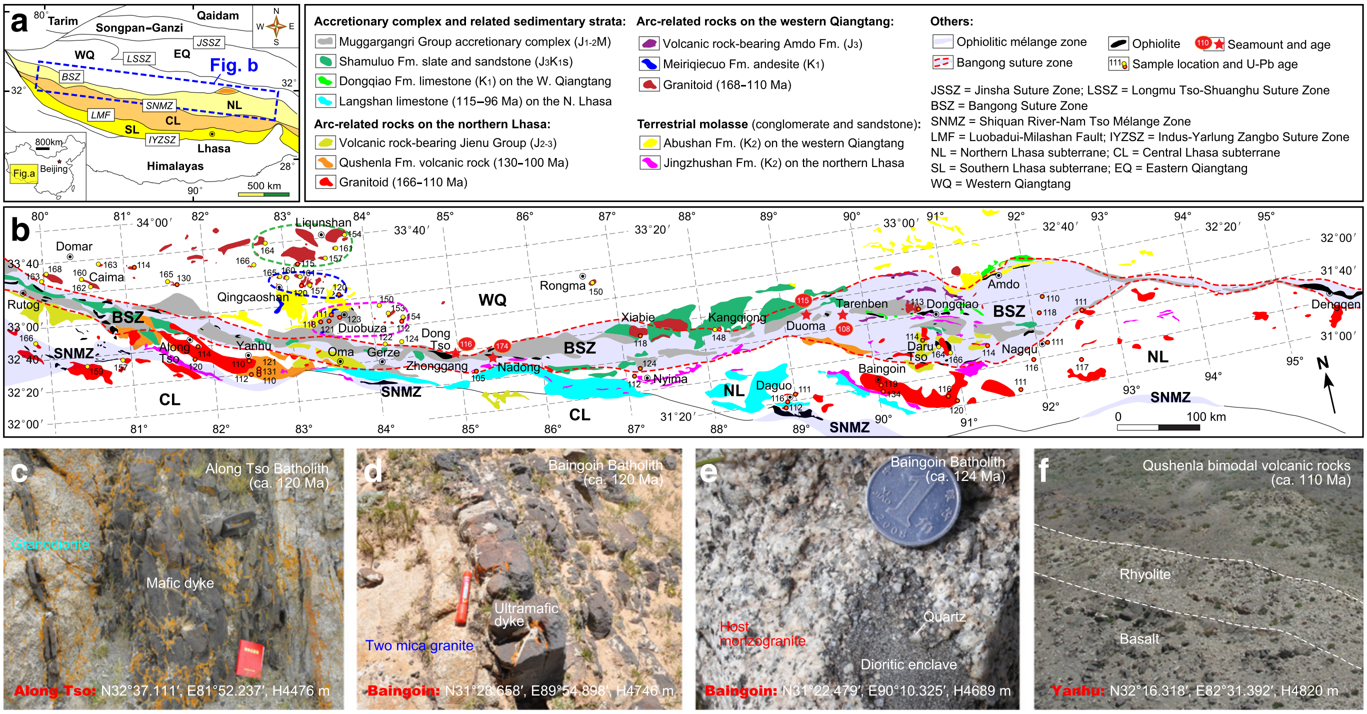

Fig. 1. (a) Tectonic outline of the Tibetan Plateau (Zhu et al., 2013) showing the location of the Bangong suture zone (red dashed line). (b) Simplified geological map showing the distinct Jurassic–Cretaceous geological records within Lhasa–Qiangtang collision zone (adapted from Wang et al., 2013). Age data sources: Western Qiangtang (Li et al., 2013b, 2014a, 2014b, 2014c, 2015a; Ran et al., 2015); Bangong suture zone (Fan et al., 2014; Zhu et al., 2006b); Northern Lhasa (Chen et al., 2014; Kapp et al., 2007; Li et al., 2015b; Zhu et al., 2011; this study). (c–f) Photos showing field occurrences of magmatic rocks in the northern Lhasa subterrane.

zone, which separates the Gondwana-derived Qiangtang and Lhasa terranes in central Tibet (Fig. 1a) (cf. Yin and Harrison, 2000; Zhu et al., 2013). The suture zone and its relationships with the bounding terranes have been highlighted as providing an important record of breakup, drift and accretion-related tectonism, magmatism, sedimentation, and metamorphism associated with the fragmentation of Gondwana's northern margin and subsequent assembly of the dispersed terranes into Asia. However, the details of the assembly history of the Bangong oceanic lithosphere including subduction polarity and timing of ocean closure remain in dispute. For example, the predominant view is that the ocean was subducted northward beneath the Qiangtang Terrane (Allègre et al., 1984; Guynn et al., 2006; Kapp et al., 2007; Yin and Harrison, 2000; Zhang et al., 2012a). Alternatively, some have argued for a divergent double-sided subduction zone involving both northward subduction beneath the Qiangtang Terrane and southward subduction beneath the Lhasa Terrane (Deng et al., 2014; Pan et al., 2012; Zhu et al., 2013). Estimates for the time of closure of the Bangong Ocean range from the Middle Jurassic to Late Cretaceous (cf. Fan et al., 2014; Kapp et al., 2007; Pan et al., 1983, 2012; Yin and Harrison, 2000; Zhang et al., 2012a; Zhu et al., 2009, 2011, 2013).

In this paper, we integrate our new geochronological and geochemical data (see Tables S1–S3) with available information from the Bangong suture zone and show that the records of magmatism, sedimentation, and metamorphism are consistent with divergent double-sided subduction and associated mantle dynamics (e.g., Soesoo et al., 1997). This synthesis corroborates the southward subduction of Bangong Ocean lithosphere beneath the Lhasa Terrane and argues that this subduction is analogous to the westward subduction of the Pacific lithosphere that led to the development of back-arc basins in the western Pacific (Cawood et al., 2009; Niu, 2014; Schellart et al., 2006), providing a good example to evaluate mantle geodynamics operating during Gondwana dispersion and Asian accretion.

2. Geological record within the Bangong suture and adjacent regions

In central Tibet, the Bangong suture zone separates the Qiangtang Terrane to the north and the Lhasa Terrane to the south (Fig. 1a) (Yin and Harrison, 2000; Zhu et al., 2013). Based on the differences in basement rock and sedimentary cover, the Lhasa Terrane is divided into northern, central, and southern subterranes, separated by the Shiquan River–Nam Tso Mélange Zone (SNMZ) and Luobadui–Milashan Fault (LMF), respectively (Zhu et al., 2011). The Qiangtang Terrane is divided into eastern and western subterranes separated by the Longmu Tso–Shuanghu suture zone (LSSZ) (Fig. 1a) (cf. Zhu et al., 2013). To evaluate the closure history of the Tethyan Bangong Ocean, this paper focuses on the Jurassic–Cretaceous sedimentary, metamorphic, and magmatic records of rock units and their relations within the Bangong suture zone and adjacent regions of the Lhasa and Qiangtang terranes, which are defined here as the Lhasa–Qiangtang collision zone (Figs. 1b and 2).

2.1. Lithostratigraphy

The Jurassic rock units in the northern Lhasa subterrane include sandstones with interstratified volcanic rocks (Jienu Group) (Fig. 1b), flysch sediments (Lagongtang Formation), and limestones (Rila Formation) (Fig. 2) (cf. Pan et al., 2004; Wang et al., 2013). These units are overlain by Lower Cretaceous volcano-sedimentary units (e.g., Qushenla and Duoni formations) (Zhu et al., 2006a) and younger limestones (Langshan Formation) and are intruded by varying-sized plutons (including the large Baingoin and Along Tso batholiths) (Fig. 2) (Haider et al., 2013 Xu et al., 1985). In the western Qiangtang subterrane a continuous Lower Jurassic succession is present (cf. Raterman et al., 2014), which contrasts with the northern Lhasa subterrane where rock units of this age are lacking. These units consist mainly of sandstones and limestones along with some Upper Jurassic volcanic rocks (Amdo Formation) (Bai et al., 2005; Sun, 2005) and are intruded by 170–150 Ma granitoids (Fig. 2). Subsequent units include Lower Cretaceous conglomerates, sandstones, and