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ScienceDirect

Palaeoworld 26 (2017) 380–395

Palaeoworld

www.elsevier.com/locate/palwor

Detrital zircon U-Pb dating of Suining Formation sandstone from the Daba Mountains, northeastern Sichuan and its stratigraphic implications

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Received 12 June 2016; received in revised form 16 February 2017; accepted 11 March 2017
Available online 21 March 2017

Abstract

The non-marine Jurassic–Cretaceous boundary in the Sichuan Basin in southwestern China has a long and highly controversial history. According to the dominant opinion, the Suining and Penglaizhen Formations are the Upper Jurassic, and the Chengqiangyan Group is the Lower Cretaceous. Based on detrital zircon U-Pb dating of the Suining Formation sandstone from the Daba Mountains, the upper limit of the deposition of the Suining Formation is given by the detrital zircon U-Pb ages. The youngest detrital zircon U-Pb age is ~120 Ma, which reflects a depositional age of younger than ~120 Ma. The detrital zircon U-Pb age of the Suining Formation shows that this widespread formation should be assigned to the Cretaceous, not the Jurassic. This study sheds new light on the location of the Suining Formation in the stratigraphic column. Additionally, these ages are very important for the regional stratigraphic correlation and tectonic evolution studies.

Keywords: Jurassic; Cretaceous; Suining Formation; Detrital zircon SHRIMP U-Pb age; LA-ICP-MS U-Pb age; Sichuan Basin

1. Introduction

The non-marine Jurassic–Cretaceous boundary in China has a long and highly controversial history (Xia et al., 1982, 1984; Li, 1984; Chen, 1999, 2000a, 2000b; Gu and Cai, 2000; Pang et al., 2002; Deng et al., 2003; He and Zhu, 2003; Tian et al., 2004; Zhu, R.X. et al., 2004a, 2004b, 2007, 2008; Chen et al., 2005, 2007; Niu et al., 2005, 2010; Wan et al., 2005, 2013, 2016; Wang and Chen, 2005; Wang et al., 2005; Chen and Li, 2006; Ji et al., 2006; Sha et al., 2006a, 2006b, 2009, 2012; Shi et al., 2006; Sha, 2007a, 2007b; Yang et al., 2007; Yang and Li, 2008; Wang, C.S. et al., 2009; Zhou et al., 2009; Wang, S.E. et al., 2013, 2015). During the Late Jurassic to Early Cretaceous, multi-directional convergence in East Asia produced intensive magmatism and mineralization and had a profound influence on the geology, mineral resources, climate, and ecosystem of the area (Dong et al., 2006, 2007, 2008, 2010, 2013). In recent years, "the Upper Jurassic volcanic rocks", which were previously thought to have formed in eastern China, have almost been proven to have formed in the Early Cretaceous thanks to considerable progress in isotope chronology (Chen et al., 1991; Xie et al., 2001; Chen et al., 2003; Niu et al., 2004; Guo et al., 2005).

In northern Hebei and western Liaoning in northeastern China, the strata previously believed to be the Upper Jurassic is actually closer to the Lower Cretaceous based on the correlation of non-marine and marine fossils (Kong et al., 2006; Sha et al., 2006a, 2006b, 2009, 2012; Sha, 2007a, 2007b), together with newer radiometric dating (Swisher et al., 1999, 2002; Wang et al., 2001a, 2001b; Liu et al., 2002, 2003; Niu et al., 2003, 2004; He et al., 2004, 2006a, 2006b, 2008; Zhang et al., 2004, 2005a, 2005b; Zhu, R.X. et al., 2004a, 2004b, 2007, 2008; Davis, 2005; Kusuhashi et al., 2006; Yang et al., 2007; Yang and Li, 2008; Chang et al., 2009). The Jurassic–Cretaceous boundary is much lower stratigraphically than previously believed (Gu and Cai, 2000; China Stratigraphic Committee, 2013; http://www.cags.ac.cn/dcw). Moreover, in other parts of China, Most of the strata previously believed to be the Upper Jurassic have been reassigned to Lower Cretaceous, and a considerable stratigraphic gap of more than 10 Myr

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http://dx.doi.org/10.1016/j.palwor.2017.03.002
1871-174X/

exists between the Jurassic and Cretaceous (Sha et al., 2012; Sha, 2013). In 2013, at the Fourth National Stratigraphic Conference in China, the Chinese commission of stratigraphy adjusted the age of the Jurassic–Cretaceous boundary to 145 Ma in the Chinese chronostratigraphic chart (China Stratigraphic Committee, 2013; http://www.cags.ac.cn/dcw), based on the definitions of the International Commission of Stratigraphy (Gradstein et al., 2004; Ogg et al., 2004; http://www.stratigraphy.org).

To date, geologists have been more concerned with whether the geological processes in eastern China were consistent with those in midwestern China during the late Mesozoic. Non-marine Jurassic–Cretaceous strata are widely distributed in the Sichuan Basin, but the isotope geochronology of these strata has not been well researched. For instance, the Suining Formation is widely distributed in the Sichuan Basin and is composed of brick red, purplish-red, grey and green, fine- to medium-grained sandstone and siltstone that are locally associated with claystone beds. The Suining Formation is characterized by conspicuous brick red sandstone and siltstone; therefore, the Suining Formation is an important marker bed for regional correlations (Xia et al., 1982, 1984). Should the Suining Formation be assigned to the Upper Jurassic or Lower Cretaceous? Because the Suining Formation is relevant to the Jurassic–Cretaceous boundary, the age of the Suining Formation is of great interest to geologists. In the traditional view, the Suining and Penglaizhen Formations are the Upper Jurassic, the Chengqiangyan Group is Lower Cretaceous, and the boundary between the Penglaizhen Formation and Chengqiangyan Group represents the Jurassic–Cretaceous boundary. Additionally, some researchers believe that the Jurassic–Cretaceous boundary in the Sichuan Basin should be placed either at the top surface of the Chengqiangyan Group or in the middle of the Chengqiangyan Group (Li, 1984; Wei, 1984, 2000; Hou et al., 2002). Furthermore, other researchers believe the Jurassic–Cretaceous boundary in the Sichuan Basin should be placed in the middle of the Penglaizhen Formation (Liu, 1984; Li et al., 2008). Recently, Sha et al. (2006b) and Shi et al. (2006) reviewed the characteristics of the main Jurassic system in China and speculated that the Suining and Penglaizhen Formations may be the Early Cretaceous in age, although the authors did not provide additional detailed evidence. The source of controversy is related to the fact that the age of these late Mesozoic non-marine strata is constrained by fossils (Bureau of Geology and Mineral Resources of Sichuan Province, 1991; Chen, 2000a, 2000b; Hao et al., 2000; Wang, 2000) and the absolute age of the late Mesozoic non-marine strata in the Sichuan Basin is not clear. Accordingly, accurately constraining the age of the Suining Formation is key to solving this problem. Meanwhile, the Jurassic–Cretaceous boundary in the northern Hebei and western Liaoning regions has been redefined, which is much lower than previously placed (China Stratigraphic Committee, 2013; http://www.cags.ac.cn/dcw). How should the Jurassic–Cretaceous boundary be adjusted in southwestern China, where late Mesozoic non-marine strata are extensively developed? The key goal of adjusting the Jurassic–Cretaceous boundary in southwestern China is the age of the Suining and Penglaizhen Formations. Therefore, determining the age of the Suining Formation and correlating this age with international standard sections of Jurassic–Cretaceous material is of great theoretical and practical significance in identifying the Jurassic–Cretaceous boundary in the Sichuan Basin.

Detrital zircon U-Pb geochronology is a powerful tool for determining the maximum depositional age of clastic sediments, characterizing potential provenance areas and assessing palaeogeographic models (Carter and Moss, 1999; Cawood and Nemchin, 2000; Nelson and Gehrels, 2007). This study dated detrital zircons from the Suining Formation in northeastern Sichuan, China, using SHRIMP and LA-ICP-MS U-Pb dating. The conclusion of this paper has great reference value for the division of Jurassic–Cretaceous strata in this region and for revealing the tectonic evolution of the Qinling and Daba Mountains (Fig. 1).

2. Geological setting

The foreland basin of the Daba Mountains is located at the transitional position between the Qinling Mountains and the Sichuan Basin in northeastern Sichuan Province. The Daba Mountains are an arc-shaped thrust-fold belt at the northeastern margin of the Sichuan Basin (Fig. 1). The forelands of the Daba Mountains extend from the Micang Mountains in the west to the East Sichuan structural belt in the southeast. The northern margin of the Upper Yangtze plate has been a passive continental margin sedimentary environment since the Nanhua Period and forms a package of shallow sea facies carbonate and clastic rock formations. Devonian and Carboniferous strata are generally absent in this region, except for the Gaochuan block, and a parallel unconformity exists between the Silurian and the Permian. With the closure of the ancient Mianlue Ocean and the rise of the Qinling orogenic belt in the Middle–Late Triassic, marine deposits ceased to be deposited in the foreland basin of the Daba Mountains and the main part of the Sichuan Basin. The Daba Mountains foreland basin and the main part of the Sichuan Basin have experienced non-marine deposition since the Late Triassic. The terrigenous detrital rocks of the Mesozoic consist of, in ascending order, the Xujiahe Formation (T_3xj, Upper Triassic), Baitianba Formation (J_1b, Lower Jurassic), Qianfoya Formation (J_2q, Middle Jurassic), Shaximiao Formation (J_2sx, Middle Jurassic), Suining Formation (J_3sn, Upper Jurassic), Penglaizhen Formation (J_3p, Upper Jurassic) and Chengqiangyan Group (K_1, Lower Cretaceous) (Figs. 2 and 3).

In 1939, Li and Chen named the Suining shale in the suburbs of Suining County (Li and Chen, 1939). Bo-Quan Yang and Wan-Quan Sun named the red mudstone layer developed around the Suining and Tongnan area between the Shaximiao Formation and Penglaizhen Formation the Suining shales series in 1946 (Wang, 2000). A Sichuan oil survey team renamed it the Suining Formation in 1955 and assigned it to the Upper Jurassic (Wang, 2000). The Suining Formation is still assigned to the Upper Jurassic today (Bureau of Geology and Mineral Resources of Sichuan Province, 1991; Chen, 2000a, 2000b; Hao et al., 2000; Wang, 2000). This formation consists mainly of brick red and red-brown mudstone with interbedded sandstone and is divided