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Early Permian mantle–crust interaction in the south-central Altaids: High-temperature metamorphism, crustal partial melting, and mantle-derived magmatism

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ABSTRACT

Early Permian mafic magmatism, the partial melting of the crust, and high-temperature metamorphism in the Chinese Altai, south-central Altaids, provide an excellent case study of exchange of energy and mass between the mantle and crust. Field and petrographic observations, together with microprobe mineral analyses, have, for the first time, allowed us to identify scapolite-bearing calc-silicate granulites along the southern margin of the Chinese Altai. The conditions of metamorphism were 680–800 °C and 6–7 Kbar, based on mineral phase relationship and compositions, as well as the results of previous studies. New LA-ICP-MS zircon U-Pb geochronology demonstrates that the high-T metamorphism in the Chinese Altai was accompanied by the emplacement of leucogranites at approximately 295 Ma. SHRIMP II dating results, combined with previously published data, reveal a mafic magmatic event at around 275 Ma in a large region of northern Xinjiang, NW China. This mafic magma was derived from N-MORB-like depleted mantle, as deduced from our new bulk geochemical and zircon Hf isotopic data. Synthesizing available geochemical (including isotopic) and geochronological data, we propose a two-stage model of mantle–crust interaction to explain the early Permian geology of northern Xinjiang. The early stage of interaction involved high-temperature metamorphism and the coeval partial melting of crustal rocks, indicating solely a heat exchange between the mantle and crust; in contrast, the later stage involved the exchange of both mass and energy between the mantle and crust.

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1. Introduction

The Altaids in Central Asia (inset of Fig. 1, Sengör et al., 1993) is the world's largest accretionary orogen (Xiao et al., 2010; Wilhem et al., 2012; Xiao et al., 2013; Xiao and Santosh, 2014) and were formed during the Paleozoic by the accretion and amalgamation of different types of allochthonous fragments such as island arcs, ophiolites, accretionary prisms, seamounts, oceanic plateaus, and continental blocks (Sengör et al., 1993; Xiao et al., 2004a,b; Windley et al., 2007; Xiao et al., 2009, 2010). Igneous activity in the Altaids spanned the entire Phanerozoic, including the Mesozoic, and was characterized by the production of abundant granitoids and volcanic rocks showing significant admixture of the mantle component (Jahn et al., 2000; Kröner et al., 2014). Numerous new geochronological data derived from modern techniques (some are marked on Fig. 1) have revealed abundant latest late Carboniferous to early Permian bimodal intrusion or extrusion of magmatic rocks throughout the south-central Altaids (inset of Fig. 1) which have been identified within all tectonic units. It would appear that early Permian basalt developed in all basins, whereas the coeval bimodal plutons only occur in the basin-bounding ranges where the pre-Permian subduction-accretion related rocks are exposed. Given this context, the south-central Altaids in Chinese Xinjiang provide a natural laboratory for the study of mantle–crust interactions.

In general, there are two aspects to mantle–crust interactions: exchanges in mass, and exchanges in energy (heat) between the mantle and crust. Most previous studies of the south-central Altaids have focused on the geochronology and geochemistry of the magmatic rocks (e.g., Han et al., 1997, 2004, 2006; Wang et al., 2006; Geng et al., 2009; T. Wang et al., 2009; Zhao et al., 2009), thereby providing fundamental data for constraining of mass exchanges. However, except for the high-pressure metamorphic rocks in the western Tianshan (e.g., Gao and Klemd, 2000), little attention has been paid to the metamorphic rocks mainly because of the generally low grade of metamorphism of the south-central Altaids. However, some high-temperature metamorphic rocks are exposed in the Chinese Altai (Wei et al., 2007; W. Wang et al., 2009), and these may provide constraints on the possible exchange of heat between the mantle and crust. Zhuang (1994) identified several metamorphic domains in the Chinese Altai, which consist of Barrow-type metamorphic belts with migmatitic granitic gneisses at their cores. T.N. Yang et al. (2011) pointed out that the metamorphism in the Chinese Altai is highly heterogeneous in space, and that the metamorphic

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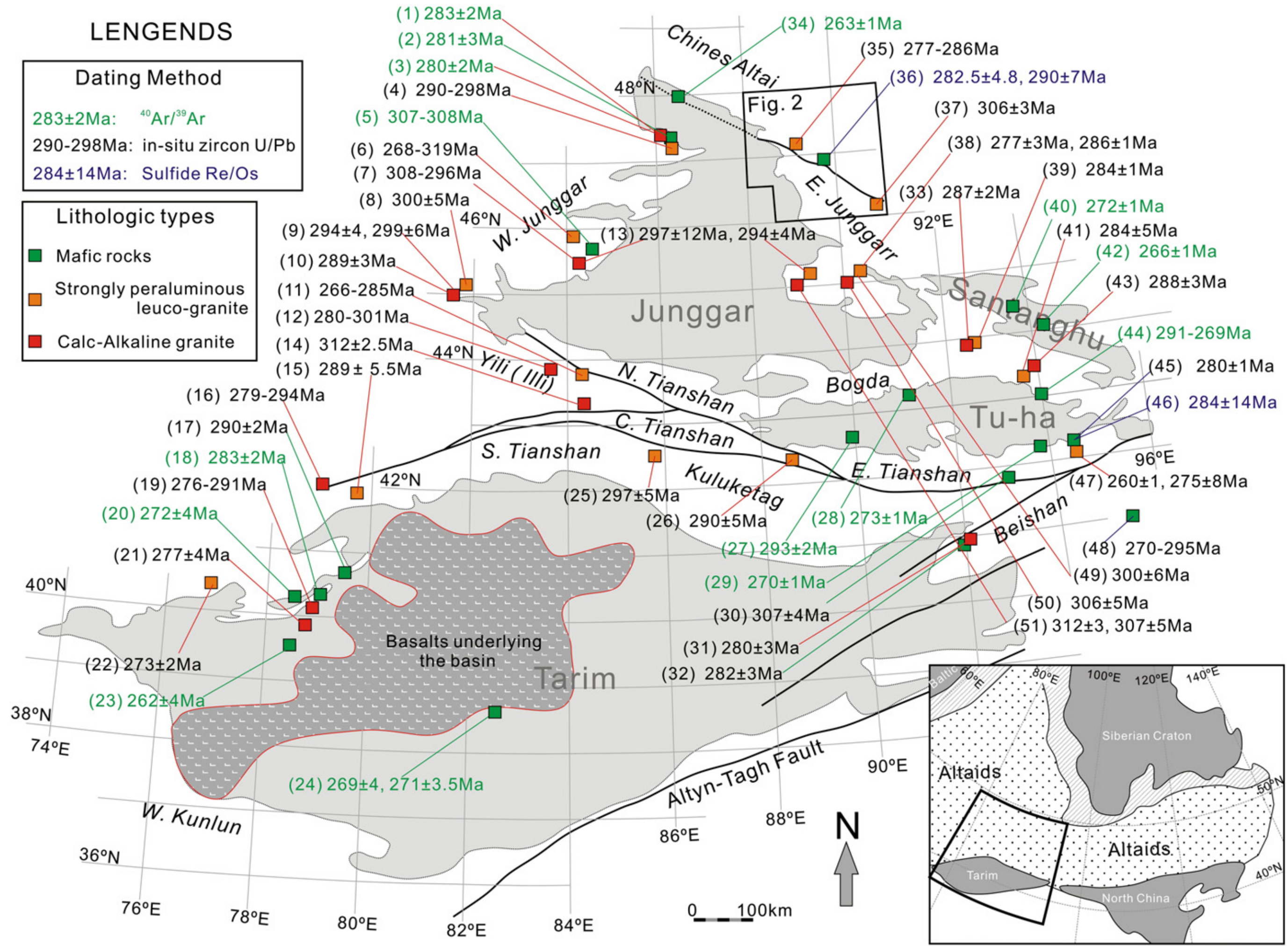

Fig. 1. Generalized map of Xinjiang Province, NW China, showing the major basins and their periphery orogenic belts. The Latest Late Carboniferous to Early Permian magmatic rocks are widespread in all tectonic units of Xinjiang Province. *Inset* shows the location of Fig. 1 in the Altaids. Position of Fig. 2 is marked. Abbreviations: W. Junggar: West Junggar; E. Junggar: East Junggar; C. Tianshan: Central Tianshan; E. Tianshan: East Tianshan; N. Tianshan: North Tianshan; S. Tianshan: South Tianshan. Age data from: (1) to (3) L.G. Tang et al. (2007); (4) Zhou et al. (2008); (5) Z.H. Zhang et al. (2008); (6) Han et al. (2006); (7) Geng et al. (2009); (8) & (9) Chen et al. (2007); (10) Tang et al. (2010); (11) & (12) Wang et al. (2007); (13) Chen and Jahn (2004); (14) L.H. Sun et al. (2008); (15) Luo et al. (2008); (16) Konopelko et al. (2007); (18) to (20), (23) & (24) Zhang et al. (2010); (21) Yang et al. (2006); (22) Wang et al. (2007); (25) Zhu et al. (2008); (26) Dong et al. (2011); (27) to (29), (40), (42), & (44) Zhou et al. (2006); (30) Yuan et al. (2010); (31) Su et al. (2011); (32) Ao et al. (2010); (33), (41) & (43) Yuan et al. (2010); (34) Chen and Han (2006); (35) Gong et al. (2007); (36) Z.H. Zhang et al. (2008); (37) H.F. Tang et al. (2007); (38) Shen et al. (2011); (39) Mao et al. (2008); (45) Han et al. (2010); (46) Z.H. Zhang et al. (2008); (47) Tang et al. (2008); (48) Zhang et al. (2011); (49) G.X. Yang et al. (2011); (50) Yuan et al. (2007); (51) Xiao et al. (2011).

domains have an obvious spatial relationship with leucogranites. Recently published geochronological and thermochronological data (e.g., Laurent-Charvet et al., 2003; Briggs et al., 2007; W. Wang et al., 2009) indicate that the regional metamorphism in the Chinese Altai occurred exclusively during the late Paleozoic, regardless of the fact that the magmatism in this region spanned from the Cambrian (Windley et al., 2002; T.N. Yang et al., 2011) to the Permian (e.g., Han et al., 1997, 2006). Thus, the Chinese Altai is an ideal region for studying these possibly complex relationships between magmatism and metamorphism.

In this paper, we document a newly identified scapolite-bearing granulite in the Altai region, northernmost Xinjiang, NW China (Fig. 1). We determined the metamorphic age of this granulite using *in situ* LA-ICP-MS zircon U-Pb dating. In addition, we report new LA-ICP-MS zircon U-Pb data for two garnet-bearing leucogranites, and sensitive high-resolution ion microprobe (SHRIMP II) zircon U-Pb data for a gabbroic pluton; for the gabbro, we also provide bulk geochemistry and zircon Lu/Hf isotopic data. We then synthesize these data with previously published geochronological and geochemical data, on which basis we discuss the spatial and temporal relationships between magmatism and metamorphism in northern Xinjiang. This case study helps to shed light on mantle–crust interactions in general.

2. Geological setting and sampling

Our study area is located in the southeastern segment of the Chinese Altai, which along with the Siberian Altai comprise the Altai-Mongolia microcontinent (Wilhem et al., 2012) in the south-central Altaids (Fig. 1). The Ertix (Irtysh-Zaysan) suture zone separates the Chinese Altai in the north from a series of Devonian to Carboniferous island arc belts (Z-C. Zhang et al., 2008; Chen et al., 2010, and references therein) in the south (Fig. 2). The Chinese Altai is regarded to have been a passive continental margin during the Cambrian to Middle Ordovician (Windley et al., 2002; Wilhem et al., 2012), consisting of fine-grained turbidite clastics and bimodal volcanic rocks (Windley et al., 2002, 2007; T.N. Yang et al., 2011). From the Late Ordovician (Wilhem et al., 2012, and references therein), a continental arc started to develop along the passive continental margin, giving rise to widespread lower to middle Paleozoic arc-like volcanics and volcaniclastics and associated plutons (Xu et al., 2002; Wang et al., 2006; Yuan et al., 2007; M. Sun et al., 2008; T.N. Yang et al., 2011).

Meanwhile, one or more early-middle Paleozoic island arcs developed in north Junger, south of the Ertix suture (e.g., Z-C. Zhang et al.,

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