



Early Carboniferous adakitic rocks in the area of the Tuwu deposit, eastern Tianshan, NW China: Slab melting and implications for porphyry copper mineralization



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ABSTRACT

Existing geochronological and geochemical data for the Early Carboniferous magmatic rocks in the eastern Tianshan, Xinjiang, have been interpreted in a variety of theories regarding petrogenesis and geodynamic setting. The proposed settings include rift, back-arc basin, passive continental margin, island arc, ridge subduction, and post-collisional environment. To evaluate these possibilities, we present new SHRIMP zircon U–Pb geochronology and geochemical data, whole-rock geochemical, Hf isotope, and S isotope data for tonalitic rocks and ores associated with the Tuwu porphyry copper deposit located in the center of the late Paleozoic Dananhu–Tousuquan arc, eastern Tianshan. SHRIMP zircon U–Pb dating indicates that the magmatic activity and thus associated copper mineralization occurred ca.332 Ma. The tonalitic rocks are calc-alkaline granites with A/CNK values ranging from 1.16 to 1.58; are enriched in K, Rb, Sr, and Ba; and are markedly depleted in Nb, Ta, Ti, and Th. They show geochemical affinities similar to adakites, with high Sr, Al₂O₃, and Na₂O contents and La/Yb ratios; low Y and Yb contents; and slight positive Eu anomalies. In situ Hf isotopic analyses of zircons yielded positive initial $\epsilon_{\text{Hf}}(t)$ values ranging from 6.9 to 17.2. The $\delta^{34}\text{S}$ values of the ore sulfides range from -3.0% to $+1.7\%$, reflecting a deep sulfur source. Our results indicate that the paleo-Tianshan oceanic slab was being simultaneously subducted northward beneath the Dananhu–Tousuquan arc, and southward beneath the Aqishan–Yamansu arc during the Early Carboniferous. The Tuwu adakitic tonalitic rocks were derived from the partial melting of the subducted paleo-Tianshan oceanic slab, which was subsequently hybridized by mantle wedge peridotites. The slab-derived magmas have considerably high copper contents and are highly oxidized, thus leading to porphyry copper mineralization. Such Early Carboniferous tonalitic rocks that are widespread in the eastern Tianshan define a province with high potential for copper mineralization.

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1. Introduction

The Central Asian Orogenic Belt was formed by the amalgamation of various continental blocks, arc complexes, and accretionary wedges (Pirajno, 2010; Xiao et al., 2010; Rojas-Agramonte et al., 2011; Goldfarb et al., 2014; Mao et al., 2014). The eastern part of the Tianshan in northwestern China is part of the southern margin of the orogenic belt (Fig. 1a), and it separates the Junggar Basin to the north from the Tu–Ha Basin to the south (Fig. 1b). The eastern

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Tianshan is characterized by widespread Carboniferous to Permian granitoids (Chen et al., 2005b; Wu et al., 2006a), and lesser Devonian granitoids (Li et al., 2006c; Zhou et al., 2010) and Triassic granitoids (Li et al., 2002; Zhang et al., 2005; Zhou et al., 2010). These eastern Tianshan granitoids have attracted much attention because they are often associated with Cu–Au–Fe–Ag mineralization. However, the petrogenesis and geodynamic setting of the granitoids are still a matter of debate, with suggested settings such as rift (Qin et al., 2002), back-arc basin (Xu et al., 2003), passive continental margin (Li et al., 2003), island arc (Rui et al., 2002; Mao et al., 2005; Zhang et al., 2008), ridge subduction environment (Sun et al., 2010, 2011), or post-collision setting (Wang et al., 2006a; Gu et al., 2006; Zhou et al., 2008). Some studies suggest that the porphyry copper-related granitic intrusions in the eastern

Tianshan may have an adakitic affinity (Wang et al., 2001; Liu et al., 2003; Han et al., 2006; Zhang et al., 2010). The intrusions are mostly tonalitic, granodiorite, and granodioritic porphyry in composition (Zhang et al., 2004). However, due to the lack of systematic, high-quality geochronological and geochemical data, the petrogenesis and geodynamic setting of the adakitic granitoids are poorly understood. As part of the magmatism research in the eastern Tianshan, this paper thus provides SHRIMP zircon U–Pb geochronological, whole-rock geochemical, Hf isotope, and S isotope data for the Tuwu intrusive rocks and ores, and discusses granitoid petrogenesis, the associated porphyry Cu mineralization, the crust–mantle interaction process, and eastern Tianshan geodynamic setting.

2. Geological setting and deposit geology

The eastern Tianshan region is one of the important producers of Cu (+/–Ni), Au, Fe, and Ag in China (Zhai et al., 1999; Mao et al., 2008; Deng et al., 2011). The eastern Tianshan may be divided into three major tectonic units, the Dananhu–Tousuquan arc, the Kangguer–Huangshan ductile shear belt, and the Aqishan–Yamansu arc, which are separated by the regional-scale Kangguer and Yamansu crustal-scale faults (Fig. 1c). The Dananhu–Tousuquan arc is situated north of the Kangguer fault, is mainly composed of Devonian to Carboniferous volcanic and intrusive rocks, and contains several porphyry Cu deposits of different sizes, including the Tuwu, Yandong, Linglong, and Chihu deposits

(Fig. 1c). The base of the Dananhu–Tousuquan arc is represented by basaltic to andesitic volcanic rocks, with locally overlying Lower Carboniferous carbonates and calcareous mudstones (Mao et al., 2005). The Kangguer–Huangshan ductile shear belt lies between the Kangguer and Yamansu faults, an area in which most rocks have undergone greenschist facies metamorphism and ductile deformation, and where there are a number of orogenic Au deposits (e.g., Kangguer) and magmatic Cu–Ni sulfide deposits (e.g., Huangshan and Huangshandong). The Aqishan–Yamansu arc is located between the Yamansu and Aqikuduke faults, mainly comprises Early Carboniferous basalt, andesite, dacite, and tuff of the Yamansu Formation and Late Carboniferous rhyolite of the Tugutubulake Formation (Ma et al., 1993). The arc hosts numerous Fe (–Cu) and Cu–Ag–Pb–Zn skarn deposits (e.g., Yamansu). The structural architecture of the eastern Tianshan is characterized by a series of E–W-trending regional faults, including the Dacotaan, Kangguer, Yamansu, and Aqikuduke faults (Qin et al., 2003).

The Tuwu porphyry Cu deposit is located in the middle of the Dananhu–Tousuquan arc and is about 1–3 km north of the Kangguer fault (Fig. 2a). Tuwu, discovered in 1997, is the largest deposit in the eastern Tianshan, with total Cu reserves of 2.04 million tonnes (Zhang et al., 2006). The country rocks in the Tuwu area, have well-developed schistosity, strike approximately E–W, and dip to the south at 43–63°. They can be divided into three lithologic sections of the Carboniferous Qieshan Group (Fig. 2b). The stratigraphically lowest section is composed of volcanoclastics and tuff; the middle section is composed of basalt and andesite, with interca-

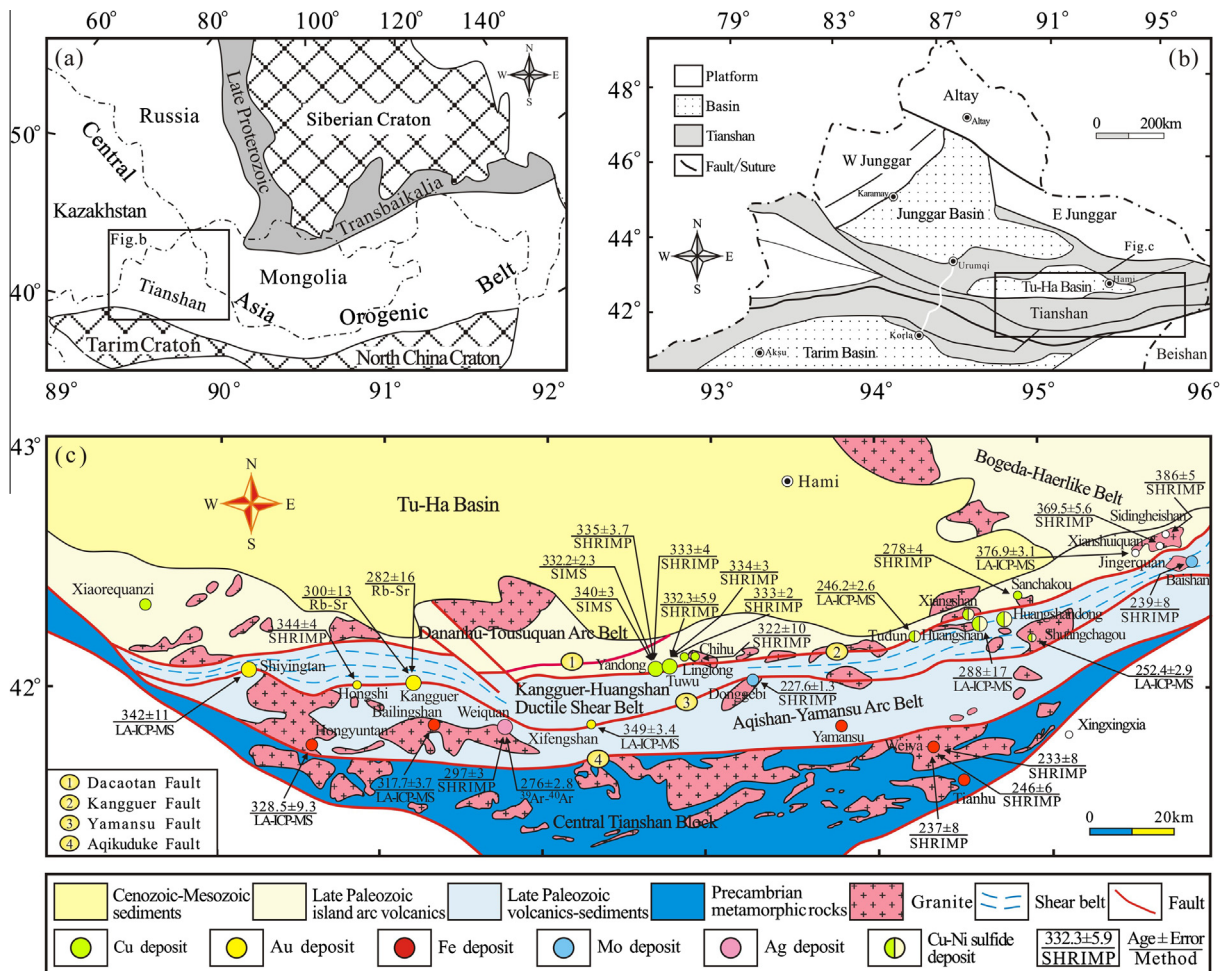


Fig. 1. (a) Location of the study area in the Central Asia Orogenic Belt (modified from Zhang et al., 2009). (b) Sketch map showing geologic units of the Tianshan (modified from Chen et al., 2012). (c) Simplified geological map of the eastern Tianshan (modified from Huang et al., 2013).

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