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Discussion

Reply to the comment by Wen-Bin Zhu et al. on "Characteristics and dynamic origin of the large-scale Jiaoluotage ductile compressional zone in the eastern Tianshan Mountains, China"☆

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1. Introduction

We thank Zhu and his colleagues for their comments on our paper (Xu et al., 2003). They agree with our main conclusions related to the ductile deformation of the JDCZ (Zhu et al., 2004). However, they dispute our model for the geodynamic evolution of the JDCZ (Xu et al., 2003, fig. 18) using the following arguments:

(1) There are no Carboniferous volcanic rocks in the middle Tianshan terrane;
(2) The Carboniferous volcanic rocks in the Aqishan–Yamansu area are arc-type volcanic rocks;
(3) There are no Proterozoic rocks in and around the Junggar basin; and
(4) The Carboniferous volcanic rocks in the Jiaoluotage and Bogda–Harlik areas are related to southward subduction of the Tianshan–Mongolia ancient-ocean.

We would like to dispute these arguments, as outlined below.

2. Carboniferous volcanic rocks in the middle Tianshan terrane

Zhu et al. (2004) assert that "no Carboniferous volcanic rocks occur in the eastern segment of the central Tianshan". This is not accurate according to current documentation; for instance, in the eastern segment of the middle Tianshan terrane in the Weiya, Yileike Hill and Mazhuangshan areas, Carboniferous volcanic rocks (Yamansu Formation (C_1y)) have been mapped (1RGSTGSBGMR, 1966; 1RGSTXJBGMR, 1965, 1966). Li et al. (1998) also show that the Carboniferous volcanic rocks and rhyolitic and dacitic porphyry in these areas were formed about 300 Ma ago.

Moreover, last summer, we discovered that there are Proterozoic amphibolite facies metamorphic rocks (AFMR) that lie under the volcanic rocks of the Yamansu Formation (C_1y) north of the Aaikkudug–Shaquanzhi fault in the Baishiquan are. At this site, the Aaikkudug–Shaquanzhi fault was a thrust fault, and was characterized by a 1–2-m-wide quartz and K-feldspar alteration zone, and the Proterozoic AFMR on the two sides of the fault are consistent and connected. This indicates that there is a Proterozoic basement connected to the middle Tianshan terrane below the Carboniferous volcanic–sedimentary rocks in the southern part of the Jiaoluotage Carboniferous volcano–sedimentary basin.

3. Tectonic environment of the Carboniferous volcanic rocks of the Yamansu Formation

The Carboniferous volcanic rocks of the Yamansu Formation in the Aqishan–Yamansu area have been considered as arc-type volcanic rocks according to their

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bi-modal features and calc-alkaline nature (e.g. Ma et al., 1993). However, the coexistence of siliceous rocks with basalt in the lower part of the Yamansu Formation (Qin et al., 2002), pillow structure in basalt in the Yamansu eastern valley (Qin et al., 2002), minor or no andesite in the Aqishan–Yamansu area (Qin et al., 2003), and a broad limestone in the upper part of the Yamansu Formation (Xu et al., 2003), do not support the arc model, but instead indicate that these rocks were deposited in a marine environment. So, we interpret that the Carboniferous volcanic rocks of the Yamansu Formation in the Aqishan–Yamansu area were formed in a marine basin.

On the other hand, the Carboniferous volcanic rocks of the Yamansu Formation (in the Mazhuangshan area, named the Hongliuyuan Formation by 1RGSTGSBGMR (1966)) in the middle Tianshan terrane, are characterized by large accumulations of aubergine-coloured-rhyolite (Jing and Xu, 1997). This is a feature that arc-type volcanic rocks should have (Chen et al., 2000).

4. Precambrian rocks in the Junggar plate

Basement features of the Junggar basin and the existence of the Precambrian basement below and around the Junggar basin have been discussed and argued for a long time (e.g. Huang et al., 1980; Feng et al., 1989; Carroll et al., 1990).

Recent research shows that the Junggar plate has an ancient continental basement, some of which is Precambrian or older. For example, Zhang et al. (1998) documented that some inclusions of granulite occur in hypersthene granite in the Miaoergou area; Li et al. (2000) reported that Laojunmiao metamorphic complex formed in the late middle Ordovician; Song et al. (2002) show that the rocks of the granite batholiths in Dananhu and Kezirkalasayi were intruded at about 383 and 357 Ma BP, respectively, implying the existence of an ancient continental basement in the Junggar basin. In addition, Zhao et al. (2000) reported that relict zircons in the Laoyazhiquan granite have an age of about 2064 Ma, suggesting that these older zircons were from the Precambrian basement. The 704 Geological Survey Team of the Xinjiang Geoexploration Bureau for Non-Ferrous Metals discovered a large exposure of AFMR, including sillimanite–biotite–quartz schist, muscovite–biotite–quartz schist, gneiss, amphibolite and granite–gneiss, in the Xiaoshitou area in the eastern Junggar basin in 1994 (Hu et al., 1997) and Zhang et al. (1996) showed that these AMFR have an age of about 670 Ma.

Recently, we discovered some clasts of AMFR, including quartzite coexisting with basaltic plasticlasts and biotite pagiogneiss in the Devonian volcanic rocks in the Toushuquan area in the eastern Junggar. This also is compatible with a metamorphic basement beneath the Devonian volcanic rocks or adjacent to them.

5. Discovery of Precambrian AMFR in the Jiaoluotage tectonic belt

As an important advancement of the geological surveying and mapping in Xinjiang in the last 10 years, numerous occurrences of Precambrian AMFR, including gneiss, plagiogneiss, amphibolite, marble, quartzite, granite–gneiss and gneissic granite, were discovered in the Jingerquanbeikuang–Xianxingxia area (6GSTXJBGMR, 1995a,b). A primary dating result shows that the corresponding metamorphism occurred at about 563 Ma BP (6GSTXJBGMR, 1995a). Metamorphic features of the AMFR are similar to the AFMR (named the Xingxingxia Group) in the Xianxingxia area in the middle Tianshan terrane. Some minor AMFR, as relicts in the granite batholith, were geologically mapped in the Yanchi area (6GSTXJBGMR, 1990a,b). We also observed some gneiss relicts in the Shuangchakou granite batholith last summer.

Moreover, our field observation and the seismic profile indicate that Carboniferous sedimentary and volcanic rocks were unconformably deposited over and upon the Proterozoic AMFR and that the seismic reflecting features of rocks on both sides of the Dachaotan fault, beneath the Carboniferous and Devonian systems in the Tulaergen area, are consistent and continuous, indicating that the basement of the Junggar plate and the Jiaoluotage tectonic belt is most likely identical and connected (Xiao et al., 2004).

An older zircon, with an age of about 593 Ma and from the deep Proterozoic basement, was discovered in Carboniferous volcanic rocks in the Kanguer area in the western Jiaoluotage tectonic belt (Ji et al., 1994). This indicates that the Proterozoic basement might also exist throughout the Jiaoluotage tectonic belt.

These features indicate that a larger Junggar plate consists of the Junggar plate, the Jiaoluotage unit, and the middle Tianshan terrane and is a united Proterozoic basement.

6. Are the Carboniferous volcanic rocks in the Jiaoluotage and Bogda–Harlik areas related to south subduction of the Tianshan–Mongolia ancient-ocean?

Zhu et al. (2004) proposed that all of the Carboniferous volcanic rocks in the Jiaoluotage and Bogda–Harlik areas should be related to southern subduction of a Tianshan–Mongolia ancient-ocean. This hypothesis is disputed by evidence that the Tianshan–Mongolia ancient-ocean, recorded by the Zhaheba–Beitashan ophiolite belt and the Karamaili–Moqinwula ophiolite belt, was closed before Carboniferous time (Li, 1995). This strongly suggests that the Junggar plate had collided with the Siberian plate in the late Devonian, and that there was no ocean and no subduction at this time in the area north of the Bogda–Harlik trace in the Carboniferous. Furthermore, the Carboniferous volcanic rocks in the Bogda–Harlik area

were formed in a continental rifting environment (Gu et al., 2000).

The subduction along the southern marginal fault of central Tianshan in Carboniferous (Allen et al., 1992) was the most possible cause for the formation of a Carboniferous middle Tianshan arc and Jioluotage back-arc basin and volcanic rocks.

7. Conclusion

Our conclusion is that the middle Tianshan terrane is a Carboniferous arc-island, whereas the Jiaoluotage unit was a back-arc basin. Both the Carboniferous arc and the back-arc basin system and the JDCZ were likely due to the subduction of the Tarim ancient-ocean and the collision of Tarim continental plate with the Junggar plate.

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