Forum Reply

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Evidence from Paleosols for low to moderate elevation of the India-Asia suture zone during mid-Cenozoic time

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Xu et al. (2018) challenge the age interpretation and the geodynamic conclusions of Leary et al. (2017) and suggest that the Liuqu Conglomerate is Eocene in age, not early Miocene as interpreted in our study. We readily acknowledge that the age of the Liuqu Conglomerate remains poorly constrained, and assigning an age to these rocks requires weighing a variety of conflicting datasets. We provided a lengthy and detailed analysis of the age of the Liuqu Conglomerate in Leary et al. (2016) based on detrital zircon U-Pb data, detrital zircon fission-track (ZFT) data, detrital zircon (U-Th)/He (ZHe) analyses, palynological data, biotite $^{40}Ar/^{39}Ar$ ages from a crosscutting dike, regional structural constraints, plant fossils, and soil carbonate $\delta^{13}C$ values compared to the global curve. Taken as a whole, the age most consistent with all these data is ca. 19 Ma.

Xu et al. selectively focus on three aspects of this dataset that they believe do not support a Miocene age. We address each of these here.

1. Detrital zircon U-Pb and ZFT data. We acknowledge that a robust age determination cannot be made using detrital zircon U-Pb data because the youngest population at ca. 18 Ma is made up of only two grains. However, un-reset ZFT maximum depositional ages from four samples, defined by youngest age peak, are 32.9 –8.8/+11.9 Ma (n=4), 32.6 –8.7/+11.8 Ma (n=4), 25.1 –4.5/+5.5 Ma (n=6), and 15.1 –3.0/+3.7 Ma (n=5) (Leary et al., 2016).

2. Biotite $^{40}Ar/^{39}Ar$ data. Analyses of biotite from a dike crosscutting the base of the Liuqu Conglomerate yielded an $^{40}Ar/^{39}Ar$ plateau age of 20.1 ± 1.0 Ma. This provides a minimum depositional age for the base of the formation. This age overlaps (including analytical uncertainty and stratigraphic position) age estimates from detrital zircon U-Pb, detrital ZFT, detrital ZHe, palynological, carbon stable isotopic, and regional structural data.

3. Soil carbonate $\delta^{13}C$ values. Xu et al. correctly note that taken in isolation, these data could indicate ages of ca. 75–50 Ma or <20 Ma. Thus, this individual dataset is consistent with age interpretations of Xu et al., Ding et al. (2017), and Leary et al. (2017).

In their Comment, Xu et al. also call attention to data presented by Ding et al. (2017) as a refinement of the age of the Liuqu Conglomerate. The first of these datasets is a collection of plant fossils on which the paleo-elevation analysis of Ding et al. (2017) was based. Xu et al. stated that 36 species have been identified and that this assemblage indicates a middle Eocene age. Ding et al. (2017) present 16 "representative" photos of these fossils in their supplemental data; however, they do not present any genera or species identifications or discuss the details of their age interpretation.

Published analysis of 39 species of plant fossils identified from the Liuqu Conglomerate has interpreted a middle to late Eocene age (Fang et al., 2006). Fang et al. noted a high degree of similarity between fossil assemblages in the Liuqu Conglomerate and the Qiuwu Conglomerate, believed at that time to be Paleogene in age. Subsequent radioisotopic dating of the Qiuwu Conglomerate yielded a Miocene age (Li et al., 2017; Ding et al., 2017). We suggest that strong paleobotanical similarity between the Liuqu and Qiuwu Conglomerates may indicate that the two formations are similar in age.

Xu et al. and Ding et al. (2017) also presented zircon U-Pb data from a "tuffite" in the Liuqu Conglomerate. These analyses yielded a youngest peak age of 59.3 ± 1.6 Ma. However, out of 89 analyzed grains, only the youngest 9 grains define this depositional age; the remaining 80 grains range in age from 69 ± 4 Ma to 2824 ± 20 Ma (Fig. 1). This range suggests that the bed sampled by Ding et al. (2017) is a detrital siltstone, not a tuff. These ages are also similar to those from a siltstone analyzed by Leary et al. 2016 (Fig. 1). Thus, the 59.3 ± 1.6 Ma age presented by Ding et al. (2017) is a maximum depositional age consistent with the early Miocene age interpreted by Leary et al. (2016; 2017).

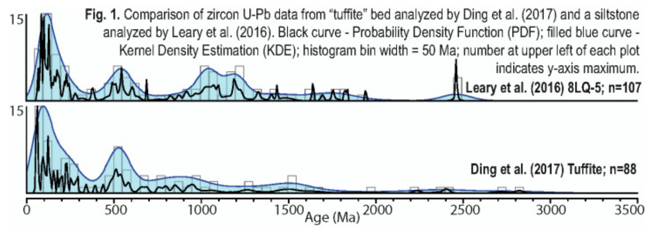

Fig. 1. Comparison of zircon U-Pb data from "tuffite" bed analyzed by Ding et al. (2017) and a siltstone analyzed by Leary et al. (2016). Black curve - Probability Density Function (PDF); filled blue curve - Kernel Density Estimation (KDE); histogram bin width = 50 Ma; number at upper left of each plot indicates y-axis maximum.

Ding et al. (2017) also support their "tuffite" interpretation with an electron backscatter image purportedly showing the presence of glass (Data Repository item DR2D). However, this image does not convincingly show glass in the sample. Clay minerals, which the authors interpret to have weathered from glass, are abundant in Liuqu Conglomerate siltstones and paleosols (Leary et al., 2016, 2017) and do not necessarily indicate a volcanic origin.

In their Comment, Xu et al. correctly identify the limitations of detrital zircon U-Pb, biotite $^{40}Ar/^{39}Ar$, and stable isotopic data. However, in their interpretation of the Liuqu Conglomerate as Eocene in age, Xu et al. and Ding et al. (2017) draw selectively from published data and fail to account for ZFT, ZHe, palynologic, and regional structural data that do not support their interpretation. We therefore reassert that early Miocene is the most robust age for the Liuqu Conglomerate because it takes into account all published data.

Finally, Xu et al. note that the paleoclimate and paleo-elevation interpretations of Ding et al. (2017) are nearly identical to those of Leary et al. (2017). This is an important result in that it confirms the overall conclusions of both studies. More work is required to further constrain the age of the Liuqu Conglomerate and to determine exactly when the India-Asia suture zone experienced these well-documented warm, wet, and low elevation conditions.

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