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Forum Reply

Direct U-Pb dating of Cretaceous and Paleocene dinosaur bones, San Juan Basin, New Mexico

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Koenig et al. (2012) question two aspects of our paper (Fassett et al., 2011): (1) that we ignored a previously published critique by Lucas et al. (2009) that questioned the use of palynologic and paleomagnetic data to determine the age of the Ojo Alamo Sandstone, and (2) that we failed to provide sufficient detail regarding the dating methodology we employed. The first criticism is not relevant: our paper reporting the U-Pb dating of two dinosaur bones is independent of "previously published work." (The Comment by Koenig et al. [2012] failed to mention that the previous critique by Lucas et al. [2009] of Fassett [2009a] was responded to in detail in Fassett, 2009b.)

The second criticism, that our dating methodology was not detailed, was due to the space limitations required by *Geology*; a more-detailed description of that methodology is in a manuscript in preparation by Heaman, Simonetti, and Fassett (Heaman, 2012, personal commun.). Koenig et al. note that there is scatter in the U-Pb data in excess of analytical uncertainty, especially for bone 22799-D. This occurred because there are regions in the bone affected by post-fossilization U-Pb disturbance, as fully discussed in the Heaman et al. manuscript in preparation (mentioned above).

Our analysis indicates, however, that there are regions in the bone samples where the geochemistry and U-Pb systematics are undisturbed. The enormous advantage of the U-Pb dating technique (Fassett et al., 2011) is that these pristine regions can be precisely targeted to obtain robust fossilization dates. Koenig et al. address the importance of establishing the time of bone fossilization because geochemical profiles in some fossil teeth and bone samples have shown that fossilization can take up to ~1 m.y., and is characterized by shallow geochemical gradients (Millard and Hedges, 1996; Trueman et al., 2004; Kohn, 2008; Koenig et al., 2009). Fossilization of most bone, however, is essentially complete in <100 k.y. (Trueman et al., 2004; Kohn, 2008). The geochemical gradients observed in bone BB-1 are steep and thus consistent with a short fossilization time. The Paleocene U-Pb age of 64.8 ± 0.9 Ma obtained for bone BB-1 is thus believed to represent the time of death within the quoted uncertainty.

The technique used to correct for common Pb in dating U-bearing minerals by laser ablation–inductively coupled plasma–mass spectometry (LA-ICPMS) is important. We (2011) and other researchers have reported that apatite can contain a large proportion of common Pb; therefore, the accuracy of U-Pb dates in such cases is very sensitive to the isotopic composition assigned to the common Pb component. For LA-ICPMS analyses, it has been noted in numerous studies (Jackson et al., 2004; Storey et al., 2006; Chew et al., 2011) that it is not possible to make an accurate correction for common Pb based on measurement of the unradiogenic ^{204}Pb content (i.e., the ^{204}Pb method) because of isobaric interferences at mass 204 (in particular ^{204}Hg). A U-Pb dating approach that does not require knowledge of the accurate abundance of ^{204}Pb is the ^{207}Pb method (Storey et al., 2006; Cox and Wilton, 2006; Simonetti et al., 2006; Chew et al., 2011). In this method, the common Pb isotopic composition is determined by projecting the uncorrected data on a Tera-Wasserburg diagram (^{238}U/^{206}Pb vs. ^{207}Pb/^{206}Pb), with the *y*-intercept delineating the ^{207}Pb/^{206}Pb ratio for common Pb. This common Pb composition can then be used to apply a common Pb correction to the measured ^{206}Pb/^{238}U ratios using well-established common Pb–radiogenic lead mixing equations (Chew et al., 2011). In studies where ICPMS and isotope dilution thermal ionization–mass spectometry (ID-TIMS) analyses have been conducted on the same mineral containing high common Pb contents, this approach has yielded accurate dates (Aleinikoff et al., 2002; Storey et al., 2006; Simonetti et al., 2006; Simonetti et al., 2008; Chew et al., 2011). Thus, we adopted this well-established ^{207}Pb method, and in our opinion, the U-Pb dates we reported are accurate. In contrast, Koenig et al. suggest that the ^{238}U/^{206}Pb isochron approach should have been used to determine ages because this method does not require any knowledge of the common Pb content or its isotopic composition. Although this method can be used for ID-TIMS dating of apatite, and in a crude way to assess the nature of isotopic disturbance in bone using ICPMS, it cannot be used to obtain accurate age results in conjunction with ICPMS techniques because of the large uncertainty associated with measurement of the combined ^{204}(Pb+Hg) ion signal. This conclusion was reiterated in the recent study of Chew et al. (2011).

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