Forum

Depleted mantle wedge and sediment fingerprint in unusual basalts from the Manihiki plateau, central Pacific Ocean: Comment and Reply

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Ingle et al. (2007) reported $^{40}\mathrm{Ar}/^{39}\mathrm{Ar}$ ages for Manihiki plateau rocks and suggested some of them were contemporaneous (~120 Ma) with lavas from the Ontong Java and Hikurangi plateaus, each some 2500 km distant (Ingle et al., 2007, their Fig. 1). Critical examination of the radiometric data suggests that widespread volcanism in the central-western Pacific at ~120 Ma is questionable.

All $^{40}\mathrm{Ar}/^{39}\mathrm{Ar}$ results need to be evaluated for (1) statistical validity of plateau segments (Baksi, 2005), and (2) the state of alteration of splits used for dating purposes. The alteration index (AI) (Baksi, 2007a, 2007b) quantitatively evaluates the freshness of samples by monitoring the quantity of $^{36}\mathrm{Ar}$ seen in the various steps of the $^{40}\mathrm{Ar}/^{39}\mathrm{Ar}$ incremental heating work. These tests are applied to the results of Ingle et al. (2007); errors are quoted at the 1σ level.

For tholeiitic sample D2–1, steps 3–6 define the best plateau; steps 7–9 are left out as they have very large associated errors (Ingle et al., 2007, their Fig. 3A). The plateau age is 117.8 ± 1.5 Ma; the mean square of weighted deviates (MSWD) value is 0.028, and the corresponding probability value is 0.994; the step age errors have been overestimated by a factor of ~5. Using these smaller error estimates yields a more "precise" plateau age of 117.83 ± 0.30 Ma, with a probability of occurrence of ~0.55. The average AI ($^{36}\mathrm{Ar}/^{39}\mathrm{Ar}$) of the plateau steps is four times higher than the cutoff value for fresh samples of <0.0006 (Baksi, 2007a). For sample D3–1 (alkalic lava), Ingle et al. selected steps 3–6 as yielding a plateau age. Step 6 is measurably younger than the others and should not be included in the plateau (Ingle et al., 2007, their Fig. 3C). The MSWD value (5.3) for steps 3–5 shows a probability of occurrence of ~0.005. This is unacceptable and the age cannot be taken to reflect the time of crystallization of sample D3–1. Further, the AI of the three plateau steps average >10 times the cutoff for fresh samples. No (proper) age was recovered for sample D3–1 and, at best, a minimum age was recovered for D2–1.

Ingle et al. compared their 117.9 ± 1.8 Ma age on sample D2–1 to the 121.8 ± 2.6 Ma ($^{40}\mathrm{Ar}/^{39}\mathrm{Ar}$ age) reported for the Ontong Java plateau by Mahoney et al. (1993) (see Baksi (2007b, their Fig. 11A). The latter specimen has been shown to be altered (Baksi, 2007b, Fig. 11B) and unlikely to yield a proper estimate of its time of crystallization. The age of the Hikurangi plateau is reported in an abstract (Hoernle et al., 2005); no isotopic data are available for statistical inspection and/or the AI test. It is premature to equate (in time) lavas from the Manihiki, Ontong Java, and Hikurangi plateaus.

The dangers associated with the unquestioning use of $^{40}\mathrm{Ar}/^{39}\mathrm{Ar}$ "ages" for oceanic rocks has been detailed elsewhere (Baksi, 1999, 2005, 2007b). This is illustrated by estimates for the age of the Bend in the Hawaiian-Emperor Chain, which are included in all introductory geoscience textbooks. Earlier work on whole-rock basalts suggested an age of 43 Ma (Dalrymple and Clague, 1976). More recent work on mineral separates (Sharp and Clague, 2006) indicates an age of 50 Ma. Sharp and Clague (2006) suggested that the earlier ages were based on dating of post-shield material and thus underestimated the age of the main shield-building phase at each seamount. This is unlikely, because the difference in age at each seamount is ~5–7 m.y., much larger than that estimated for shield–post-shield volcanism (~2 m.y.). As suggested elsewhere (Baksi, 2007b), the discrepancy in the ages results from the dating of altered material over three decades ago. The AI of the whole-rock samples dated by Dalrymple and Clague (1976) are >10 times the cutoff value ($^{36}\mathrm{Ar}/^{39}\mathrm{Ar} < 0.0006$). AI values ($^{36}\mathrm{Ar}/^{37}\mathrm{Ar}$) for the plagioclase samples of Sharp and Clague (2006) average ~0.00006, the cutoff for fresh samples. These (HF) acid-leached mineral separates yielded ages close to the crystallization value; the age of the Bend in the Chain is ~50 Ma.

Seafloor rocks are prone to alteration; this leads to considerable loss of $^{40}\mathrm{Ar}^*$ from the component silicate phases. It is critical that all $^{40}\mathrm{Ar}/^{39}\mathrm{Ar}$ ages obtained on submarine rocks be critically assessed for statistical validity, as well as by the AI method. In the absence of high quality radiometric data for such rocks, speculation on immense volcanic events (plumes?), making up large sections of the seafloor such as in the central-western Pacific Ocean, is premature.

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REPLY: doi: 10.1130/G24882Y.1

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The validity of two ^{40}Ar/^{39}Ar ages presented in our recent paper on the Manihiki Plateau (Ingle et al., 2007) is questioned by Baksi (2008). We welcome the opportunity to clarify the strengths and weaknesses of the data underpinning these ages.

Very little is known about the geochemistry, age, and origin of the Manihiki Plateau, one of several Early Cretaceous large igneous provinces (LIPs) present in the western Pacific Ocean. Several recent papers addressing the origin of the giant Ontong Java Plateau (e.g., Fitton et al., 2004; Ingle and Coffin, 2004), ~2500 km to the west of Manihiki, have stimulated renewed interest and debate about relationships among these LIPs (e.g., Taylor, 2006). The primary purpose of our paper was to analyze and interpret rocks of unusual composition that are not represented in rocks recovered thus far from the Ontong Java or Hikurangi Plateaus, or indeed from any other oceanic location.

A secondary purpose of our paper was to present two ^{40}Ar/^{39}Ar dates which we interpret to reflect crystallization ages. The original data are: D2–1, a tholeiitic basalt, yielded an age of 117.9 ± 3.5 Ma (2σ), and D3–1, a trachybasalt, gave an age of 99.5 ± 0.7 Ma (2σ). Baksi is correct that alteration of Cretaceous rocks on the seafloor is a pervasive problem that needs to be carefully evaluated when employing Ar-dating techniques (Koppers et al., 2000). As it was not possible to obtain mineral separates from the rocks we analyzed, we were required to use groundmass material for Ar isotope analysis. We took precautionary steps for groundmass sample preparation, and followed careful analytical methods (detailed in Data Repository item 2007150, published with our paper), but it is clear that alteration remains a problem in the published Ar data. As the alteration index described in Baksi (2007) was published several months after our paper, it was impossible to assess our data according to those criteria.

In favor of our data, we point out that each sample produced a plateau and isochron age that agreed within error; both isochrons also had intercepts within error of the atmospheric value. Although Baksi (2008) states that errors on the plateau steps of D2–1 are overestimated, analysis of low-K altered tholeiites is difficult, and large analytical uncertainties resulting from the low signal strength are not unexpected. Exclusion of the youngest age step (Baksi, 2008) for D3–1 has no effect on the plateau age for this sample, as the ages are weighted inversely by their errors; furthermore, the isotope composition of this age step lies on the same isochron produced by the other three steps.

Baksi states that ^{40}Ar/^{39}Ar results need to be evaluated for statistical validity and alteration extent; however, he neglects the importance of geological context. Regarding the older age for Manihiki, it coincides with a published Aptian age based on biostratigraphic markers determined from sediments immediately overlying basement rock drilled at Deep Sea Drilling Project Site 317 (Bukry, 1976) on the Manihiki Plateau. It is also contemporaneous with several published ^{40}Ar/^{39}Ar ages from the Ontong Java Plateau—in addition to the Mahoney et al. (1993) paper cited by Baksi (2008)—including those of Tejada et al. (2002). The significance of the younger ^{40}Ar/^{39}Ar age in regards to a relationship among the three LIPs is not clear. In our paper, we stated that late-stage volcanism affected all three LIPs; however, the relationship between (presumably) minor late-stage volcanic events and main construction events is commonly ambiguous.

The origin of LIPs remains enigmatic. We remain cautious in linking the Ontong Java, Hikurangi, and Manihiki plateaus. Any purported links cannot be made solely on the basis of geochronology. As we suggested in our paper, these three giant plateaus share several characteristics including (preliminary) age, geochemical, geophysical, and tectonic relationships. We agree fully with Baksi that much more supporting data are needed to substantiate a temporal connection among the Hikurangi, Manihiki, and Ontong Java plateaus. Recent cruises to the Hikurangi and Manihiki plateaus by the R/V *Sonne* recovered large numbers of basement samples (Hoernle et al., 2004;Werner et al., 2007, respectively). The analyses of these samples should dramatically improve our understanding of massive volcanism in early Cretaceous times.

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