The rift-to-drift transition in the southern North Atlantic: A stuttering start of the MORB machine?: COMMENT and REPLY

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Jagoutz et al. (2007) argue for a long history of alkaline to mid-oceanic ridge basalt (MORB)-type magmatism occurring during the transition from anamagmatic to magmatic rifting at the Iberia-Newfoundland conjugate margin. U-Pb zircon ages suggest that magmatism spanned the range of 110–127 Ma. Ar-Ar ages suggest a similar range for magmatism, along with a complex cooling and alteration history. The general premise put forward by Jagoutz and others, that magmatism at the Iberian margin began slowly during asthenospheric upwelling and progressed, probably with fits and starts, over a period of 15 m.y. or so to a full-blown mid-ocean ridge, is widely accepted (Schärer et al., 2000; Beard et al., 2002; Chazot et al., 2005).

This Comment arises from a disagreement with the authors concerning their petrologic and geologic interpretation of the albitites and kaersutite pegmatites at Ocean Drilling Program (ODP) site 1070 (ODP leg 173; Iberia Abyssal Plain) and the detailed regional models that follow from this interpretation. Key to the authors’ arguments regarding an alkaline to enriched MORB (EMORB) transition at the Iberia margin is the interpretation of the albitites from site 1070 (zircon age 127 ± 4 Ma [U-Pb, SIMS]) as a suite of magmas different from and unrelated to the physically proximal, chemically similar and, within error, age-equivalent kaersutite pegmatites (hornblende Ar-Ar ages 124 ± 0.7 Ma). First, there are problems with the suggested distinction between EMORB and alkaline magmatism at site 1070. Certainly, there is no chemical or petrographic evidence that the site 1070 albitites are more “alkaline” than the pegmatites or, for that matter, alkaline at all. Jagoutz et al. base this distinction on mineralogical characteristics—e.g., the presence of sodic feldspar, biotite, zircon, and other trace phases in alkaline rocks versus pyroxenes, andesine, ilmenite, and kaersutite in MORB-derived rocks—that are easily attributed to fractionation. There is no petrological or geological reason to doubt a genetic relationship between the site 1070 pegmatites and albitites. Albite and kaersutite pegmatite occur together not only in clasts in the overlying breccia but also as intrusions in basement at site 1070 (Whitmarsh et al., 1998; Beard et al., 2002). Both the sodic character of the plagioclase and the high Zr content of the albite are consistent with derivation from the Na- and Zr-rich pegmatites. The plagioclase in the pegmatites is zoned andesine (An$_{50}$), which shows consistent Na enrichment toward the rims of igneous plagioclase (Beard et al., 2002). Na enrichment in interstitial melts in the pegmatites is also recorded by zoning in zoned igneous amphiboles (Beard et al., 2002). The high Zr content of the pegmatite is manifested by Zr concentrations of 100 ppm in the amphiboles and nearly 200 ppm in the ilmenite, some grains of which contain exsolution lamellae of baddeleyite (Beard et al., 2002). Finally, while Jagoutz et al. emphasize the biotite content of the albite, biotite is less abundant than amphibole in these rocks. Although no pristine igneous amphibole (or biotite) was found in the albitites, analysis of metamorphosed amphiboles shows very high TiO$_2$ content (e.g., 1.5%©) that clearly suggests derivation from a high-Ti (e.g., kaersutite) precursor. The available data favor a genetic relationship between the pegmatite and albitite, over the correlation postulated by Jagoutz et al.—i.e., that the albitite is related to a biotite gabbro that was drilled 5000 km away in Newfoundland and, even at the time of formation, was likely hundreds of kilometers away (Jagoutz et al.). This is particularly true since (given its stated mineralogy; no chemical or detailed mineralogical data are provided) the Newfoundland gabbro is evidently a potassic rock, while the site 1070 albitite and pegmatite (like many Iberia margin mafic rocks; e.g., Chazot et al., 2005) are strongly sodic.

With respect to the age of magmatism, the Ar-Ar ages on kaersutite must be interpreted cautiously. The assumption that the 600 °C closure for amphibole approximates an igneous age may not be justified. This is not a normal oceanic environment. Beard et al. (2002) argue that the ambient temperature at the time of pegmatite emplacement may have exceeded 1000 °C. At the very least, the amount of time separating pegmatite emplacement and exhumation at site 1070 is poorly constrained. In the final analysis, however, this is moot: the zircon age of the albitite, and the hornblende cooling age of the pegmatite lie within analytical error of one another. Given that the cooling age is at least nominally postmagmatic, arguments that the two ages represent a real difference in age of magmatism are open to question.

Jagoutz et al. agree with previous studies that concluded that the onset of melting at the Iberia margin is related to the increasing thermal influence of hot ascending asthenospheric mantle, which culminates (eventually and outbound) in the formation of a full-blown spreading center. However, the suggested link between denudation faulting, variation in depth of melting, and magmatic variability between 128 and 124 Ma (as depicted in their Fig. 3), while technically possible, is speculative and does not appear to be supported by the available evidence from the Iberian margin.

At the latitude of interest, there is little hard evidence for any magmatism at either Iberia or Newfoundland between emplacement of the Iberian pegmatite/albitite suite at ca. 127 Ma and the injection of a gabbroic dike at the Newfoundland margin at ca. 113 Ma (see Schärer et al. [2000] for a discussion of the variation in age of magmatism during south-to-north propagation of the rift). In the absence of a credible distinction between the site 1070 albitites and pegmatites, the argument for chemically variable magmatism related to the details of denudation, uplift, and asthenospheric upwelling prior to the inception of MOR magmatism is severely compromised. There is little doubt that igneous rocks were emplaced at the Iberia-Newfoundland margin during this interval. Until these rocks are sampled, however, the nature of geochemical variability prior to the inception of MOR magmatism must remain an open question.

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Beard’s (2008) welcome Comment offers us the opportunity to discuss and clarify certain aspects of our paper (Jagoutz et al., 2007). Beard raises points about our reinterpretation of his originally postulated genetic link between albitite clasts recovered from a breccia and a coarse-grained kaersutite pegmatite intrusive into peridotites (site 1070, Ocean Drilling Program [ODP] leg 173) (Beard et al., 2002). It is essential to first review the geological and petrological aspects of the albitite clast and pegmatite. However, we emphasize that our model is not affected by the relationship between the albitite clasts and the pegmatite.

The albitite clast was recovered from a breccia drilled at ODP site 1070 on the Iberia Margin (Fig. Supp. 1, Data Repository item 2007270 of Jagoutz et al., 2007). The breccia is a heterogeneous assemblage of clasts containing calcite, serpentine and possibly amphibolite clasts together with gabbroic and albitite clasts (Whitmarsh et al., 1998), and it is unknown whether it is composed of locally derived components. It is separated by an ~20-cm-wide gouge zone from the underlying unit, which contains the kaersutite pegmatite. A genetic link between the albitite clast and the pegmatite is thus an interpretation that awaits further investigation. It has been shown that albitites (or plagiograni tes) might be substantially younger than gabbros (Costa and Caby, 2001). Recent work proposed that hydrous partial melting of mafic rocks is an alternative mechanism to form plagiograni tes (Koepeke et al., 2007). The proposed magmatic link is the key of to the interpretation of Beard et al. (2002), who equated the U-Pb data on a single zircon from an albitite clast to the intrusion age of the kaersutite pegmatite. Out of six spot analyses, only four yield statistically significant results of 124, 126, 130 and 112 (all ± 7) Ma. A weighted mean age (excluding the 112 Ma age) yielded 127 ± 4 Ma (Beard et al., 2002).

Beard et al. (2002) interpreted the albitites as modified differentiation products derived from the kaersutite pegmatite. The only argument put forward in favor of this interpretation by Beard et al. (2002, p. 900, lines 13–14) is the “high” TiO₂ content (1.26 wt% and not 1.5 wt% as stated in the Comment) observed in tremolitic hornblende, which “clearly suggest derivation from a high-Ti (e.g., kaersutitic) precursor” (Beard, 2008). The observed TiO₂ content is not unusual for hornblende and is significantly lower than that found in the kaersutitic amphibole (4.3–5.2 wt%). Therefore, the genetic relationship between albitite and kaersutite pegmatite based solely on Ti content of metamorphic amphibole is highly speculative. Beard further argues that Na enrichment in the hornblende rim reflects the igneous evolution of the interstitial melt. This statement is not supported by Beard et al.’s (2002) data. In their amphibole zoning plot (their Fig. 5), it is not Na₂O that increases, but the a-site occupancy. The latter cannot be related to Na₂O concentration in amphibole as Na occupies two different sites, M4 and A. The Na₂O concentration (Table 2 of Beard et al., 2002) is 2.94 wt% in the amphibole core and 3.13 wt% in the Fe-rich rim. This is not a significant Na enrichment, but a subtle variation considering microprobe uncertainties. The change from tschermakite to Fe-paragasite is typical for blackwall formation in altered mafic rocks within ulameric bodies (Frost, 1975), and is unrelated to igneous processes. We note also the dramatic decrease of K₂O and TiO₂ in the amphibole toward the rim (Beard et al., 2002), which are likely to increase in igneous zoning. We conclude that the statements of Beard et al. (2002) and Beard (2008) that albitites are easily attributed to fractionation remain unproven. Beard speculates that the mineral assemblage used by us to distinguish between different magmatic sequences could again be easily attributed to fractionation. It is beyond the scope of this Reply to document in detail why they are not easily related. On the basis of mineral assemblage and major and trace element chemistry (Müntener and Manatschal, 2006) we emphasize the similarity of albitite dikes from ODP sites 1070 and 1277. In addition, the paleodistance between sites 1070 and 1277 at the moment of their accretion (about M1) does not exceed 20–30 km, differing from the statement by Beard.

Beard questions our statement that the amphibole age approximates the pegmatite intrusion age. However, the inferred ambient temperature of >1000 °C at the time of pegmatite emplacement (Beard et al., 2002) is a strong speculation, as this high ambient temperature would leave almost no temperature window for amphibole crystallization.

Finally, we agree that the magmatic history of the Iberia-Newfoundland margin needs more high-resolution U-Pb ages to resolve temporal differences between different magmatic pulses.

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