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Reply to Deevsalar and Shinjo (2020) comments on "Petrogenesis of gabbroic rocks from the Malayer plutonic complex, Sanandaj-Sirjan zone, west Iran" (Esna-Ashari and Tiepolo, Periodico di Mineralogia 89, 91-104, 2020)

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First, we thank Deevsalar and Shinjo for their stimulating commentary on Petrogenesis of gabbroic rocks from the Malayer plutonic complex, Sanandaj-Sirjan zone, west Iran, published by Esna-Ashari and Tiepolo (2020). We embrace this opportunity to elaborate on our model of felsic magma-ultramafic rock reaction and elucidate the doubts about this important mechanism for generating a gabbroic melt. Although their comments are not itemized, for the sake of clarity we assign numbers to individual comments in our reply below.

1) Regarding the statement "conclusions in Esna-Ashari and Tiepolo (2020) must be limited to the cumulate rocks …" we would like to clarify that Tangsaran Hill is the largest outcrop of mafic rocks in the Malayer-Boroujerd Plutonic complex (MBPC) (Deevsalar et al., 2014, 2017, 2018a) and all the mafic rocks from the MBPC (either the stocks or the dykes, cumulate or non-cumulate ones, including those from the Tangsaran Hill) are interpreted as cogenetic (Deevsalar et al., 2014, 2017, 2018a, 2018b). Furthermore, by adding mineral and whole rock chemical data from literature, we were able to expand our conclusions to a larger area. Based on our conclusions, compositions of many of the MBPC samples and the calculated compositions of the melts in equilibrium with their clinopyroxenes and amphiboles are similar to the compositions of the Aligoodarz Plutonic Complex (APC) quartz-diorite (Figure 1a). Also, ultramafic rocks of the two complexes are chemically very similar (Figure 1b).

2) Deevsalar and Shino (2020) claim parental melts with different compositions were in equilibrium with clinopyroxene, amphibole and plagioclase (Figure 1c in Deevsalar and Shinjo, 2020). Their assertion differs from the results of our calculations which indicate same composition for the primary melts (Figure 1a; Figure 6 in Esna-Ashari and Tiepolo, 2020). This difference in conclusion is likely to have originated from an incorrect selection of $^{S/L}D$. Mineral-melt partition coefficients largely depend on the composition of the equilibrium melt and in particular on its SiO_2 content (e.g., Tiepolo et al., 2007). Deevsalar and Shinjo (2020) used the $^{S/L}D$ from Ersoy et al. (2010) who borrow values from the experimental work of Adam and Green (2006). The latter present $^{S/L}D$ values for amphibole, obtained for equilibrium melts with less than 40 wt% of SiO_2 (experiment 1950; Adam and Green, 2006) which is not consistent with the compositions of the MBPC rocks in which amphibole and clinopyroxene were found. For this reason, the melt in equilibrium with amphibole will become extremely rich in incompatible trace elements. As we will point out further, there is no rock type with such degree of enrichment in the MBPC to consider as the parent melt of the amphibole. Inconsistent $^{S/L}D$ also accounts for the difference between the trace element composition of the melt in equilibrium with plagioclase and that in equilibrium with amphibole and clinopyroxene. Furthermore, the fact that concentrations

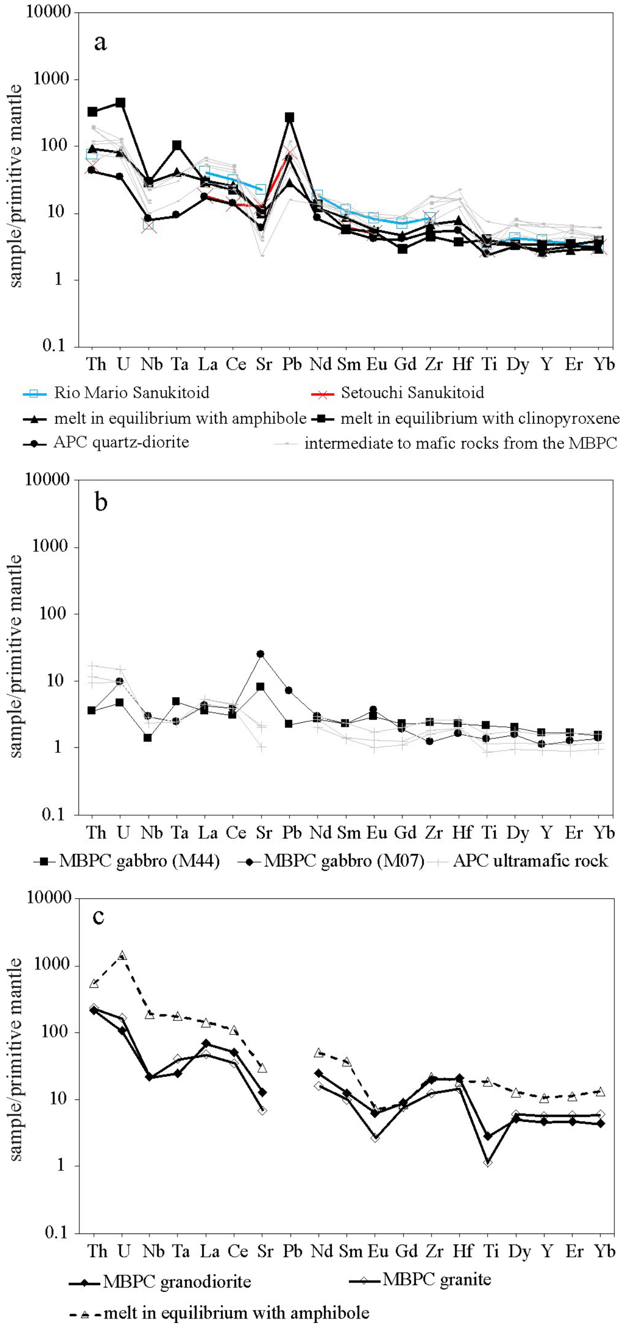

Figure 1. Primitive mantle normalized incompatible trace element patterns of a) the melts in equilibrium with clinopyroxen and amphibole from the MPC gabbro that are compared with some intermediate to mafic samples from the MBPC (samples MN2a, BR02, BR07, M23, G11, G12, B2A28; Deevsalar et al., 2018a, 2018b), APC quartz-diorite (Esna-Ashari et al., 2012), Rio Mario sanukitoid (De Oliveira et al., 2010) and Setouchi sanukitoid (Tatsumi and Ishizaka, 1982; Shimoda et al., 1998); b) MBPC and APC ultramafic rocks (respectively from Deevsalar et al., 2014; Esna-Ashari et al., 2016); c) melt in equilibrium with amphibole that its chemistry calculated by using $^{S/L}D$ used in Deevsalar and Shinjo (2020). This melt is compared with the granodiorite and granite from the MBPC (Ahmadi Khalaji et al., 2007).

of a large number of trace elements in plagioclase are very low to even below their detection limits implies that the calculated composition of the melt in equilibrium with plagioclase (Deevsalar and Shinjo, 2020) must have been affected by a large error, also amplified by the uncertainty in partition coefficients of plagioclase relative to that of amphibole and clinopyroxene.

Our study on the Malayer Plutonic Complex (MPC) (Esna-Ashari and Tiepolo, 2020) in addition to what is shown in figure 1a, indicate that clinopyroxene and amphibole in the gabbro crystallized from an intermediate melt compositionally similar to APC quartz-diorite with the range of SiO_2 between 51 and 59 wt% all of which are comparable with sanukitoid-type magma (Figure 1a). In contrast, according to Deevsalar and Shinjo (2020), amphiboles in the MPC gabbro crystallized from a highly evolved felsic magma with SiO_2 content varying between 63 to 73 wt%. This range of SiO_2 is related to crustal derived granitoids of the MBPC (Ahmadi Khalaji et al., 2007; Deevsalar et al., 2017) whereas the range of SiO_2 in the MBPC mafic to intermediate rocks varies between 43 and 62 wt% (Deevsalar et al., 2014, 2017, 2018a, 2018b). Besides, the crystallization of amphiboles from such silica-rich melt must shift isotopic signature of the host gabbros towards that of the crustal melt. However, isotopic crustal signature of the gabbros including those from the Tangsaran Hill is not supported by Deevsalar et al. (2017). Moreover, the melt that Deevsalar and Shinjo (2020) propose as the parent melt of the amphibole is even more enriched in incompatible trace elements than the granitoid rocks of the MBPC (Figure 1c). Therefore, occurrence of such highly enriched melt is not supported by the published data on the MBPC.

3) Concerning our suggested extensive assimilation of early-formed boninitic assemblage, we would like to clarify that Esna-Ashari and Tiepolo (2020) propose that fractional crystallization of the quartz-dioritic parent magma (F=0.6 not 0.66) and assimilation of an ultramafic rock compositionally similar to sample M44 (R=0.5) gave rise to the MPC gabbro (Esna-Ashari and Tiepolo, 2020). In contrast, Deevsalar and Shinjo (2020) consider F as the extent of fractional crystallization of granitic magma to produce quartz-dioritic melt via reaction with ultramafic rocks.

4) With respect to the model that Deevsalar and Shinjo (2020) propose for the formation of sanukitoid magma, we draw the attention that Sanukitoids may also form in crustal depths. In such cases, the felsic crustal-derived magma interacts with the ultramafic rocks that have been emplaced at middle or upper crustal levels by previous orogenic processes, leading to the formation of a sanukitoid magma (Qian and Hermann, 2010). This model is very similar to what Esna-Ashari and Tiepolo

(2020) have suggested on the genesis of the Aligoodarz intermediate rocks.

Sr-Nd sotopic signature of the MPC gabbro also indicates the role of crustal-derived felsic melt in the genesis of gabbro (Figure 2). Even the gabbro that is proposed to be uncontaminated (Deevsalar et al., 2017, 2018a, 2018b), overlaps with the field of the presumably crustal quartz-diorite and granitoid in the south-east part of the MBPC (Ahmadi Khalaji et al., 2007). There is a curvilinear trend between MBPC gabbro in one side and APC granitoid (as the source of contamination in the APC) in the other side, suggesting interaction between felsic and mafic endmembers with the APC quartz-diorite showing the intermediate composition (Figure 2). The latter overlap the field of diorite and gabbro from the MBPC (samples SB12, SB10, SM05; LM40; BR12) originated by mixing between mantle-derived mafic and crustal derived felsic magmas (Deevsalar et al., 2018a). Observations suggest that MBPC gabbros do not represent isotopic signature of their mantle source but record some degrees of isotopic evolution. Their isotopic signature is intermediate between a depleted mantle source like boninites and a felsic magma similar to the APC granitoids.

5) With reference to Deevsalar and Shinjo (2020) comment on classification of boninites, Pearce and Reagan (2019) have proposed the latest classification according to which boninites can be identified. According to these authors, boninite definition needs to be more sophisticated than that presented in the IUGS classification of boninites in Le Bas (2000). Our studies show that APC ultramafic rocks crystallized from a chemically highly depleted boninitic magma (Esna-Ashari et al., 2016). However, the main point in Esna-Ashari and Tiepolo (2020) is not whether ultramafic rocks are boninitic or not. The main issue is the effect of the boninitic ultramafic rocks on the genesis of intermediate to mafic rocks.

6) On the possible asthenospheric upwelling in the northern Sanandaj-Sirjan Zone we would like to draw attentions to the 187±3 Ma (Early Jurassic) granites of the MPC (Ahadnejad et al., 2011). This age is in good agreement with 1) the Late Triassic to Early Jurassic timing of subduction initiation in the Sanandaj-Sirjan zone (Arvin et al., 2007; Hassanzadeh and Wernicke, 2016), and 2) the accepted mode of the formation of boninitic magma at the onset of subduction (e.g., Crawford et al., 1989; Stern, 2010).

Even though zircon U-Pb dating of the non-cumulate gabbros have yielded Middle-Jurassic ages (Deevsalar et al., 2017), it is too early to say that all different types of mafic rocks in MBPC have the same age. It is likely that the MBPC cumulate rocks that are chemically comparable with APC ultramafic rocks are older than the

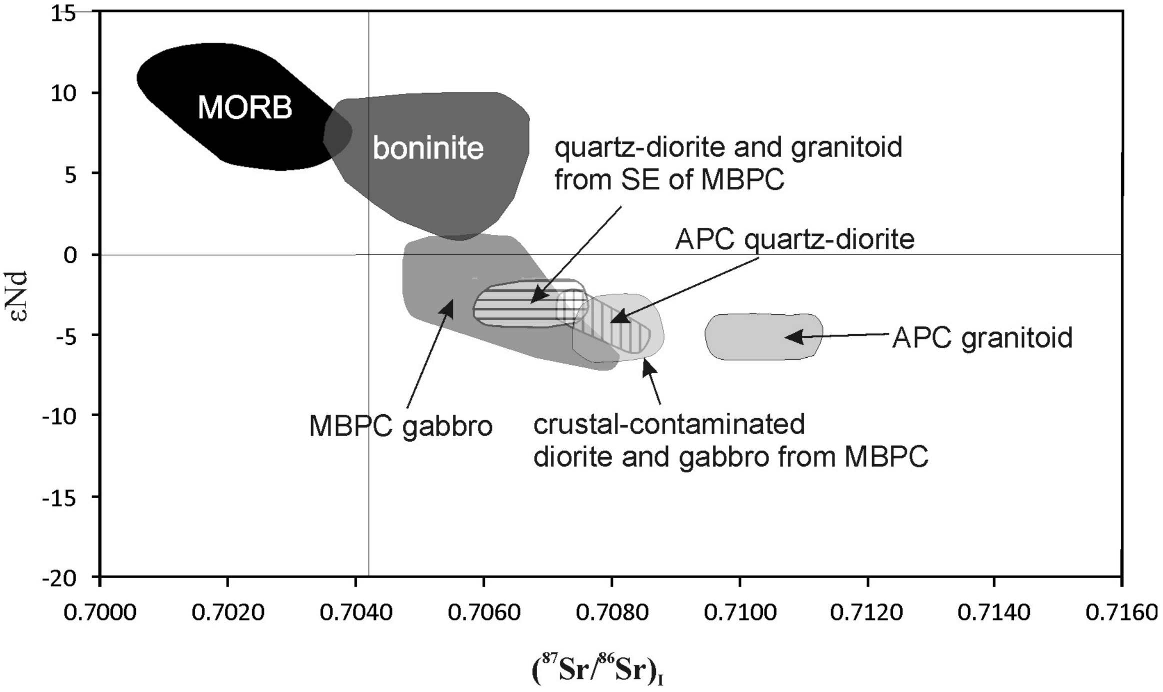

Figure 2. εNd vs (^{87}Sr/^{86}Sr)$_i$ binary diagram showing the isotopic composition of 1- MBPC gabbro that according to Deevsalare et al. (2017, 2018a, 2018b) display isotopic signature of their mantle source; 2- quartz-diorite and granitoid from south east (SE) of MBPC (Ahmadi Khalaji et al., 2007); 3- APC quartz-diorite (Esna-Ashari et al., 2012); 4- crustal-contaminated diorite and gabbro from MBPC (Deevsalar et al., 2018a); 5- APC granitoid (Esna-Ashari et al., 2012). Field of boninites is from Cameron et al. (1983).

more widespread Middle-Jurassic gabbros.

We hope that our reply has clarified that most of the doubts about our model had roots in use of different partition coefficients in melt-crystal compositional modelling, misinterpretation of timing of the magmatic history recorded in the plutonic complexes of the region, and ignoring the chemical similarities between MBPC and APC, which according to several evidence are co-genetic.

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