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Tracing Ancient Mantle Sources: Origin of Gabbros and Peridotites from the ATC Ophiolite in Central Asia – Petrological, Trace Element and Isotopic Constraints

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Massive gabbros, occurring in the upper part of the lower oceanic crust, are generally regarded as frozen melts with very similar compositions to overlying sheeted dikes and pillow lavas. In contrast, modally layered gabbros are regarded as cumulates that crystallized from a melt in a magma chamber or subsiding melt lens (Boudier et al., 1996), or as former sill-like melt lenses either in the lower oceanic crust or within the crust-mantle transition zone (Korenaga & Kelemen, 1997). Due to their position close to the Moho or even below, petrological and geochemical as well as isotopic variations within layered gabbros should reflect primary heterogeneities inherited from their mantle source. However, these heterogeneities may be superimposed by post-melting processes, e.g. melt migration, mixing, and fractionation. To resolve petrological and geochemical variations and associate them either to primary source heterogeneities or to subsequent modifications, we analyzed a suite of peridotites and massive as well as layered gabbros from the 570 Ma old Agardagh-Tes Chem (ATC) ophiolite in Central Asia (50.3°N, 94.5°E).

The peridotites consist of serpentinized residual harzburgites and dunites as well as ultramafic cumulates (wehrlites and pyroxenites). Calculated melts in equilibrium with Cpx from ultramafic cumulates and gabbros have Mg# between 0.27 and 0.75. Cr and Ti concentrations in the most primitive equilibrium melts (Mg# = 0.75) are higher for Cr and lower for Ti than in primitive ocean floor basalts. This suggests a refractory source for the parental melts and requires substantial fractionation to explain the huge range in Mg# and Cr and Ti concentrations.

The gabbros are characterized by low abundances of incompatible trace elements (REE abundances for all but two samples 0.5-5 times chondritic) and show significant negative Nb anomalies with an average primitive mantle normalized $(Nb/La)_n$ of 0.14, which is much lower than in MORB-type ophiolites (0.97 in Oman gabbros, MacLeod & Yaouancq, 2000; 0.54 in Gabal Gerf gabbros, Zimmer et al., 1995). This Nb anomaly is due to the influence of a subduction zone during melt generation. Positive Pb anomalies with $(Ce/Pb)_n$ ratios between 0.05 and 0.21 require a crustal component within the magma source as oceanic basalts and MORB-type gabbros have usually $(Ce/Pb)_n>1$. All gabbros are depleted in Th relative to Ba ($(Th/Ba)_n$ between 0.014 and 0.39) and $(Th/Ba)_n$ is positively correlated with $(Th/La)_n$ (between 0.10 and 2.8 with an average value <1). $(Th/Ba)_n$ ratios are comparable to other, MORB-type ophiolite gabbros, but tend to be slightly lower than in recent ocean floor gabbroic rocks (J. Snow, personal communication). Several gabbros have U-shaped LREE patterns characterized by $(La/Nd)_n$ ratios between 1.4 and 5.4, compared to LREE depleted gabbros with $(La/Nd)_n$ = 0.5-1.0. We attribute this enrichment in La, Ce and Pr relative to Nd to high abundances of modal plagioclase rather than to variable amounts of trapped melt.

Gabbro whole rock chips and feldspar separates were analyzed for Pb isotopic composition using a highly precise triple spike technique (Galer 1999). Isotopic compositions are variable with $^{206}Pb/^{204}Pb$ = 17.854 - 18.452, $^{207}Pb/^{204}Pb$ = 15.530 - 15.665, $^{208}Pb/^{204}Pb$ = 37.590 - 38.246 (Fig. 1). These data indicate the evolution of at least two distinct reservoirs before 570 Ma, with different Th/U and $^{238}U/^{204}Pb$ ratios (μ_2 <9.47 and >10.1, respectively, assuming the two-stage evolution after Stacey and Kramers, 1975). Melt generation occurred about 570 Ma ago from the low $^{238}U/^{204}Pb$ reservoir (depleted mantle) and subsequent addition of a more radiogenic component (e.g. eroded and subducted upper crustal material) produced a heterogeneous mixture from which the ultramafic cumulates and gabbros crystallized. Because of the isotopic and trace element heterogeneities mixing was not a very efficient process. This is supported by Sm-Nd data forming a linear but scattered array in terms of $^{147}Sm/^{144}Nd$ vs. $^{143}Nd/^{144}Nd$ and yield initial $\varepsilon_{Nd}(570)$ between 4.8 and 7.1.

To summarize, we conclude that the trace-element patterns comprise primary signatures inherited from their magma source as well as later stage fractionation related patterns. Mixing is not evident from trace-element data, but is required by isotopic heterogeneities. Finally, layered and massive gabbros analyzed during this study are very similar within their geochemical signatures, suggesting a closely related evolution from a single melt lens.

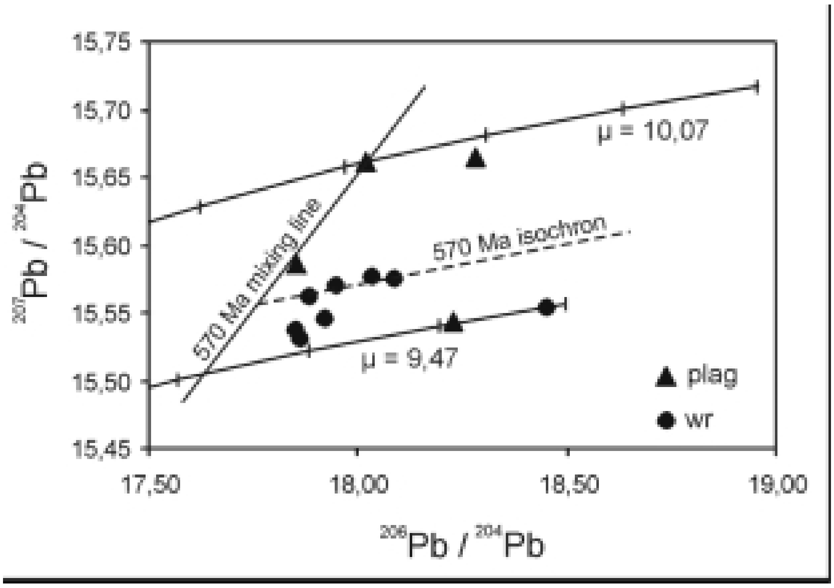

Fig.1. ^{206}Pb/^{204}Pb vs. ^{207}Pb/^{204}Pb for wr gabbros (points) and plagioclase separates (triangles). Also shown are two Pb-Pb evolution lines calculated after Stacey and Kramers (1975) to fit the highest and lowest plagioclase isotopic ratios. The corresponding μ_2 values are 9.47 as upper limit for the depleted source and 10.07 as lower limit for the more enriched, crustal contaminant. Tick distance: 200 Ma. Dashed line: 570 Ma secondary isochrone.

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