Melt generation beneath ocean ridges: Re-Os isotopic evidence from the Polar Ural ophiolite

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We present Re and Os isotope data for a set of well characterized rocks from the crustal and mantle sections of the Voykar Massif, Polar Urals Ophiolite Complex and investigate the nature and possible role of mantle heterogeneities in melt generation and formation of the oceanic lithosphere under spreading centers. The origin of the mid-ocean ridge basalt (MORB), especially the mechanisms of melt formation and extraction, are issues that are still poorly understood. In particular, recent indications that osmium isotopes may be systematically more radiogenic in MORB than in oceanic peridotites (Snow and Reisberg, 1995; Schiano *et al.* 1997) have rejuvenated an old debate about chemical and isotopic equilibrium between melt and residue and about the role of local heterogeneities in controlling the composition of the melt. Moreover, neodymium isotope studies of crustal and mantle lithologies exposed in ophiolite complexes have indicated that the igneous rocks of the oceanic crust are not always in equilibrium with the bulk of the underlying peridotites. Finally, there is circumstantial evidence from Lu-Hf systematics and from Th-U partitioning data that MORB melting may occur in the presence of garnet. All of this has revived speculation that MORB melts may be produced from mixed sources consisting of a peridotite component and a garnet pyroxenite component, derived from subducted oceanic crust (Allègre and Turcotte, 1986; Hirschmann and Stolper, 1996). If MORB really are pooled melts derived from separate and compositionally different source components, then the various crust-mantle lithologies exposed in ophiolites may provide more detailed information on probable source materials and their interaction.

Samples

We determined Re and Os concentrations and Os isotopic compositions of six well characterized rocks from the mantle (two harzburgites V-2 and V-32, a chromite from V-2 and a dunite V-32) and crustal (two gabbros V-1 and V-15 and a diabase V-17) sections of the Polar Urals Ophiolite Complex (see Table 1). On a Sm-Nd isochron plot all the rocks, with the exception of V-32, define an isochron with an age of 387 ± 34 Ma with $\varepsilon_{Nd}(I) = 8.6 \pm 1.8$ (Sharma *et al.*, 1995). This age is identical to that obtained from the southern Urals and indicates that all the rocks (except V-32) were produced from the melting of depleted mantle (similar to the MORB mantle) and are genetically related to each other. Determinations of *LREE* contents in the ultra depleted samples have shown that the samples have much higher La/Sm ratios than that expected from any realistic partial melting scenario. Yet the Nd isotopic composition of these rocks dictates that they have not been contaminated by old continental material. These observations have suggested that the ultra depleted samples have been re-fertilized by transient *LREE*-enriched basaltic melts (Sharma and Wasserburg, 1996).

Results

The Re-Os isotopic and concentration data are given in Table 1. We note that the Re contents of the rocks from the crustal (Sheeted Dikes and Layered Complex) and mantle sections appear not to vary in a regular fashion. In contrast, the samples from the crustal section contain one to two orders of magnitude less Os than those from the mantle section. Consequently, the $^{187}Re/^{188}Os$ ratios of the crustal rocks are one to four orders of magnitude higher than those of mantle samples. Samples V-1 and V-17 display highly radiogenic $^{187}Os/^{188}Os$ ratios, the highest measured in terrestrial silicate samples. When corrected for the ingrowth of ^{187}Os in the last 387 Ma, these two samples still show extreme initial $^{187}Os/^{188}Os = 6.5$ and 7.1. Sample V-15, although not as radiogenic as V-1 and V-17, still has

TABLE 1. Re-Os data from the Voykar Massif, Polar Urals ophiolite complex

	Weight (g)	Re (pg/g)	Os (pg/g)	$\left(\frac{^{187}Re}{^{188}Os}\right)_C^*$	$\left(\frac{^{187}Os}{^{188}Os}\right)_M^*$	$\left(\frac{^{187}Os}{^{188}Os}\right)_C^*$	$\left(\frac{^{187}Os}{^{188}Os}\right)_I^*$
Sheeted dyke complex							
V-17 diabase	2.74	775	6.437	1872	17.2	18.4	6.5
V-15 gabbro	3.38	349	49.5	36	0.527	0.527	0.298
Layered complex							
V-1 gabbro	3.18	176	2.498	818	11.0	12.3	7.1
Mantle sequence							
V-26 dunite	2.18	1269	4117	1.489	0.146	0.146	0.136
V-2 harzburgite	1.78	20.26	3788	0.026	0.123	0.123	0.122
V-2 chromite	0.10	–	35773	–	0.121	0.121	
V-3 harzburgite	0.49	–	4320	–	0.125	0.125	
V-32 harzburgite	2.99	222	3944	0.271	0.123	0.123	0.121

Except for V-2 Chromite and V-3, the samples were measured at the MPI, Mainz. Typical uncertainty on the measured ratios is less than 1%. The samples are corrected for the following blanks measured at the same time as the samples: [Re] = 10 picogram, [Os] = 417 femtogram with ($^{187}Os/^{188}Os$) = 0.71. V-2 chromite and V-3 were analysed at Caltech.

* Subscripts; M = measured ratio; C = Blank corrected ratio; I = Initial ratio at 387 Ma.

initial $^{187}Os/^{188}Os$ a factor of 2 higher than the mantle rocks, which have $^{187}Os/^{188}Os$ ratios similar to those estimated for the depleted MORB mantle around 400 Ma ago.

Discussion

In contrast to the Sm-Nd results (Sharma *et al.*, 1995), the Re-Os data from the Voykar Massif indicate that there is no simple genetic relationship between the samples from the crustal sequence and the underlying mantle rocks. We suggest two alternative scenarios: (1) The melts were predominantly derived from a mantle reservoir with high long-term Re/Os and $^{187}Os/^{188}Os$ ratios, most likely a pyroxenite. The Sm/Nd and $^{143}Nd/^{144}Nd$ ratios of this pyroxenite were similar to those of the surrounding peridotite, perhaps because the pyroxenite was originally derived from the peridotite by a relatively large degree of melting. Interaction of this melt with the osmium residing in the peridotite is then required to have been minimal, so as to preserve the very high $^{187}Os/^{188}Os$ derived from the pyroxenite. One possible scenario for this is that osmium in the peridotite was sequestered in a phase which did not equilibrate with the melt (Hofmann *et al.*, in review). On the other hand, there is no restriction on the interaction of Sm and Nd between the melt and the two source components. (2) Melting of a mantle lherzolite around 600 Ma ago produced a basaltic diapir which was frozen close to the lithosphere. This diapir remelted about 210 Ma later (required to grow $^{187}Os/^{188}Os$ = 7 from a basalt with $^{187}Re/^{188}Os$ of 2000, and $^{187}Os/^{188}Os$ = 0.1) giving rise to the magmatic precursors of V-1 and V-17. In either case, the results require maintenance of high Re/Os and low Os reservoirs in the mantle for long periods of time, and highly preferential melt extraction from these reservoirs during magma generation. Another profound implication of these results is that the nature of melt focusing may lead to a variable expression of mantle components with extreme $^{187}Os/^{188}Os$ ratios. This fact may be utilized to map the ocean floor for short and long wavelength isotopic variations.

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