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RESEARCH NOTE

OXYGEN ISOTOPE SYSTEMATICS OF SIBERIAN BASALTS

It has recently been suggested (Campbell and Griffiths, 1990; White and McKenzie, 1989) that flood basalt volcanism is produced by melting of the head of starting plumes that originate at the core-mantle boundary and grow by entrainment as they rise to the bottom of the lithospere. This plume model offers a simple explanation for the stupendous volume, vast lateral extent and short duration of flood basalt eruptions.

In the light of a plume model for the Siberian Flood Basalt Province (SFBP), Sharma *et al.,* (1991, 1992) have assessed Sr, Nd and Pb isotopic data on stratigraphically controlled sequences of the Siberian lavas. They have proposed that the Siberian magmas were derived mainly from two mantle reservoirs - the 'near-chondritic' mantle plume and the subcontinental lithospheric mantle (SCLM) with minor modifications in a few cases by the Archaean to Proterozoic lower continental crust through which they ascended.

Since the oxygen isotopic compositions of mantle and crustal reservoirs are distinct, oxygen isotope data in conjunction with Sr, Nd and Pb isotopic compositions of stratigraphically controlled lava sequence can lead to a better characterization of different magma sources and magma modification in the continental crust (Taylor, 1980; James, 1981). We report here oxygen isotopic data for 19 Siberian basalt samples along with 3 mineral separates from a picrite basalt and discuss them in conjunction with Sr, Nd and Pb isotope data on analogous samples reported by Sharma *et al.,* (1991, 1992).

The SFBP presently occupying an area of 337,000 km^2 with an average thickness of 1 km (Lurie and Masaitis, 1964) has been divided (Zolotukhin and Al'mukhamedov, 1988) into three subprovinces - Putorana, Norilsk and Maimecha-Kotui (Fig.1a). The Putorana and Maimecha-Kotui rocks are relatively homogeneous tholeiites, with the former representing an overwhelming 90% of the bulk SFBP. Though small volumetrically (only about 7%), the Norilsk rocks show a wide variation from picritic through tholeiitic to subalkaline basalts and basaltic andesites. The Putorana lavas are divided into three rock suites, while the Norilsk rocks into 11 suites. The correlation between the two sequences is given by Zolotukhin and Al'mukhamedov (1988) and Sharma *et al.,* (1991), according to which the lower suites of Norilsk rocks represent the early lava eruptions. $^{40}Ar/^{39}Ar$ dating indicates that nearly the entire sequence of lavas had erupted within about 1 Ma at the Permo-Triassic boundary (248 Ma B.P., Renne and Basu, 1991).

The 19 samples (9 from Putorana on Ayan river section and 10 from Norilsk, see Fig. 1a for sample locations) analysed were fresh with only a few showing a minor amount (<1%) of chlorite. Oxygen was extracted from the whole-rock samples using the conventional BrF_5 fluorination technique (Clayton and Mayeda, 1963) followed by conversion to CO_2 for mass spectrometric analysis. All samples were analysed in duplicate interspersed with NBS 28 quartz standard which gave $\delta^{18}O = 9.8\pm0.2‰$ relative to SMOW, the reported value being 9.64 ‰. The $\delta^{18}O$ results are given in Table. I and plotted against their relative stratigraphic positions in Fig. 1b.

The two vertical dashed lines in Fig. 1b mark the extreme limits (5.2 to 6.2%) for unaltered mid-ocean ridge basalts, MORB (Kyser *et al.,* 1982). It can be seen that all the

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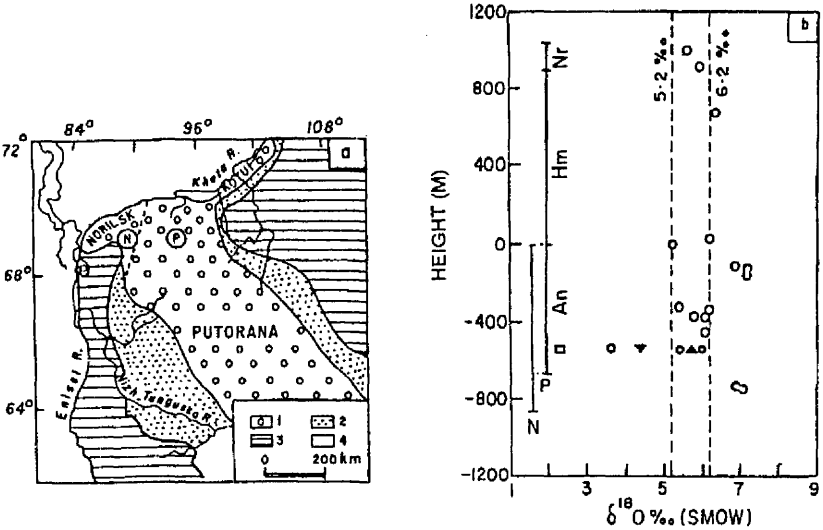

Fig.1. (a) Schematic map of the Siberian Flood Basalt Province (modified after Zolotukhin and Al'muckhamedov, 1988). 1. basalts, 2. intrusive traps and tuffs, 3. platform sedimentary sequence, 4. Tertiary-Quaternary sediments. The sample locations are shown by N (Norilsk) and P (Putorana).
(b) Variations in $\delta^{18}O$ against relative stratigraphic positions along the Mt. Sundook (Section on Gluboke lake) and Putorana (section on Ayan river) basalt sequences. The base of the Honnamakitsky suite (Hm) is taken as the reference datum for the samples collected from Putorana region. The Norilsk samples are assigned arbitrary heights with the top of Morongovsky flow coinciding with the reference datum. The two Gudchikhinsky picrites of core SG-9 (sample Nos. 4 and 5) are also plotted at the same height as that of sample No.3. Putorana- open circles; Norilsk- filled circles; opaques- square; pyroxene- triangle; plagioclase- inverted triangle.

Putorana samples fall well within or only marginally away from the MORB limits. So, if the bulk of the volume of the Siberian basalts, as represented by the Putorana lavas, is plume-derived as inferred by Sharma *et al.* (1991, 1992), then the oxygen isotopic composition of the plume rising from the lower mantle is indistinguishable from that of the MORB sources in the upper mantle. In contrast to the Putorana samples, the Norilsk rocks show wide variations beyond the MORB limits in their oxygen isotopic compositions, as indeed they do in Sr and Nd isotopes also. Sharma *et al.*, (1991, 1992) have cited these latter variations as evidence of variable interaction of the early magmas with the lower continental crust. Since lower continental crust has generally higher $\delta^{18}O$, the slight enrichment of the 5 Norilsk samples is consistent with the inference of Sharma *et al.*, (1991, 1992).

Of the three picritic basalt samples from the Gudchikhinsky suite in the Norilsk sequence, two fall within the MORB limits, whereas one from the Gluboke lake section represented by sample No.3 in Table I (about 100 km east of the other two) is conspicuously depleted with a $\delta^{18}O$ of 3.6‰. In order to explain the depleted nature of sample 3, mineral separates from this sample were analysed for oxygen isotopes. We find that while the $\delta^{18}O$ value of pyroxene separates is 5.7‰. and falls within the MORB limits, plagioclases and opaques are depleted in $\delta^{18}O$ with values of 4.4 and 2.3‰ respectively. Anderson *et al.*, (1971) showed that the plagioclase-pyroxene $\delta^{18}O$ fractionation (Δ^{plag}_{pyx}) typically found in basalts is about 0.6‰. If plagioclase is depleted in $\delta^{18}O$ relative to coexisting pyroxene then

Table I. Oxygen isotopic composition of Siberian basalts.

Sample No.	Suite	Type	Whole-rock/Mineral $\delta^{18}O‰$ (SMOW)*
Norilsk basalts (Mt. Sundook on Gluboke lake section)			
1.	Ivakinsky	Subalkaline basalt	7.1
2.	Ivakinsky	Subalkaline basalt	6.9
3.	Gudchikhinsky	picrite	3.6
3a.	Gudchikhinsky	pyroxene	5.7
3b.	Gudchikhinsky	plagioclase	4.4
3c.	Gudchikhinsky	opaques (mag + ilm)	2.3
4+.	Gudchikhinsky	picrite	5.9
5+.	Gudchikhinsky	picrite	5.5
6.	Tuklonsky	picrite	5.4
7.	Nadezhdinsky	tholeiite	7.2
8.	Nadezhdinsky	tholeiite	7.2
9.	Nadezhdinsky	tholeiite	7.2
10.	Morongovsky	tholeiite	5.2
Putorana plateau basalts (section on Ayan river)			
11.	Ayansky	tholeiite	6.1
12.	Ayansky	Subalkaline picrite	5.8
13.	Ayansky	Subalkaline picrite	6.1
14.	Ayansky	tholeiite	5.7
15.	Ayansky	tholeiite	6.9
16.	Honnamakitsky	tholeiite	6.2
17.	Honnamakitsky	tholeiite	6.4
18.	Nerakarsky	tholeiite	5.9
19.	Nerakarsky	tholeiite	5.6

* error : within ± 0.2‰

\+ from Core SG-9 (about 100 km west of Mt. Sundook)

Δ^{plag}_{pyx} becomes negative and cannot represent isotopic equilibrium at any plausible temperature. It has been shown for Skaergaard instrusion by Taylor and Forester (1979) that negative Δ^{plag}_{pyx} can result in basaltic rocks if circulation of high temperature hydrothermal fluid takes place. Such an interaction would bring down the $\delta^{18}O$) value of plagioclase rapidly compared to that of pyroxene, as the rate of isotopic exchange of plagioclase is much faster than that of pyroxene for similar grain sizes. Combining all these evidences it seems possible that localized hydrothermal fluid circulation at high temperature is responsible for the unusually low $\delta^{18}O$ whole-rock value for the Gudchikhinsky picrite at Mt. Sundook.

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