Conference Paper

Pb, Sr and Nd Isotope Ratios of Permian-Triassic Flood Basalts in the Basement of the West Siberian Plate

S V Berzin, K S Ivanov, M V Streletskaia, M V Zaytseva, and N G Soloshenko

A.N. Zavaritsky Institute of Geology and Geochemistry, Ural Branch RAS, 15 Academic Vonsovsky st., Ekaterinburg 620016, Russia

Abstract

Permian-Triassic flood basalts are widespread across an extremely large area of the Siberian plate in the pre-Jurassic basement of the West Siberian plate. We show that Permian-Triassic flood basalts are similar to the trap basalts of the Siberian Platform with regard to geochemical features and Pb, Sr and Nd isotopic composition. Strontium and neodymium isotope ratios indicate the contribution to the formation of the flood basalts of the EM1 reservoir. We will also show a possible contamination of basalt magma by the Palaeozoic island-arc and orogenic rock complexes.

1. Introduction

Permian-Triassic flood basalts are widespread across an extremely large area of the Siberian plate, particularly in the pre-Jurassic basement of the West Siberian plate in the Middle Urals, in the Timan-Pechora region and in Kuzbass [1-2, 9-10, etc.]. In the pre-Jurassic basement of the West Siberian plate, the flood basalts form rifts and grabens and are present on the surface of the basement [3-5, 11].

However, the Permian-Triassic basalts in the basement of the West Siberian Plate have been studied to a significantly lesser degree than have the trap basalts of the Siberian platform. This is mainly due to the absence of outcrops. Data on the isotopy of lead, strontium and neodymium for the Permian-Triassic basalts in the basement of the West Siberian Plate are almost completely absent. The tasks in this research are to study the geochemical features and the isotope ratios of lead, strontium and neodymium in samples of Permian-Triassic flood basalts from various regions in the West Siberian plate.
2. Samples and analytical methodology

In this work, we will study samples of Permian-Triassic flood basalts from deep and superdeep boreholes: Yen-Yakhinskaya SG-7, with depths of 6428, 8009 and City 8250 m, Tyumenskaya SG-6, with a depth of City 6975 m, Urengoiskaya 414-1, with a depth of City 5470.54 m (the northern part of West Siberia); Zapadno-Chistinaya 501, with a depth of City 3500 m (Yugansk-Koltogorsk zone), Ust-Iuskaya 8000, with a depth of City 1794 m, Severo-Shushminskaya 10208, with a depth of City 2037 m (the western part of West Siberia), and 27 Lekosskaya, with depths of 2575.5 and 2577, City 5 m (the eastern part of West Siberia).

The basalt samples studied are presented as relatively non-altered basalts, which consist of clinopyroxene, plagioclase and altered basalts. In non-altered basalts, the clinopyroxene is diopside – an augite with f 0.26-0.31 % and Wo 44-46%. The plagioclase grains have a zonal structure: The core is labradorite (An 62-69) and the margin is andesine (An 35-40). There are rare sanidin grains in basalts with Kfs 0.30-0.47 %, Ab 0.46-0.61 % and An 0.06-0.10 %. An altered basalt consists of albite, prehnite, chlorite, epidote and pumpellyite, and has a relict igneous structure.

All analyses were performed at the Zavaritsky Institute of Geology and Geochemistry UB RAS. The measurement of the chemical composition was conducted by Nadezhda P. Gorbunova using the X-ray fluorescence analyser XRF-1800. The measurement of the elemental composition of rock samples was performed the ICP-MS ELAN-9000 by Dr Daria V. Kiseleva.

Sample preparation was carried out in the class 1000 clean-room facility at the Zavaritsky Institute of Geology and Geochemistry UB RAS. The samples were dissolved in clean Savillex vessels, using a mixture of concentrated HF and HNO₃ at ∼120 °C on hotplates over three days, followed by treatment with concentrated HCl at ∼120 °C for one day. Prior to the dissolution, each sample was spiked with a mixed ¹⁴⁷Sm–¹⁵⁰Nd or ⁸⁴Sr–⁸⁵Rb spike according to the type of analysis. No spike was used for the Pb isotopic analysis. After the dissolution, the samples were passed through the chromatographic column in order to isolate Nd, Sm, Rb, Sr and Pb. A two-stage column procedure was used for the initial REE isolation on a TRU-spec column and for the final Sm and Nd separation on a LN-spec column [8]. Sr and Rb were isolated using the anion-exchange resin Dowex 50X8 with extra purification of Sr using an Sr-spec resin. Pb isolation was performed using the conventional HBr-HCl technique [6]. The procedural blanks for Sr and Rb were 0.3 ng and 0.05 ng, respectively. The blank correction for Nd, Sm and Pb
was not applied due to their low values, which did not exceed 0.01% of the sample concentrations.

All measurements of Nd, Sm and Pb isotope ratios were performed by Neptune Plus (Thermo Finnigan), while Rb and Sr were determined via Triton Plus (Thermo Finnigan) at the Zavaritsky Institute of Geology and Geochemistry UB RAS. Nd and Sm isotope ratios were measured in 3% HNO₃ in static mode, with all data processing being taken off-line. Neodymium samples were run routinely at a 142Nd beam size of ∼2 V for 90 cycles. The Analysis of samarium was carried out in 60 cycles. Strontium was loaded in 1 µL 3% HNO₃ with a Ta₂O₅ activator on an Re filament, and was collected in static mode for 90 cycles. Rubidium was analysed in double filament mode from 1 µL 3% HNO₃ load. Data were collected in static mode for 15 cycles. The measurement of lead was performed using the Tl-normalisation technique[^14]. Each sample was dissolved in 3%HNO₃ and doped with thallium prior to the analysis in order to obtain a thallium concentration of 25 ppb. Data processing was carried out on-line, including a 204Pb interference correction using the ratio 202Hg/204Hg = 4.350370, and was normalised via the exponential law.

### Table 1: Chemical composition (wt%) of Permian-Triassic flood basalts of the basement of the West Siberian plate.

| Borehole     | Depth, m | SiO₂  | TiO₂  | Al₂O₃ | Fe₂O₃ | FeO  | MnO  | MgO  | Na₂O | K₂O  | P₂O₅ | L.o.i | Total |
|--------------|----------|-------|-------|-------|-------|------|------|------|------|------|------|------|-------|
| ZCh 501      | 3500     | 44.26 | 1.07  | 18.72 | 5.69  | 4.1  | 0.146| 6.56 | 5.00 | 2.40 | 0.11 | 0.15 | 12.0  | 100.19|
| Yen-Yakhinskaya SG-7 | 8009     | 50.95 | 0.88  | 14.78 | 5.94  | 4.6  | 0.178| 8.92 | 5.35 | 2.86 | 1.17 | 0.15 | 4.0   | 99.60 |
|              | 8250     | 51.01 | 1.30  | 14.70 | 8.54  | 4.2  | 0.174| 6.50 | 6.03 | 2.66 | 0.26 | 0.22 | 4.5   | 99.92 |
|              | 7673     | 44.67 | 0.98  | 14.19 | 6.13  | 5.2  | 0.183| 5.98 | 12.12| 2.44 | 0.19 | 0.25 | 7.6   | 99.75 |

Note: borehole ZCh 501 - Zapadno-Chistinaya 501.

The Merck Nd standard, traceable to SRM NIST Nd₂O₃, was used to access the long-term instrumentation reproducibility yielded in 143Nd/144Nd = 0.511720 ± 15 (1 SD, n = 40). For strontium measurements, NIST SRM 987 was used as a standard, with 87Sr/86Sr = 0.710256 ± 11 (1 SD, n=59). The accuracy and long-term reproducibility of the lead isotope ratio determination was estimated using NIST SRM 981, and yielded 204Pb/206Pb = 0.059061 ± 2, 208Pb/206Pb = 2.16799 ± 5, 207Pb/206Pb = 0.914524 ± 9 (1 SD, n=58). Moreover, the analyses of the geological samples andesite USGS AGV-2 and basalt USGS BHVO-2 were performed on a regular basis and retrieved 143Nd/144Nd = 0.517267 ± 11 (1 SD, n = 15), 87Sr/86Sr = 0.703974 ± 47 (1 SD, n = 35) and 143Nd/144Nd = 0.512985 ± 15 (1 SD, n = 20), 87Sr/86Sr = 0.703475 ± 31 (1 SD, n = 35), respectively. In order to control
the sample preparation procedure, a Pb isotopic analysis of AGV-2 was performed and yielded $^{206}\text{Pb}/^{204}\text{Pb} = 18.863 \pm 9$, $^{208}\text{Pb}/^{204}\text{Pb} = 38.327 \pm 19$, $^{207}\text{Pb}/^{204}\text{Pb} = 15.615 \pm 6$ (1 SD, n=13).

Table 2: Element composition (ppm) of Permian-Triassic flood basalts of the basement of the West Siberian plate.

| Borehole | U 8000 | S 10208 | CityUr 414 | 27 Lekosskaya | SG-6 | Yen-Yakhinskaya SG-7 | ZCh 501 |
|----------|--------|---------|------------|---------------|-----|----------------------|--------|
| Depth, m | 1974   | 2037    | 5470       | 2577.5        | 2575.5 | 6975                 | 6428   |
| Li       | 4372   | 8470    | 12971      | 4378          | 4507  | 10662                | 8825   |
| Be       | 1106   | 1228    | 1549       | 0593          | 0732  | 0878                 | 1108   |
| Sc       | 19621  | 19211   | 4053       | 18412         | 17795 | 31781                | 16491  |
| Ti       | 9345   | 8734    | 5313       | 5564          | 5509  | 15383                | 12647  |
| V        | 22123  | 23567   | 57822      | 16382         | 16463 | 19325                | 16114  |
| Cr       | 54275  | 1510    | 9043       | 22008         | 20937 | 19935                | 11570  |
| Mn       | 8903   | 1319    | 49277      | 75260         | 91484 | 20806                | 12861  |
| Co       | 2901   | 33537   | 10204      | 30098         | 75495 | 53851                | 26439  |
| Ni       | 5849   | 33746   | 8500       | 12291         | 16301 | 57133                | 78231  |
| Cu       | 6066   | 47908   | 18858      | 62180         | 61427 | 83395                | 45742  |
| Zn       | 9739   | 10613   | 64433      | 42888         | 10156 | 13951                | 58645  |
| Rb       | 23219  | 19320   | 46488      | 11634         | 11329 | 0575                 | 49019  |
| Sr       | 45864  | 56930   | 97455      | 13890         | 13771 | 66813                | 65527  |
| Y        | 23745  | 21399   | 11702      | 13287         | 14422 | 24406                | 15889  |
| Zr       | 15498  | 16948   | 15066      | 10443         | 103777| 96950                | 18215  |
| Nb       | 15349  | 13008   | 21152      | 8148          | 7932  | 13748                | 53006  |
| Cd       | 0265   | 0302    | 0218       | 0167          | 0184  | 0198                 | 0250   |
| Sn       | 1444   | 1252    | 1717       | 0604          | 0580  | 1002                 | 1545   |
| Sb       | 0056   | 0100    | 0495       | 0046          | 0044  | 0063                 | 0642   |
| Te       | 0005   | -       | -          | -             | -     | -                    | 001    |
| Cs       | 0553   | 1037    | 0715       | 0107          | 0102  | 0090                 | 2393   |
| Ba       | 5121   | 2808    | 3974.7     | 83611         | 81407 | 12523                | 35776  |
| La       | 30346  | 33496   | 31778      | 34321         | 33862 | 11954                | 25485  |
| Ce       | 69406  | 77319   | 60569      | 77599         | 76856 | 28703                | 52645  |
| Pr       | 8488   | 9622    | 7119       | 9502          | 9486  | 3876                 | 6086   |
| Nd       | 34445  | 38722   | 25360      | 36916         | 37836 | 17477                | 23503  |

DOI 10.18502/keg.v3i4.2224
3. Another section of your paper

The samples of Permian-Triassic basalt studied were tholeiitic basalt and picrite-basalt (SiO$_2$ 44-51 wt.%) (Table 1). They varied from a low-potassium to a medium-potassium series, with TiO$_2$ 0.9-1.3 wt.% Fe/(Fe+Mg) ratio is 0.38-0.51. Flood basalts were characterised by a negative REE trend (La$_n$/Yb$_n$ ratio is 2, 2-16, 2); the total REE was 73-190 ppm (see Table 2). All samples had a slightly negative Eu-anomaly (Eu$_n$/Eu$_n^*$ 0.68-0.98). The samples were depleted in Rb, Th and Y, and were enriched in U and Ba. Some basalt samples were slightly depleted in Nb and Ta. The Permian-Triassic basalt was characterised by a significant variation in the content of Sr (60-1389 ppm).

The initial isotope ratios by age 250 Ma in the Permian-Triassic flood basalts are $^{206}$Pb/$^{204}$Pb, 17,331-19,536, $^{207}$Pb/$^{204}$Pb, 15,492-15,607, $^{208}$Pb/$^{204}$Pb, 37,541-38,097.
\[ {^{87}\text{Sr}}/{^{86}\text{Sr}}, \; 0.704210-0.705211 \quad ^{143}\text{Nd}/^{144}\text{Nd}, \; 0.512403-0.512542, \; \varepsilon_{\text{Nd}} \text{ is up -1.9 to -4.6} \] (Table 3).

**Table 3:** Pb, Sr, Nd isotope ratios of Permian-Triassic flood basalts of the basement of the West Siberian plate.

| Borehole   | U 8000 | 10208 | 414  | 27 Lekosskaya | SG-6 | Yen-Yakhinskaya SG-7 | ZCh 501 |
|------------|--------|-------|------|---------------|------|-----------------------|---------|
| Depth, m   | 1794   | 2037  | 5470 | 2577.5        | 2575.5| 6975                  | 6428    |
| Measured:  |        |       |      |               |      |                       |         |
| \(^{206}\text{Pb}/^{204}\text{Pb}\) | 18.569 | 18.511| 20.662| 18.616       | 18.644| 18.807                | 18.686  |
| \(\pm\)SE | 0.004  | 0.004 | 0.004 | 0.004        | 0.004| 0.004                 | 0.004   |
| \(^{207}\text{Pb}/^{204}\text{Pb}\) | 15.6106| 15.6036| 15.579| 15.5354      | 15.5307| 15.6020               | 15.5434 |
| \(\pm\)SE | 0.0004 | 0.0007| 0.0008| 0.0004       | 0.0004| 0.0005                | 0.0004  |
| \(^{208}\text{Pb}/^{204}\text{Pb}\) | 38.389 | 38.414| 38.457| 37.778       | 37.755| 38.165                | 38.498  |
| \(\pm\)SE | 0.001  | 0.002 | 0.002 | 0.001        | 0.001| 0.001                 | 0.001   |
| \(^{87}\text{Sr}/^{86}\text{Sr}\) | 0.1371 | 0.0885| 0.1360| 0.0222       | 0.0224| 0.0284                | 0.0007  |
| \(\pm\)SE | 0.0017 | 0.0011| 0.0017| 0.0003       | 0.0003| 0.0004                | 0.0004  |
| \(^{87}\text{Sr}/^{86}\text{Sr}\) | 0.705245| 0.705316| 0.70531| 0.704221   | 0.704289| 0.705312 | 0.705312 |
| \(\pm\)SE | 0.000021| 0.000020| 0.000020| 0.000016 | 0.000039| 0.000019 | 0.000019 |
| \(^{147}\text{Sm}/^{144}\text{Nd}\) | 0.120224| 0.11666| 0.106208| 0.099707 | 0.100371| 0.154595 | 0.00007 |
| \(\pm\)SE | 0.000007| 0.000011| 0.000014| 0.000012 | 0.000009| 0.000086 | 0.000086 |
| \(^{143}\text{Nd}/^{144}\text{Nd}\) | 0.512599| 0.512602| 0.512678| 0.512705 | 0.512706| 0.512705 | 0.000007 |
| \(\pm\)SE | 0.000007| 0.000009| 0.000005| 0.000006 | 0.000006| 0.000049 | 0.000049 |
| Initial:   |        |       |      |              |      |                       |         |
| \(^{206}\text{Pb}/^{204}\text{Pb}\) | 18.061 | 18.044| 19.533| 18.039       | 18.054| 18.028                | 18.785  |
| \(^{207}\text{Pb}/^{204}\text{Pb}\) | 15.5846| 15.5797| 15.6004| 15.5059      | 15.5004| 15.5621               | 15.4973 |
| \(^{208}\text{Pb}/^{204}\text{Pb}\) | 38.023 | 37.990| 38.101| 37.568       | 37.550| 37.868                | 37.689  |
| \(^{87}\text{Sr}/^{86}\text{Sr}\) | 0.704757| 0.705001| 0.704547| 0.704142  | 0.704210| 0.705211 | 0.705211 |
| \(^{143}\text{Nd}/^{144}\text{Nd}\) | 0.512403| 0.512419| 0.512504| 0.512542 | 0.512541| 0.512452 | 0.00007 |
| \(\varepsilon_{\text{Nd}}\) | -4.59  | -4.27 | -2.62 | -1.87       | -1.88 | -3.63                 |         |

Note: boreholes as in the Table 2.

### 4. Discussion and conclusions

In general, the samples of the flood basalts studied are similar to the Permian-Triassic basalts from the basement of the West Siberian plate based on the distribution of REE and some incoherent elements such as [7. 11]. In addition, the basalt samples are
geochemically similar to the Permian-Triassic trap basalts of the Siberian platform by [1]. However, the basalt samples studied have a high content of U (up to 7.9 ppm), Ba (up to 3974 ppm) and of Sr (up to 1389 ppm), and have a reduced Y content (12-37 ppm) when compared to Siberian trap basalts. This was reflected in the high values of the ratio Sr/Y, which were up to 105.

Most of the samples were similar to the mantle and lower crustal reservoirs by [15]. The Pb isotope ratios of most of the basalt samples corresponded to the trap basalts of the Siberian platform at diagrams $^{206}\text{Pb}/^{204}\text{Pb} - ^{207}\text{Pb}/^{204}\text{Pb}$ and $^{206}\text{Pb}/^{204}\text{Pb} - ^{208}\text{Pb}/^{204}\text{Pb}$ according to [13] (Figure 1). This indicates a common source of basaltic volcanism in these provinces. Samples from the Zapadno-Chistinaya 501 and Urengoiskaya 414-r boreholes differ this field of composition towards the increased ratio of U/Pb. This may be due to the influence of contaminated core material. Both these boreholes are located within the central “axial” zone of the Permian-Triassic rift structures in the basement of the West Siberian Plate. However, in other boreholes in this central “axial” zone (Yen-Yakhinskaya SG-7, Tyumenskaya SG-6), such anomalies are not observed.

![Figure 1](image)

**Figure 1:** Diagrams $^{206}\text{Pb}/^{204}\text{Pb} - ^{207}\text{Pb}/^{204}\text{Pb}$ (a) and $^{206}\text{Pb}/^{204}\text{Pb} - ^{208}\text{Pb}/^{204}\text{Pb}$ (b) for Permian-Triassic flood basalts of the West Siberian plate. Gray field – trap basalts of the Siberian platform by [13]. Reservoirs by [15].

In the diagram $^{87}\text{Sr}/^{86}\text{Sr} - \epsilon\text{Nd}$, the points of the Permian-Triassic flood basalts lie along the main mantle trend, mainly in the III quarter (Figure 2). The Permian-Triassic basalts are similar to the field of the trap basalts of the Siberian platform in terms of Sr and Nd isotope ratios. However, the basalts of the West Siberian platform deviate towards the Enriched Mantle 1-st type (EM1). The effect of the EM1 reservoir is shown in the diagram as $^{206}\text{Pb}/^{204}\text{Pb} - ^{207}\text{Pb}/^{204}\text{Pb}$, particularly for basalts from the
Yen-Yakhinskaya SG-7 borehole. This can be explained by the contamination of this basalt magma by the lower continental crust. Similar conclusions have been obtained by other researchers in the study of the traps of the Siberian Platform [12, etc.].

Thus, new data regarding the Pb, Sr and Nd isotope ratios in the Permian-Triassic flood basalts from different regions of the pre-Jurassic basement of the West Siberian Plate are presented in this article. We show that Permian-Triassic flood basalts are similar to the trap basalts of the Siberian platform in terms of geochemical features and Pb, Sr and Nd isotopic composition. Samples from two boreholes incline towards the increased ratio U/Pb. This can be explained by contamination of this basalt magma by the Palaeozoic island-arc and orogenic rock complexes. Strontium and neodymium isotope ratios indicate their contribution to the formation of the flood basalts in the EM1 reservoir.

The authors are grateful to the Chief geologist of SibSAC Dr. Vladimir S. Bochkarev for providing the well samples. The work is executed at financial support of Russian Scientific Foundation (No. 16-17-10201).

**References**

[1] Al’mukhamedov A I, Medvedev A Ya and Zolotukhin V V 2004 *Petrology* 12 297-311
[2] Dobretsov N L, Borisenko A S, Izokh A E and Zhmodik S M 2010 *Russian Geol. and Geophys.* 51 903-924
[3] Ivanov K S, Erokhin Yu V, Ponomarev V S, Pogromskaya O E and Berzin S V 2016 Int. J. of Environmental and Sci. Edu. 11 6409-6432
[4] Ivanov K S, Puchkov V N, Fyodorov Yu N, Erokhin Yu V and Pogromskaya O E 2013 *J. of Asian Earth Sci.* **72** 12-24

[5] Ivanov K, Fyodorov Yu, Pogromskaya O and Erokhin Yu 2011 Proceedings. *The Fifth Workshop on 1:5M Int. Geo. Map of Asia* (Beijing, Elsiver) p 53-62

[6] Kamber B S and Gladu A H 2009 *Geostandards and Geoanalytical Res.* **33** 169-181

[7] Medvedev A Ya, Al’mukhamedov A I and Kirda N P 2003 *Geologiya I Geofisica.* Vol. 44. № 1-2. P. 86-100

[8] Pin C and Zalduegui J E S 1997 *Anal. Chim. Acta* **339** 79-89

[9] Reichow M K, Pringle M S, Al’Mukhamedov A I, Allen M B, Andreichev V L, Buslov M M, Davies C E, Fedoseev G S, Fitton J G, Inger S, Medvedev A Ya, Mitchell C, Puchkov V N, Safonova I Yu, Scott R A and Saunders A D 2009 *Earth and Planet. Sci. Let.* **277** 9-20

[10] Reichow M K, Saunders A D, Whitea R V, Al’Mukhamedov A I and Medvedev A Ya 2005 *Lithos* **79** 425-452

[11] Saraev S V, Baturina T P, Ponomarchuk V A and Travin A V 2009 *Russian Geology and Geophysics* **50** 1-14

[12] Sharma M, Basu A R and Nesterenko G V 1992 *Earth and Planet. Sci. Let.* **113** 365-381

[13] Wooden J L, Czamanske G K, Fedoreno V A, Arndt N T, Chauvel C, Bouse R M, King B W, Knight R J and Siem D F 1993 *Geochim. et cosmochim. acta* **57** 3677-3704

[14] Woodhead J J. 2002 *Anal. At. Spectrom.* **17** 1381-138

[15] Zartman R E and Haines S M 1988 *Geochim. et cosmochim. acta* **52** 1327-1339