МИНИСТЕРСТВО НАУКИ И ВЫСШЕГО ОБРАЗОВАНИЯ РОССИЙСКОЙ ФЕДЕРАЦИИ

НАЦИОНАЛЬНЫЙ ИССЛЕДОВАТЕЛЬСКИЙ

ТОМСКИЙ ГОСУДАРСТВЕННЫЙ УНИВЕРСИТЕТ

Attraction of the leading scientists to Russian institutions of higher learning, research organizations of the governmental academies of sciences, and governmental research centers of the Russian Federation

# LARGE IGNEOUS PROVINCES THROUGH EARTH HISTORY: MANTLE PLUMES, SUPERCONTINENTS, CLIMATE CHANGE, METALLOGENY AND OIL-GAS, PLANETARY ANALOGUES (LIP – 2019)

Abstract volume of the 7 International Conference
Tomsk, Russia, 28 August – 8 September 2019

# КРУПНЫЕ ИЗВЕРЖЕННЫЕ ПРОВИНЦИИ В ИСТОРИИ ЗЕМЛИ: МАНТИЙНЫЕ ПЛЮМЫ, СУПЕРКОНТИНЕНТЫ, КЛИМАТИЧЕСКИЕ ИЗМЕНЕНИЯ, МЕТАЛЛОГЕНИЯ, ФОРМИРОВАНИЕ НЕФТИ И ГАЗА, ПЛАНЕТЫ ЗЕМНОЙ ГРУППЫ (КИП – 2019)

Тезисы VII Международной конференции
Томск, Россия 28 августа – 8 сентября 2019

pretation of granitic rocks // J. Petrol. 25: 956-983
6. Perfilova O.Yu., Mikhaylenko V.V., Koptev I.I., Sidoras S.D. (1999). Koshkulak standard of the Ordovician volcano-plutonic association (Kuznetsk Alatau). Krasnoyarsk: RIC KNIIGiMS: 159 (In Russian)
7. Rublev A.G., Shergina Yu.P., Berzon E.I. (1999). The isotopic age of Paleozoic volcanoes of the Krasnoyarsk Rise and the problem of the stratigraphy of the Byskarian series. Domestic Geology 3: 47-54
8. Shkol'nik S.I., Ivanov A.I., Reznitsky L.Z., Letnikova E.F., Hyaiyu He, Zhiglang Y., Youjueen Li., Vishnevskaya I.A., Barash I.G. (2017) Middle ordovician effusive rocks of the Khamsara terrane (Tyva) as an indicator complex. Russian Geology and Geophysics 58 (9): 1032-1044
9. Sun S.-s., McDonough W. F. (1989). Chemical and isotopic systematics of oceanic basalts: implications for mantle composition and processes. Geological Society. London, Special Publications, 42: 313-345
10. Vetrov, E.V., Chernykh, A.I., Babin, G.A. (2019). Early Paleozoic granitoid magmatism in the East Tannu-Ola sector of the Tuvinian magmatic belt: geodynamic position, age, and metallogeny. Russian Geology and Geophysics 60 (5): 492-513
11. Vorontsov A.A., Perfilova O.Yu., Kruk N.N. (2018). Geodynamic setting, structure, and composition of continuous trachybasalt-trachyandesite-rhyolite series in the north of Altai-Sayan area: the role of crust-mantle interaction in continental magma formation. Russian Geology and Geophysics 59(12):1640-1659

# ORDOVICIAN–DEVONIAN VOLCANISM IN THE NORTH OF THE ALTAI–SAYAN FOLDED AREA (GEOLOGY, GEOCHEMISTRY, GEODYNAMICS)

Vorontsov A. A.[1,2], Perfilova O. Y. [3], Grinev O. M. [4], Ernst R. E. [4,5]

[1] *Vinogradov Institute of Geochemistry, Siberian Branch, Russian Academy of Sciences, Irkutsk, Russia*
[2] *Irkutsk State University, Irkutsk, Russia*
[3] *Siberian Federal University, Krasnoyarsk, Russia*
[4] *National Research Tomsk State University, Tomsk, Russia*
[5] *Carleton University, Ottawa, Canada*

***Keywords:*** *volcanic series, geochemistry, Ordovician, Devonian, Minusa basin*

## Introduction

A volcanic series is widespread in the north of the Altai–Sayan folded area (ASFA) comprising the Minusa basin and its mountainous surroundings. Two magmatic stages are recognized from geologic and geochronological (Rb–Sr, K–Ar, Ar–Ar and U–Pb) studies: 480–430 Ma (Ordovician–early Silurian) and 410–390 Ma (Early–Middle Devonian). The volcanic rocks of these two stages are concentrated within the Minusinsk depression and share a similar rock association, petrographic characteristics and total alkalinity (Perfilova, 2004; Vorontsov et al., 2015). However, geochemical appraisal of basaltoids in both series (Vorontsov et al., 2017) indicates different contents of HFSE (High Field Strength Elements), LILE (Large Ion Lithophile Elements) and Sr and Nd isotopes reflecting differences in the sources, as well as the paths for primary magma evolution, and possibly indicating differences in geodynamic settings for magma generation. Herein, we provide a comprehensive comparison of geochemical and isotope characteristics of both the Ordovician–early Silurian and Early–Middle Devonian suites.

## Results

### *Geology*

Volcanic rocks of the Ordovician–early Silurian stage include trachybasalts, basaltic trachyandesites, trachyandesites, trachytes and trachyrhyodacites. There also associated volcano-plutonic units that include numerous syenite–granite plutons in the basement to the Minusa basin (e.g., East Sayan, West Sayan, and Kuznetsk Alatau mountains). The volcanic series of the Early–Middle Devonian stage include trachybasalts, basaltic trachyandesites, trachyandesites, trachytes, trachydacites, trachyrhyolites, and rhyolites. Their formation is linked with the development of the Minusa basin. The rocks of the series comprise part of sedimentary-volcanic sequences lying with structural unconformity over the pre-Devonian folded basement. Approximate values show that the volume of Ordovician–early Silurian volcanics is less than half the size of the Early–Middle Devonian volcanics (about 20,000 $km^3$) of the Minusa-basin.

### *Geochemistry*

Three geochemical subgroups are distinguished that each include units of both stages (Ordovician–early Silurian and Early–Middle Devonian).

<u>Subgroup 1 (trachybasalts and basaltic trachyandesites, SiO2 47–55 wt.%)</u>. Normalized to primitive mantle, the shape of multi-element spectra of all volcanics of this subgroup (irrespective of which stage they belong to) seem close to that for island arc basalts (IAB) with typical minima in Th, Nb, Ta, Ti and maxima in Ba and Sr. However, the absolute values of all incompatible elements exceed their contents in IAB. Such excess is most distinct for LILE, as well as REE (Rare Earth Elements), their contents reaching the values observed in within-plate basalts (OIB). The Ordovician–early Silurian basaltoids (belonging to this subgroup) are distinguished by a high degree of REE fractionation basically due to LREE enrichment ((La/Yb)n which varies from 11.6 to 32.8). In the Early–Middle Devonian volcanics the (La/Yb)n value varies

from 7.6 to 13.0. In all rocks of the Ordovician–early Silurian series, in contrast to the Early–Middle Devonian series, there is direct correlation between $TiO_2$ and La/Yb value.

Subgroup 2 (trachyandesites, $SiO_2$ 55–63 wt.%). These rocks retain a high degree of REE fractionation. The $(La/Yb)_n$ value varies from 10.2 to 23.8 in trachyandesites of the Ordovician–early Silurian and from 9.6 to 14.1 in trachyandesite of the Early–Middle Devonian. The rocks of both age groups retain Th, Nb, Ta minima, Ba maximum; dispersion arises in Sr. Subgroup 2 has the poorer Ti and Eu, but the higher Rb.

Subgroup 3 (trachytes, trachydacites, trachyrhyodacites, trachyrhyolites, and rhyolites, $SiO_2$ 63–77 wt.%). In this subgroup, volcanics of the two different age stages differ in geochemical specifics. Thus, in the Ordovician–early Silurian volcanics with increasing $SiO_2$ the concentrations of many incompatible elements increase as well, except for P (fractionation of apatite), Ti (fractionation of titanium-magnetite) and Ba decreasing to 57 ppm, Sr decreasing to 7 ppm and Eu (fractionation of feldspars). In subgroup 3 the selective depletion in Nb and Ta is not intensive as in the rocks of basic and intermediate compositions; however, the $(La/Yb)_n$ varies from 7.4 to 18.2. In contrast, in the Early–Middle Devonian volcanics there are two types of rocks with different distributions of rare elements. The first type is close to the Ordovician–early Silurian volcanics, differing from them by the absence of rocks with anomalously low contents of Ba and Sr, weak Eu minimum, and narrow range in total REE and LREE to HREE ratios ($(La/Yb)_n$ varies from 6.6 to 10.5). In the rhyolites ($74.0 < SiO_2 < 76.6$ wt.%) with respect to trachyrhyolites ($72.0 < SiO_2 < 74.0$ wt.%) HSFE, REE, and Y concentrations decrease, violating the tendency of accumulating incompatible elements during fractionation. Their composition is close to that of upper crustal values, and island arc and accretionary–collisional granites of the Central-Asian fold belt.

*Isotope composition of Sr and Nd in basaltoids*

In the εSr(T)– εNd(T) diagram data from the two age stages plot in the first quadrant, and concentrate in two isolated fields. One field characterizes the substrates giving rise to melting of Ordovician–early Silurian (εNd(476) 0.4–1.0 and εSr(476) 11.3–12.8). The other field is for Early–Middle Devonian (εNd(391) 3.5–4.7 and εSr(391) 5.7–7.9) basaltoids. Both fields are displaced from the line of mantle correlation towards substrates enriched in radiogenic strontium. Such a deviation points to assimilation of melts of moderately depleted mantle (with intermediate characteristics between PREMA and EMII) with an additional component having high Sr, increased $^{87}Sr/^{86}Sr$ and low REE values. The compositions of this additional component is most likely common for carbonate rocks, which could be involved in the Vendian–Cambrian subduction processes and magma formation, enriching the substance of mantle wedge with radiogenic strontium and forming the metasomatic mantle substratum-giving rise to fusion of primary magmas of the volcanic series.

## Conclusions

The Ordovician–early Silurian and Early–Middle Devonian volcanic series which occur in the northern part of the Altai–Sayan region are composed of rocks of primarily moderately–alkaline series, with $SiO_2$ varying from 45 to 77 wt.%. The Ordovician–early Silurian series is distinguished from the Minusa trough volcanics by low $TiO_2$ content (less than 1.7 wt.%), $Fe_2O_3tot$ and increased $Al_2O_3$ concentrations in all rock varieties, and a more fractionated pattern of REE distribution in trachybasalts. Both series are governed by the two contemporaneous mechanisms of magma evolution. The major process—the fractional crystallization is responsible for origination of the rock spectrum ranging from trachybasalts to trachyrhyodacites. The secondary mechanism is contamination of fractionated melts with crustal components, anatectic crustal melting and mixing of deep-seated magmas with crustal melts. Specifics of these processes are common for both age stages; they are controlled by the composition of parent melt sources. Their geochemical characteristics are typical of the Central Asian Foldbelt areas, in which a mantle plume interact with lithospheric mantle metasomatically modified during the preceding Vendian–early Cambrian subduction processes related to the development of the Kuznetsk Alatau and Altai–North Sayan island arc systems. The composition of the products of magmatism was determined by the processes of mantle metasomatism and crustal contamination.

## Acknowledgements

This work was conducted as a task of RFBR, project No. 19-05-00300.

## References

1. Perfilova O.Yu., Makhlaev M.L., Sidoras S.D. (2004). Ordovician volcanic-plutonic association in structures of the folded surrounding of the Minusa depression. Russ. Lithosphere 3: 137–152.
2. Vorontsov A.A., Gazizova T.F., Yarmolyuk V.V., Fedoseev G.S., Travin A.V., Perfilova O.Y., Posokhov V.F. (2015). Differentiated volcanic association of the Minusa trough: mechanisms of formation and sources of melts, as examplified by Batenevo rise. Petrology 23 (4): 353–375.
3. Vorontsov A.A., Perfilova O.Yu., Buslov M.M., Travin A.V., Makhlaev M.L., Dril S.I., Katraevskaya Ya.I. (2017). Plume magmatism in the northeast of Altay-Sayan area: stages, composition of sources, geodynamics (exemplified by the Minusa basin). Dokl. Earth Sci. 472 (4): 449–455.