
GEOLOGY

Formation Setting of Early Mesozoic Basalts of the Russian Far East: Accretion of the Pacific Guyots or Epicontinental Rifting?

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The formation setting and origin of alkali basalts hosted in Mesozoic siliceous–terrigenous rocks of the Russian Far East remain controversial issues. Some geologists believe that these basalts are remains of Pacific guyots in accreted oceanic terranes. Based on the presence of such basalts, the host fold-thrust structures are interpreted as open oceanic deposits transported over many hundreds of kilometers. Subsequently, they were adjoined to the continent as accretionary prisms in the Jurassic, Jurassic–Early Cretaceous, and Early Cretaceous [1]. According to another concept, the Mesozoic alkali basalts are related to volcanism in the epicontinental basins (rift-grabens) [2]. In the Russian Far East (Primor’e and Amur regions), Mesozoic alkali basalts occur in the Triassic–Lower Cretaceous siliceous–terrigenous rocks and the matrix and inclusions of olistostromes. They are abundant in the Taukha and Samarka structural zones, in the Anyui dome, and at the boundary of the Badzhal salient. The K–Ar data indicate that Late Jurassic volcanic rocks are the oldest ones in all of the aforementioned zones. However, younger (Albian; Late Cretaceous; and, occasionally, Paleogene) rocks also occur in some places. High contents of HFSE (Ti, Zr, Nb, Ta), LILE (Rb, K, Ba), and LREE (La and Ce), as well as Nd and Sr isotopic compositions, suggest the genetic link of these basalts with a plume [3]. The location scheme, contents of major and trace elements, and ages of rocks are reported in the aforementioned publications.

The Far East domain of Mesozoic alkali basalts (Fig. 1) is located at the boundary between two large within-plate provinces: the northwestern Pacific province controlled by the Pacific plume and the Mongol–Transbaikal province affected by the North Asian

plume [4]. The formation setting of basalts in the Far East can be deciphered by the isotope–geochemical correlation with their counterparts in other provinces. In the present work, we used the content of Ba and its ratio to the less incompatible trace elements to compare within-plate alkali volcanic rocks of the Far East with their counterparts in areas affected by the East Pacific and North Asian plumes. Accumulation of Ba is related to mantle metasomatism. At present, 57% Ba is confined to the continental crust. The worldwide geochemical data summarized by P.B. Kelemen et al., G.L. Farmer, and A.W. Hofmann (see [5]) did not confirm the concept that suprasubduction fluids were the major source of Ba in areas of the generation of island-arc and within-plate basalts. According to Hofmann (see [5]) and Ryabchikov [6], barium characterized by a low distribution coefficient is concentrated in low-degree melts, which serve as the main source of incompatible elements in the crust and metasomatized protoliths of enriched melts. Barium was most rapidly transported during the Archean protocrust formation [7]. The intensity of the input of Ba was different in various segments of the Earth, resulting in the appearance of high-Ba magmatic series in some regions and low-Ba varieties in the newly formed Archean continental nuclei [8]. According to these data, the Anabar, Aldan, and Sino-Korean shields, as well as the Okhotsk massif, belong to the high-Ba province of east Eurasia (Fig. 1). In such provinces, mafic volcanics of greenstone belts (for example, NW Australia) are also high-Ba rocks associated with large Early Archean barite deposits in some places. In the Phanerozoic, the less frequent pulses of high-Ba mafic magmatism were confined to long-lived pathways, which controlled the location of kimberlites, lamprophyres, lamproites, and alkali basalts of continental rifts. These rocks have the highest Ba content ($n \cdot 10^3 - n \cdot 10^5$ ppm) among the basic and ultramafic rocks. Judging from xenoliths, these high-Ba rocks postdated the most intense mantle metasomatism (phlogopite- and amphibole-bearing peridotites and pyroxenites).

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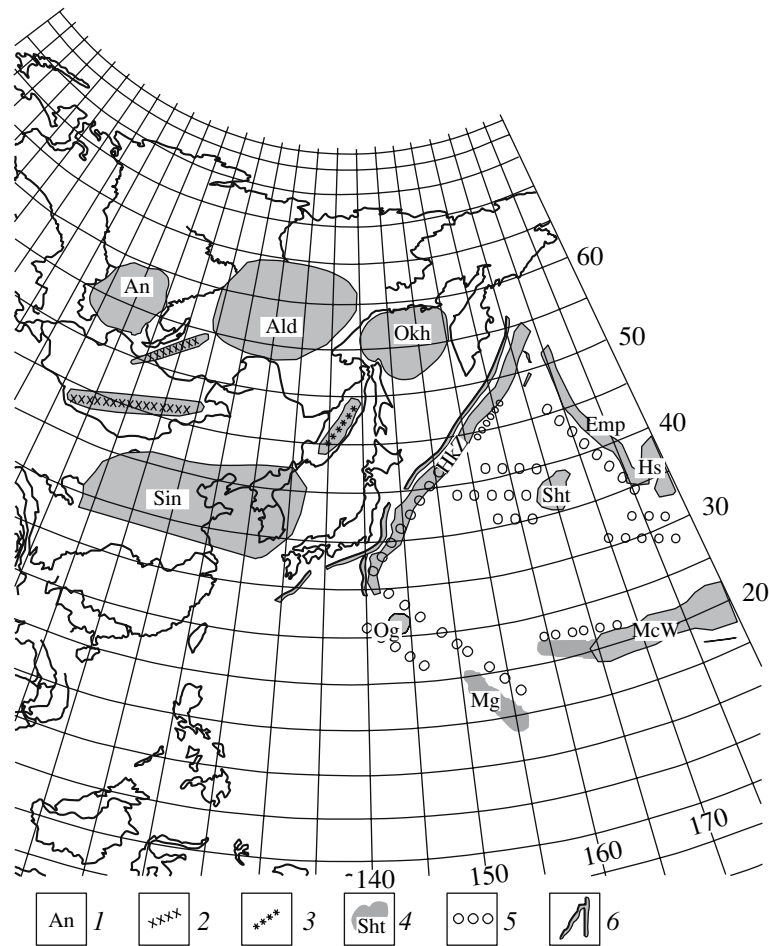


Fig. 1. Location scheme of high- and low-Ba magmatic areas in East Asia and the northwestern Pacific. (1–3) High-Ba nuclei and within-plate belts: (1) nuclei: (Ald) Aldan, (An) Anabar, (Okh) Okhotsk, (Sin) Sino-Korean [8]; (2) belts of Late Mesozoic within-plate basalts of the Mongol–Transbaikalian region [4], (3) field of high-Ba Mesozoic basalts of the Russian Far East; (4–6) areas of Mesozoic–Cenozoic low-Ba within-plate basalts of the northwestern Pacific: (4) oceanic rises: (Sh) Shatsky, (Hs) Hess, (Emp) Emperor Range, (Og) Ogasawara plateau, (Mg) Magellan Seamounts, (McW) Marcus Wake, (HkZ) Hokkaido–Zenkevich swell; (5) areas of maximal concentration of seamounts and guyots [10, 11, 14]; (6) deep-water trenches with low-Ba sediments [15].

We studied Mesozoic alkali basalts in the Far East characterized by high content of Ti, the presence of Nb, and a Ba/La ratio ranging from 10–15 to 30–40. The high $(La/Nb)_n$ ratio ranging from 12–17 to 25–30 indicates the concentration of LREE in the protolith. The $^{143}Nd/^{144}Nd$ and $^{87}Sr/^{86}Sr$ ratios are 0.5126–0.5127 and 0.7036–0.7063, respectively. Chemically, these basalts are similar to the rocks of the East African rifts. The Mesozoic riftogenic basalts in the Mongol–Transbaikalian province are mainly represented by low-Ti potassium volcanic rocks. Like similar series in Tibet, Taiwan, and the southwestern United States, as well as high-Ba lamprophyres in Northern Australia and southeastern Canada, the basalts are Nb-depleted rocks [5]. The rocks of the Uda–Vitim graben [4] are the closest compositional analogues of alkali basalts in the Far East. The Late Mesozoic basalts of the Far East continental margin are similar to those of the Mongol–Transbaikalian province in terms of Nd and Sr isotopic compositions, the Ba/La

ratio (15–40), and high Ba contents. In both provinces, the Ba content is more than 1000–1500 ppm (often >3000 ppm). Therefore, these rocks can be ascribed to high-Ba basalts. In terms of Ba content, they differ from coeval alkali basalts of seamounts and guyots of the northwestern Pacific.

The northwestern Pacific is characterized by an abundance of oceanic rises with the crust up to 25–40 km thick (Fig. 1) and with intense within-plate volcanism. The equatorial northwestern Pacific region alone incorporates more than 1300 seamounts and guyots of different ages. Active volcanism in the northwestern Pacific commenced in the Late Jurassic–Early Cretaceous. The seafloor basalt beneath guyots of the Magellan seamounts have an Ar–Ar age of 165–160 Ma. Basalts from the seafloor were estimated at 140–150 Ma in the Shatsky Rise and Magellan Seamounts, 75–130 Ma in the Mid-Pacific, 100–125 Ma in Ontong Java, 95–115 Ma in Marcus Wake, and 115–125 Ma in

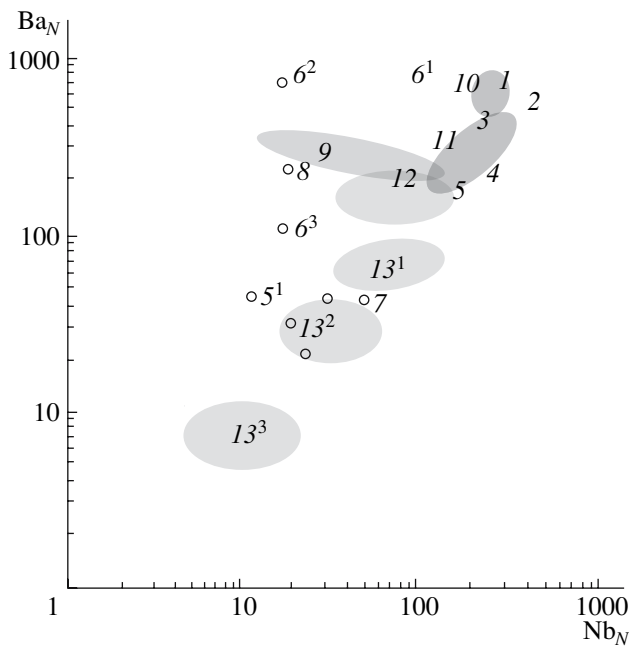


Fig. 2. Ba vs. Nb relation in the basalts of guyots in the northwestern Pacific, Mesozoic structures of the Russian Far East and Mongol–Transbaikalian region, and some other typical within-plate structures of other provinces. The contents are PM-normalized (after [4]). Points and compositional fields (points 1–8 are average compositions based on [5]): (1) Orangeites, (2) kimberlites of Sierra Leone; (3) basalts of the East African Rift; (4) high-Ti alkali basalts (potassic); (5, 5') the upper and lower compositional limits of high-Ti alkali (sodium and potassium) basalts; (6¹–6³) the same for the low-Ti potassium basalts (Tibet, Taiwan, and others); (7) average oceanic island basalts; (8) continental flood basalts; (9–11) dark gray fields: (9) Jurassic and Early Cretaceous basalts of the South Hangai and Western Transbaikalian areas (average compositions [4]), (10) field of the Mesozoic alkali basalts of the Primor'e region, (11) the same, the Badzhal and Anyui areas in the Far East; (12, 13) light gray fields (based on [10, 14]): (12) high-Ba basalts in the zone affected by the Polynesian plume (Samoa and Marquesas Islands), (13¹) basalts of guyots in the Magellan Seamounts and Marcus Wake Rise; (13²) the same, south of the Emperor Range and Ogasawara Rise; (13³) the same, Obruchev Range and northern Emperor Seamounts.

Manihiki [10, 11]. The datings of individual seamounts suggest long-term volcanic activity (from the Early Cretaceous to the Miocene). The volcanic sequences are dominated by olivine tholeiites, alkali basalts, ankaramites, and hawaiites. The rocks of seamounts are mainly ascribed to high-Ti but Nb- and Zr-depleted rocks. As compared to basalts in the Far East with comparable contents of Ti, Nb, Zr, and K, the high-Ti alkali and subalkali basalts of ocean islands, asymmetrical rises, and guyots are marked by low Ba content. This feature is also typical of Late Paleozoic–Late Cenozoic lavas and sediments of deep-water trenches [12]. According to available data, the low-Ba alkali and subalkali volcanic rocks occur in seamounts and guyots in the northwestern Pacific (Shatsky and Hess rises,

Emperor Range, Ogasawara and Ontong Java plateaus, as well as the Magellan, Marcus Wake, Mid-Pacific seamounts, and marginal swells (Hokkaido–Zenkevich swell)). Little information is available on the pre-Cenozoic rocks. The oldest rocks are Carboniferous basalts of accretionary prisms in southwestern Japan [13] and Late Jurassic potassium volcanic rocks at the base of the Shatsky Rise. High-Ti alkali and subalkali basalts of the northwestern Pacific guyots (250 analyses) [14] are also depleted in Ba (Fig. 2). The exception is single finds of phonolites (1200–1800 ppm Ba, 1000 ppm Zr, 160–200 ppm Nb), which are geochemically different from the studied basalts and are not considered in this work.

The Pacific Ocean includes a province with high-Ba within-plate alkali volcanic rocks that are coeval to the studied basalts (beginning of volcanism at 150–90 Ma). This province is not in contact with the Asian margin and is located in the Polynesian plume domain [13] in the southeastern Pacific (approximate coordinates 165°–120° W, 0°–25° S). As in the continental areas, the high-Ba rocks in the Pacific do not form large exposures and they reveal the following specific features: confinement to individual linear zones and tectonic junctions and association with the subalkali and alkali potassium series located in the riftogenic faults along aseismic volcanic rises, in deep-seated hot spots (Marquesas and Rarotonga Islands types [10]), and occasionally in transform faults (Easter Island). Volcanic rocks of some islands of the Marquesas Archipelago are similar to the Early Mesozoic within-plate basalts of the Mongol–Transbaikalian and Far East regions in major, trace, and Nd–Sr isotopic composition.

Huge continental and oceanic provinces associated with different superplumes are distinguished not only by the Nd and Sr compositions of lavas, but also by the presence (or absence) of high-Ba volcanic rocks. In particular, the North Asian and Polynesian superplumes produce high-Ba rocks, while the Pacific Superplume produces low-Ba rocks. However, the Pacific and Polynesian provinces are characterized by variation of the Ba content not only in the within-plate lavas, but also in the sediments. The Ba contents in the sediments of deep-water trenches [15] are comparable with those in the Cenozoic basalts of adjacent oceanic plates. Like basalts of the oceanic rises, marginal swells, and seamounts of northwestern Pacific, the sediments of the Kamchatka, Kuril, Izu–Bonin, Japan, and Mariana trenches are relatively depleted in Ba (<500, occasionally up to 600 ppm). The sediments from deep-water trenches around the Polynesian area (partly Tonga–Kermadec trench) and eastern boundary of the ocean (Aleutian, Peru, Columbia, and Centam trenches) have high Ba contents (1200–2500 ppm). The Ba content in oceanic sediments reflects not only the composition of eroded material, but also the high- or low-Ba composition of the within-plate magma chamber.

CONCLUSIONS

The Mesozoic high-Ba alkali basalts of the Russian Far East margin cannot be ascribed to the low-Ba guyots of the western and northwestern Pacific, where high-Ba volcanism is atypical. The presence of these basalts is related not to the migration of crustal blocks of an open ocean, but to the fact that the Asian continental margin already occupied the present-day position in the Late Jurassic. The Mesozoic high-Ba alkali basalts of the Primor'e and Amur regions are similar to the Late Mesozoic within-plate volcanic rocks of Transbaikalia and Mongolia in terms of the Ba content, Ba/La ratio, and Sm–Nd isotopic composition. We suppose that the Mesozoic alkali basalts formed above the eastern periphery of the North Asian Superplume in epicontinental basins of the Mesozoic Asian margin.

Like Archean provinces, large petrographic provinces related to the Phanerozoic plumes can be subdivided into high- or low-Ba types. The high-Ba type includes the North Asian and Polynesian provinces, while the low-Ba type comprises provinces of the Pacific Superplume.

Sediments of deepwater trenches in the Pacific and Polynesian provinces have different Ba contents. This feature presumably reflects the high- or low-Ba composition of the within-plate magma chamber.

Basalts with a high content of Ba (1600–1800 ppm) are rare in the oceanic settings. The geochemical and isotopic similarity of these volcanic rocks in the continental and oceanic settings (in particular, Polynesian Marquesas complexes are similar to the Central Asian and Far East ones) likely indicates the sublithospheric nature of high-Ba plumes.

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