ISSN 1028-334X, Doklady Earth Sciences, 2006, Vol. 411, No. 8, pp. 1293–1298. © Pleiades Publishing, Inc., 2006.
Original Russian Text © A.A. Vorontsov, V.V. Yarmolyuk, S.V. Andryushchenko, S.I. Dril, M.I. Kuz'min, 2006, published in Doklady Akademii Nauk, 2006, Vol. 411, No. 1, pp. 100–105.

GEOCHEMISTRY

Magmatism of the Khambin Graben and Early History of the Late Mesozoic Rift System Formation in the Western Transbaikal Region

A. A. Vorontsov[a], **Corresponding Member of the RAS V. V. Yarmolyuk**[b], **S. V. Andryushchenko**[a], **S. I. Dril**[a], **and Academician M. I. Kuz'min**[a]

Received May 23, 2006

DOI: 10.1134/S1028334X06080290

The western Transbaikal region was repeatedly subjected to rifting during the Mesozoic. The Early Mesozoic was marked by the formation of a system of grabens filled in with Late Triassic–Early Jurassic bimodal volcanic sequences of the Tsagan-Khurtei Group and Kunalei Complex, which is traced by massifs of alkalic granites [1–5]. In the Late Mesozoic, a new rift system, generally conformable with the previous one, appeared [6–9] and began to develop until the Late Cenozoic. Therefore, the grabens and horsts of the rift system are readily traceable in the present-day topography. The Late Mesozoic epoch commenced with the formation of the bimodal basalt–trachybasaltic andesite–trachydacite–trachyrhyolite–comendite volcanic association of the Ichetui Formation. Its compositional and structural similarity to the Tsagan-Khurtei Group served as the basis for determining the age of bimodal volcanic associations in some areas of the region, resulting in misleading interpretation of the structure, scale, and geodynamic settings of different-age rifting events. This problem can be exemplified by the Khambin volcanic field (Fig. 1), one of the largest in the region. The volcanic field is outlined as a ridge in geological maps, because it resembles the majority of outcrops of the Tsagan-Khuntei Formation in the topography [10, 11]. In such an interpretation, the field occupied the westernmost part of the Early Mesozoic rift system and, thus, governed its dimensions and structural peculiarities in the pinchout area. At the same time, the Khambin field, located between the western (Dzhida) and central (Khilok–Tugnui) segments of the Late Mesozoic rift system (Fig. 1, inset), occupies a relatively large fragment of the rift system. In available maps, the fragment is shown as an anomalous zone because of the absence of Late Mesozoic magmatism. In this communication, we present systematic geological and geochronological (Rb–Sr, K–Ar) data, which point to the formation of Khambin field lava sequences as a result of Late Mesozoic rifting in several stages of volcanic activity. This conclusion is consistent with the multistage character of magmatic processes in other areas of the rift system. The materials obtained allow us to scrutinize specific features of the manifestation of early stages of Late Mesozoic rifting.

The Khambin volcanic field extends in the NNW direction for more than 40 km and associates with the Khambin Ridge, which serves as a western horst boundary of the Late Mesozoic Gusinoe Ozero Depression (Fig. 1). The volcanic field is largely composed of subalkalic–alkalic volcanic associations with subordinate trachybasalts, trachybasaltic andesites, phonolites, essexites, trachytes, trachyrhyolites, trachydacites, and comendites. Our K–Ar and Rb–Sr dates of volcanic activity in the lava field combined with published Rb–Sr dates of essexites from the Murtoi (Gusinoe Ozero) dike [12] allow us to define three magmatic stages with a duration of approximately 40 Ma (from 159 to 117 Ma ago) in the development of the volcanic field.

The *Late Jurassic stage* corresponds to the formation of thick (up to 1000 m) volcanic sequences, which are traceable virtually continuously through the entire graben as packets of trachyte, trachydacite, and subordinate trachyrhyodacite and pantellerite lava flows. The less common basic and intermediate volcanics are represented by trachybasalts, trachybasaltic andesites, and trachyandesites. These sequences occur between Paleozoic granitoids and Lower Cretaceous sediments and form a large anticline with a dip angle up to 30° at the limbs. The core of the anticline coincides with the axial zone of the graben and includes extrusive bodies of largely megaphyric trachyrhyodacites and trachytes.

[a] *Vinogradov Institute of Geochemistry, Siberian Division, Russian Academy of Sciences, ul. Favorskogo 1-a, Irkutsk, 664033 Russia; e-mail: voron@igc.irk.ru*

[b] *Institute of Geology of Ore Deposits, Petrography, and Mineralogy, Russian Academy of Sciences, Staromonetnyi per. 35, Moscow, 119017 Russia*

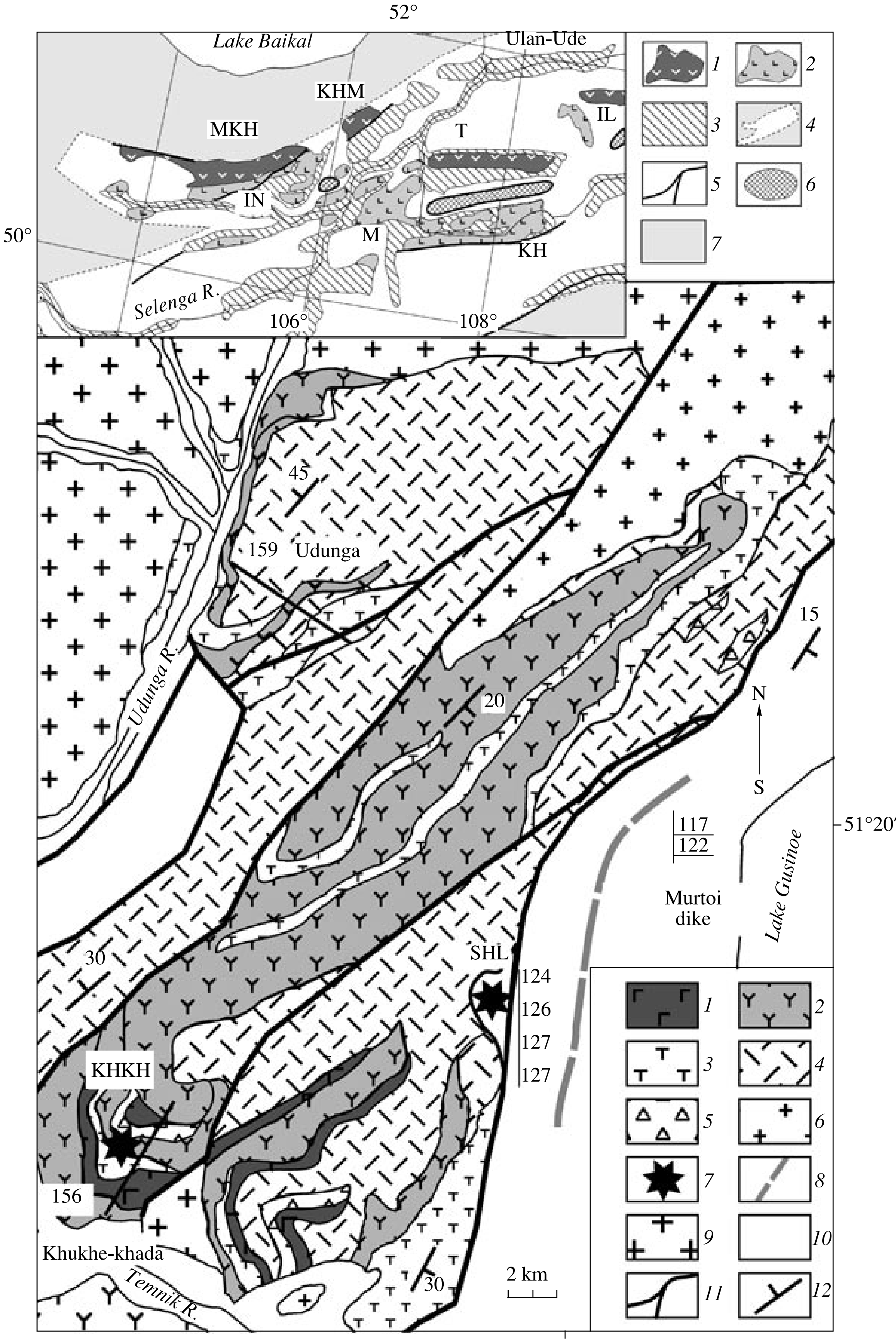
52°
Lake Baikal
Ulan-Ude
KHM
MKH
IL
T
IN
M
KH
50°
Selenga R.
106°
108°
1
2
3
4
5
6
7
45
159
Udunga
15
N
S
20
Udunga R.
117
122
51°20′
Murtoi
dike
Lake Gusinoe
30
SHL
124
126
127
127
KHKH
156
Khukhe-khada
Temnik R.
30
2 km
106°20′
8
9
10
11
12

Table 1. Rb and Sr contents and Sr isotopic ratios in rocks from volcanic sequences

Sample	Rock	Rb	Sr	$^{87}Rb/^{86}Sr$	±2*s*	$^{87}Sr/^{86}Sr$	±2*s*
		g/t					
Khukhe-Khada area							
GO-5/1	Trachyte	67	550	0.35472	0.00092	0.70655	0.00009
GO-5/3	Trachybasaltic andesite	55.8	1561	0.10336	0.00036	0.70605	0.00026
GO-5/4	The same	68	150	0.13207	0.13207	0.70588	0.00023
GO-5/5	Trachydacite	199	13.8	41.9982	0.2053	0.7973	0.0003
GO-5/6	The same	250	35.1	20.696	0.05134	0.75125	0.00012
GO-5/7	″	183.5	10.7	50.04161	0.2929	0.81823	0.0001
GO-2/2	Pantellerite	282	49	16.5462	0.26	0.74248	0.00039
Udunga area							
CH-16/3	Pantellerite	250	50	47.80887	0.15477	0.81451	0.00033
CH-16/4	The same	220	55	30.21559	0.106985	0.77348	0.00039
CH-16/5	″	210	57	49.70368	0.115648	0.81758	0.00016
CH-16/6	″	250	56	40.09167	0.097339	0.79529	0.00014
CH-16/8	Trachydacite	160	47	21.07153	0.036238	0.75321	0.00015
CH-16/1	Trachyte	92	48	4.788217	0.007266	0.71590	0.00014
CH-16/16	The same	120	74	5.815219	0.009413	0.71879	0.00014
CH-16/19	″	130	84	6.642274	0.009407	0.72008	0.00007

Note: Rb and Sr contents were measured with a MI-1201 mass spectrometer using the method of isotope dilution at the Institute of Geochemistry, Irkutsk (G.P. Sandimirova and Yu.A. Pakhol'chenko, analysts). Rb and Sr contents were determined with an accuracy of 0.2–0.5%; $^{87}Sr/^{86}Sr$ value, with an accuracy of 0.01–0.02%. The accuracy of isotope analysis was controlled using the VNIIM-Sr (strontium carbonate) and All-Russian ISG-1 (granite) standards.

We studied two sample collections for the isochron Rb–Sr analysis. They characterize the southern (Khukhe-Khada area) and northeastern (Udunga area) flanks of the Khambin volcanic field (Table 1). In the $^{87}Sr/^{86}Sr$–$^{87}Rb/^{86}Sr$ diagram (Fig. 2a), data points of rocks from the Khukhe-Khada area define a regression line with the slope corresponding to 155.6 ± 2.5 Ma $(^{87}Sr/^{86}Sr)_0$ = 0.70575 ± 0.00015, MSWD = 2.28. The distribution of data points of rocks from the Udunga area corresponds to 159.1 ± 2.7 Ma $(^{87}Sr/^{86}Sr)_0$ = 0.70534 ± 0.00031 and MSWD = 2.66 (Fig. 2b). With account for measurement accuracy, both dates are virtually identical and similar to the K–Ar age estimate of 156.4 ± 4.7 Ma obtained for trachybasaltic andesite from the volcanic sequence of the Khukhe-Khada area (Table 2). The dates obtained are consistent with the timing of volcanics of the Ichetui Formation (146–167 Ma) in the Western Transbaikal rift system (WTRS) [6–9]. It should be noted that both sialic and basic rocks were used to obtain the isochron correlation. Consideration of the geochemical data demonstrated the coincidence of trends in changes of rare elements in compositionally different rock associations and, consequently, their origin from the same magmatic melts. This inference is supported, for example, by the similarity of primary $^{87}Sr/^{86}Sr$ values derived from both isochrons. They also

Fig. 1. Schematic geological structure of the Khambin volcanic field. Late Mesozoic igneous rocks: (*1*) trachybasalt; (*2*) trachybasaltic andesite and trachyandesite; (*3*) trachyte; (*4*) trachyrhyodacite, trachyrhyolite, and comendite; (*5*) acid lava breccia; (*6*) subalkalic micrograniteѕ; (*7*) paleovolcanoes: (KHKH) Khukhe-Khada, (SHL) Shaluta; (*8*) essexites of the Murtoi dike; (*9*) pre-Mesozoic granitoids; (*10*) Lower Cretaceous and Quaternary sediments; (*11*) faults; (*12*) attitude elements. Numbers designate sampling sites and age (Ma) of igneous rocks. Underlined numbers are ages (Ma) of rocks from [12]. The inset shows the western and central segments of the Late Mesozoic–Cenozoic WTRS. (*1*) Late Jurassic volcanics; (*2*) Early Cretaceous and Cenozoic volcanics; (*3*) Meso–Cenozoic terrigenous sediments; (*4*) contours of the WTRS; (*5*) faults; (*6*) complexes of metamorphic cores (after [15]); (*7*) framing of the WTRS. Grabens: (MKH) Malyi Khamar-Daban, (KHM) Khambin, (T) Tugnui, (KH) Khilok, (M) Margentui, (IN) Inzagatui, (IL) Il'kin.

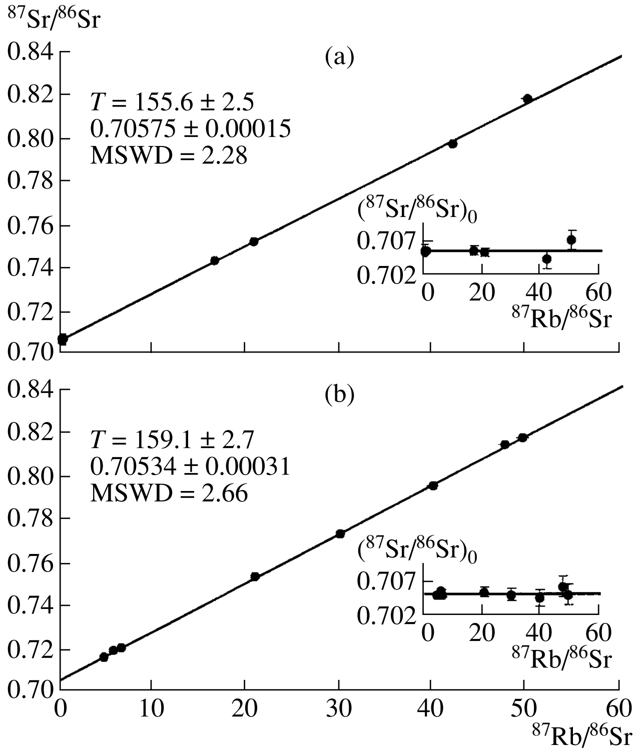

Fig. 2. Rb–Sr isochron diagrams for volcanics of the Khambin graben. (a) Khukhe-Khada area, (b) Udunga area.

match the values in basic rocks even if the latter rocks are omitted from the isochron correlation. The data obtained indicate that magmatic sources of examined volcanic rocks were enriched in radiogenic strontium as compared with the average mantle (or UR after [13]), where the $^{87}Sr/^{86}Sr$ value is 0.70433 for an age of 150 Ma.

The *middle Early Cretaceous stage* is characterized by at least two (Shaluta and Khukhe-Khada) paleovolcanoes composed of alkalic rocks. The Shaluta paleovolcano located at the eastern wall of the Khambin graben comprises subvolcanic and volcanic facies. Rocks of the subvolcanic facies make up two lenticular extrusive bodies (approximately 2.5 km^2 in total) in the central part of the paleovolcano. The extrusive bodies are composed of fine-grained gray biotite trachytes and trachydacites. Marginal parts of the extrusive bodies contain lava breccia, bomb and lapilli tuffs of the intermediate and basic compositions, and small (approximately 5 × 10 m) lenses of trachyte glass. The volcanic facies is represented by flows of bluish gray vesicular tephrites and phonolitic tephrites gently dipping (10°–20°) toward the Gusinoe Ozero Depression. The total thickness of the lava sequence does not exceed 30 m.

The K–Ar isotopic age of rocks of the Shaluta paleovolcano is estimated at 124–127.9 Ma (Table 2), which corresponds to the age (119–134 Ma) of alkalic associations in the Malyi Khabar-Daban, Khilok, Uda, and Eravnin grabens, i.e., in the entire western Transbaikal volcanic region [6, 7].

The *middle–terminal Early Cretaceous stage* corresponds to the timing of the Murtoi essexite dike as a ridge (up to 25–30 m high) that extends in the NE direction parallel to the graben strike for 6–7 km. The dike is 4–6 to 12–15 m thick and dips southeastward at an angle of 70°–80°. At its southeastern and northeastern margins, one can see systems of three or four subparallel or diverging dikes (0.5 to 5 m thick) composed of fine-grained essexites. The main dike has a complex internal structure related to the development of at least three emplacement phases of alkalic melts. Rocks of these phases are characterized by different (glassy to medium-grained) textures and sharp boundaries. At the same time, they are similar to each other in chemical and mineral compositions, probably suggesting a lack of differentiation in the magma chamber. The geological age of the dike is defined by its emplacement into

Table 2. K–Ar dates obtained for rocks of the Khambin volcanic field

Sample	Rock	K, wt %	Ar_{rad}, ppm	Age, Ma
Volcanic rock from the Khukhe-Khada area				
Go-3/1	Trachybasaltic andesite	3.34	37.49 ± 1.1	156.4 ± 4.7 (S)
Shaluta paleovolcano				
Kham-3/5	Alkalic trachyte	4.73	43.9 ± 1.3	126.5 ± 3.8 (S)
Kham-3/12	Phonolite	3.04	28.2 ± 0.8	127.9 ± 3.8 (S)
Kham-3/15	Tephrite	1.75	15.6 ± 0.3	124 ± 3 (A)
Kham-3/19	Trachydacite	5.00	45.8 ± 0.4	127.5 ± 3 (A)

Note: Measurements were conducted by V.N. Smirnov (S) at the Institute of Geochemistry (Irkutsk) and M.M. Arakelyants (A) at the Institute of Geology of Ore Deposits, Petrography, Mineralogy, and Geochemistry (Moscow). Potassium was measured by the method of flame spectroscopy. The following constants were used in calculations: $\lambda_K = 0.581 \cdot 10^{-10}$ yr^{-1}, $\lambda_\beta = 4.962 \cdot 10^{-10}$ yr^{-1}, and $^{40}Ar = 0.01167$ (at %).

Lower Cretaceous conglomerates. According to [12], the Rb–Sr isochron age of essexites is 117 ± 6 Ma $(^{87}Sr/^{86}Sr)_0 = 0.70537 \pm 0.00017$), while the K–Ar age of biotite from essexites is 122 Ma. Within the limits of error, these dates are similar to estimates obtained for rocks from paleovolcanoes. They are also similar to the age of trachybasalts and associated teschenites (glenmuirites and crinanites) from the Borgoi Depression (103–120 Ma) located in the southeastern periphery of the Khambin Ridge. Since essexite dikes intrude into the Lower Cretaceous sediments, which overlie rocks of paleovolcanoes, the essexites should be related to the same magmatic phase that produced alkalic rocks of the Borgoi Depression [14].

Thus, the obtained data combined with previously established geological relationships make it possible to define stages in the formation of the Khambin volcanic field. The first stage (156–159 Ma) was marked by intense volcanic activity within a relatively narrow trough or graben, as is evident from the great thickness of volcanic sequences and their confinement to the volcanic field. Volcanism was characterized by simultaneous eruptions of trachybasaltic andesites, trachydacites, trachyrhyolites, and comendites, which formed the contrasting sequence that was compositionally and structurally similar to the Ichetui Formation of the Malyi Khabar-Daban and Tugnui grabens located east and west of the Khambin graben, respectively. Products of younger (Early Cretaceous) volcanic stages are observable beyond the Khambin graben near its present-day southeastern boundary with the Gusinoe Ozero Depression formed in the Early Cretaceous. The earliest stage (124–128 Ma) corresponds to the formation of local central-type volcanoes composed of tephrites, phonolites, alkalic trachytes, and their tuffs and lava breccia. The youngest stage (122–117 Ma) is represented by the extended Murtoi essexite dike.

Evolution trends similar to those in the Khambin lava field (multistage volcanism and replacement of early bimodal associations by their substantially basic counterparts with elevated alkalinity) can also be observed in other areas of the Late Mesozoic rift system. In this respect, the Khambin volcanic field is virtually identical to other segments of the system. Therefore, we can consider this field as a structural element connecting the Malyi Khamar-Daban and Khilok–Tugnui segments of the rift zone (Fig. 1, inset). This approach makes it possible to define principally new regularities in the formation of the Late Mesozoic rift zone at its early developmental stages.

The rift zone commenced to develop as a narrow extended trough (or an echelon of grabens) in the Late Jurassic. In the present-day structure, they are represented by the Malyi Khamar-Daban, Khambin, Tugnui, Il'kin (inset in Fig. 1), and Uda grabens. Their development was characterized by the compensating mode, and volcanic products accumulated only within these grabens.

The rift zone continued to evolve in the earliest Cretaceous with the formation of an additional system of grabens associated with eruptions of plateau basalts of the Khilok Formation. The newly formed Khilok, Margentui, and Inzagatui grabens extended nearly parallel to, and south of, the Late Jurassic rift. The late multistage magmatic activity in the Early Cretaceous (and Late Cretaceous and Cenozoic in some segments of the rift zone) was confined precisely to this new system of grabens, whereas their Late Jurassic counterparts were passive.

Such a reorganization of magma-controlling structures in the rift zone can probably be explained by the development of metamorphic cores at the Jurassic–Cretaceous transition. Following [15], we assume that high-temperature heating of the crust in the region under consideration and its extension above the mantle plume, which provoked rifting, promoted the formation of the SE-verging detachment zone at the base of the rift zone. The surface of the detachment zone blocked the migration of mantle melts to Late Jurassic grabens. In some places, the surface was bent upward along the southern boundaries of the grabens (for example, in the Zagan Ridge [15]) under the influence of the ascending flow of the heated crustal substrate, resulting in the formation of metamorphic cores. The Cretaceous graben system formed above steep segments of the detachment zone that subsided toward the extension source, i.e., toward the plume, which was responsible for the origination of magmatic melts with similar Sr isotopic characteristics ($(^{87}Sr/^{86}Sr)_0$ = 0.70534–0.70575) in the period from 159 to 117 Ma. This stimulated development of a stable system of magma-conducting channels beneath grabens that functioned during the entire subsequent geological history of the rift zone.

ACKNOWLEDGMENTS

This work was supported by the Russian Foundation for Basic Research (project nos. 04-05-64279, 05-05-64000, and 05-05-64332) and Program no. 10 of the Earth Sciences Division of the Russian Academy of Sciences.

REFERENCES

1. V. V. Yarmolyuk, V. I. Kovalenko, E. B. Sal'nikova, et al., Geotectonics **36**, 293 (2002) [Geotektonika **36** (4), 42 (2002)].
2. A. A. Vorontsov, V. V. Yarmolyuk, and D. N. Baikin, Geochemistry Int., No. 11, 1046 (2004) [Geokhimiya, No. 11, 1186 (2004)].
3. B. A. Litvinovskii, V. V. Yarmolyuk, A. A. Vorontsov, et al., Geol. Geofiz. **42**, 445 (2001).
4. V. V. Yarmolyuk, B. A. Litvinovskii, V. I. Kovalenko, et al., Petrology **9**, 302 (2001) (Petrologiya **9**, 351 (2001)].
5. V. V. Yarmolyuk, A. A. Vorontsov, V. G. Ivanov, et al., Dokl. Earth Sci. **373**, 871 (2000) [Dokl. Akad. Nauk **373**, 78 (2000)].

6. V. V. Yarmolyuk and V. G. Ivanov, Geotectonics **34**, 121 (2002) [Geotektonika **34** (2), 43 (2002)].
7. V. V. Yarmolyuk, A. A. Vorontsov, V. G. Ivanov, and V. G. Nikiforov, Petrology **10**, 448 (2002) (Petrologiya **10**, 510 (2002)].
8. I. V. Gordienko, V. S. Klimuk, V. G. Ivanov, and V. F. Posokhov, Dokl. Earth Sci. **353**, 253 (1997) [Dokl. Akad. Nauk **352**, 799 (1997)].
9. V. G. Ivanov, V. V. Yarmolyuk, and V. N. Smirnov, Dokl. Akad. Nauk **345**, 648 (1995).
10. *The State Geological Map of the USSR. New Series. Scale 1 : 1 000 000* (Mingeo SSSR, Moscow, 1973) [in Russian].
11. *The State Geological Map of the Buryat ASSR. Scale 1 : 500 000* (BF SO AN SSSR, Ulan-Ude, 1977) [in Russian].
12. B. A. Litvinovskii, V. F. Posokhov, M. G. Shadaev, and V. L. Shalagin, Dokl. Akad. Nauk SSSR **308**, 946 (1989).
13. G. Faure, *Principles of Isotope Geology* (Wiley, New York, 1976; Mir, Moscow, 1989).
14. A. A. Vorontsov, V. V. Yarmolyuk, V. G. Ivanov, and V. N. Smirnov, Geol. Geofizika **38**, 1305 (1997).
15. E. V. Sklyarov, A. M. Mazukabzov, and A. I. Mel'nikov, *Complexes of Metamorphic Cores of the Cordillera Type* (SO RAN, Novosibirsk, 1997) [in Russian].