ISSN 1819-7140, Russian Journal of Pacific Geology, 2020, Vol. 14, No. 5, pp. 415–420. © Pleiades Publishing, Ltd., 2020.
Russian Text © The Author(s), 2020, published in Tikhookeanskaya Geologiya, 2020, Vol. 39, No. 5, pp. 34–40.

The Middle Paleocene–Early Eocene (60.5–53.0 Ma) Magmatic Stage in the Southern Russian Far East

A. V. Grebennikov[a, *], **S. A. Kasatkin**[a], **D. G. Fedoseev**[a], **and A. I. Khanchuk**[a, b]

[a] *Far East Geological Institute, Far East Branch, Russian Academy of Sciences,*
pr. 100-letiya Vladivostoka 159, Vladivostok, 690022 Russia
[b] *Institute of Geology of Ore Deposits, Petrography, Mineralogy and Geochemistry (IGEM), Russian Academy of Sciences,*
Staromonetny per. 35, Moscow, 109017 Russia
**e-mail: greandr@hotmail.com*

Received March 12, 2020; revised May 15, 2020; accepted May 19, 2020

Abstract—The Sikhote-Alin orogenic belt is a key area for understanding the evolution of the lithospheric plate interaction in the East Asian paleocontinent margin. At the same time, only limited and fragmentary precision isotope–geochemical and geochronological data are available for this region. New age data on the Early Paleogene magmatism supplement the available material and substantiate a specific Middle Paleocene–Early Eocene magmatic stage (60.5–53.0 Ma) dominated by A-type acid rocks in the southern Russian Far East during the geodynamic reconstruction of the continental margin.

Keywords: Paleocene–Early Eocene, A-type rocks, Sikhote-Alin orogenic belt, Russian Far East

DOI: 10.1134/S1819714020050024

INTRODUCTION

The southern Russian Far East contains abundant Cretaceous–Paleogene magmatic rocks, which are subdivided into numerous complexes on the basis of geological data [9]. The poor precision of their geochronological dating complicates age correlation and, respectively, leads to controversial conclusions concerning the peculiarities of magmatic activity and evolution of the convergent plate boundary in the Late Cretaceous–Paleogene.

According to the plate tectonics concept, two alternative models exist on the Cretaceous–Paleogene geodynamic evolution of Sikhote-Alin. The first model unites the Cretaceous and Early Paleogene stages and suggests uninterrupted NW subduction of the Pacific Plate beneath the Asian paleocontinent (e.g., [7, 26, and references therein]). According to the second model, the continental margin at the beginning of Paleogene was involved in extension, with formation of volcanotectonic structures orthogonal to its strike; oceanic subduction gave way to a transform margin setting [19–21, 25].

It has been demonstrated in some works that the Early Paleogene magmatic complex of Sikhote-Alin (the Bogopol volcanic and Yakut a plutonic complexes) consists of rocks of a peculiar mineralogical–geochemical composition, which sharply differ from those of the previous and subsequent magmatic stages. This complex is characterized by a highly differentiated composition of volatile-rich primary magmas and ascribed to A-type magmatism (e.g., [4, 5, 14, 24, 25]). However, a limited number of precision geochronological data prevented their assignment to definite magmatic stages during global geodynamic reconstruction of the Pacific margin of the Asian continent.

New U–Pb zircon age data obtained by LA–ICP–MS dating on rocks from the key objects of Sikhote-Alin make it possible to substantiate the age range of the Early Paleogene magmatic stage in the southern Russian Far East.

FACTUAL MATERIAL

Based on geological maps on a scale of 1 : 1000000 [2, 9, 16], the Paleocene–Early Eocene volcanoplutonic complexes are widespread over the entire territory of Sikhote-Alin and Amur region. They are extended for 1500 km along the coast of the Sea of Japan and the termination of the Tan Lu fault (Fig. 1a). With allowance for previously published data [1, 5, 11–13, 17, 18, 24, 26, 28, 29, 32], the Paleocene–Early Eocene magmatic complexes comprise complexes of similar composition that are indexed in geological maps and explanatory notes at Late Cretaceous to Early Paleogene. The westernmost occurrence of these rocks is noted in NW China [27, 31].

In the southern Sikhote-Alin, the rocks of these complexes fill volcanotectonic structures (VTSs) and central-type calderas of sublatitudinal and northwestern strike both among the volcanic fields of the East-

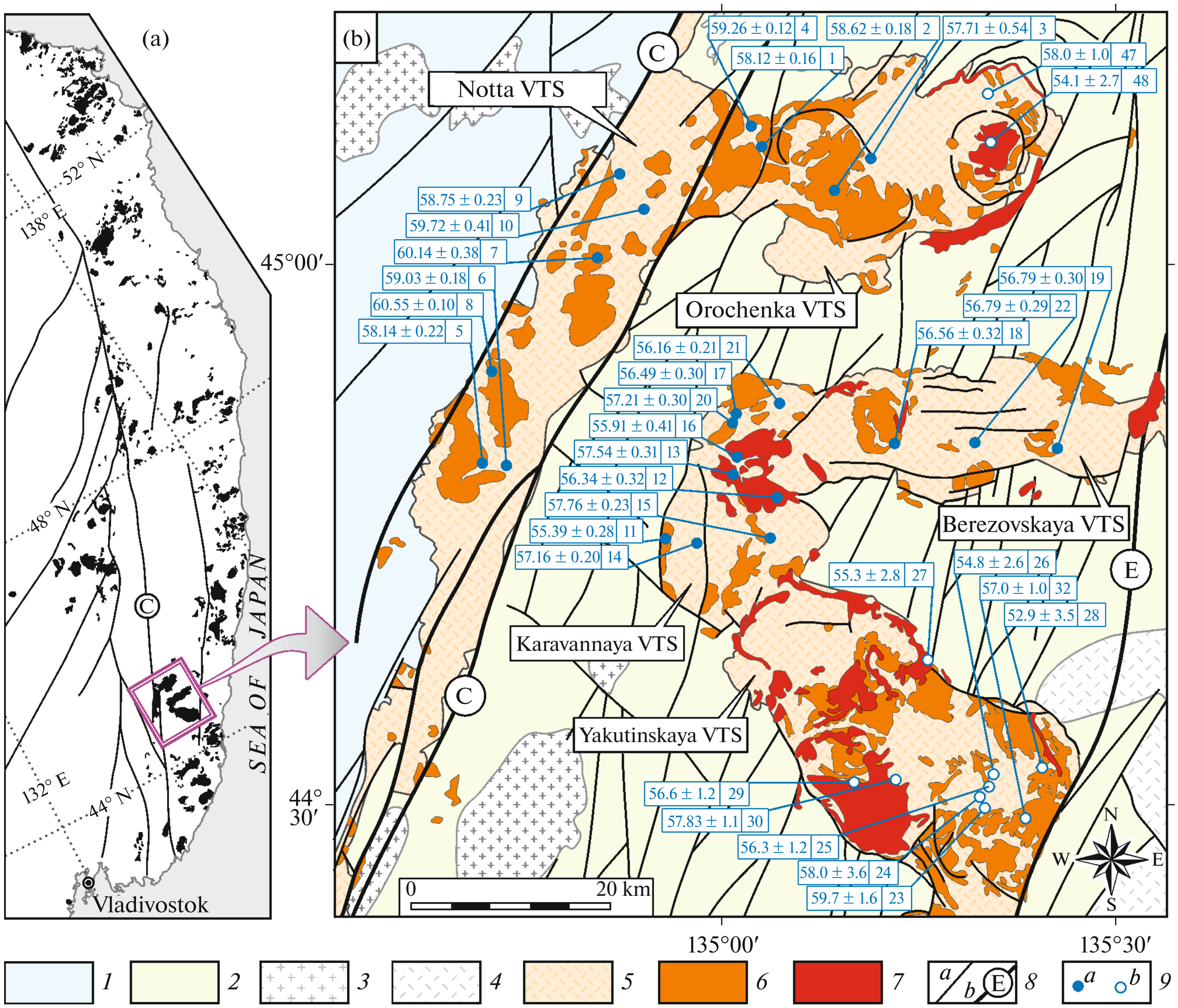

Fig. 1. Paleocene–Early Eocene magmatic rocks of the southern Russian Far East and northeastern China. Compiled by A.I. Khanchuk on the basis of maps on a scale 1 : 1 000 000 [2, 9, 16] (a); the scheme of the development of Cretaceous and Paleocene magmatic complexes in southern Sikhote-Alin according to [8] (b). (*1–2*) Terrigenous sediments: Samarka terrane of the Middle–Late Jurassic accretionary wedge (*1*) and Zhuravlevka–Amur Early Cretaceous turbidite basin (*2*); (*3*) Late Cretaceous granitoids; (*4*) Late Cretaceous volcanogenic rocks; (*5–7*) Paleocene–Early Eocene magmatic complexes: volcanic (*5*); extrusive (*6*); intrusive (subvolcanic) (*7*); (*8*) main faults (a) and major strike-slips (b): (C) Central Sikhote-Alin, (E) Eastern; (*9*) geochronological dates: original (a) and literature (b) data according to the ordinal number in Table 2.

ern Sikhote-Alin volcanoplutonic belt (ESAVB) and beyond it (e.g., [10, 21]). The sizes of separate VTSs, with allowance for an erosion level to the subsurface magma chambers, reaches 40 × 20 km (e.g., Yakutinskaya, [24]), while the total volume of volcanic products is an order of magnitude higher than that of the Yellowstone caldera (northwestern USA). The rhyodacite–rhyolite complex consists of volcanic, extrusive, and vein rocks of felsic and moderately felsic composition. The granitoids of the leucogranite complex are genetically related to the volcanic rocks and are characterized by gradual transitions to the latter. In separate cases, they fill conduits or arc and radial faults that formed through tectonomagmatic subsidence of a VTS and are a residual melt that was crystallized under subsurface conditions [10].

With allowance for large scales, geological–structural factors, and the wide range of rock varieties, the Notta, Orochen, Berezovskaya, and Karavavannaya VTSs from the southern Sikhote-Alin were chosen as the top-priority subjects (Fig. 1b). They are located between two of the largest fault structures of Sikhote-Alin: the Central and Eastern faults. The main structural feature of these VTSs is their sharp discordance with folding in the sedimentary basement. They contain abundant pyroclastic rocks (from lithic to welded

Table 1. The LA–ICP–MS U–Pb zircon isotope data on the Paleocene magmatic rocks of the Notta, Orochenka, Berezovskaya, and Karavannaya VTS.

Ordinal no.	Sample no.	Number of points	U/Th (± σ)	MSWD (concordance)	Probability (concordance)	Age, Ma (±2σ)	VTS
1	AB-98/2	24	0.86 ± 0.23	0.15	0.70	58.12 ± 0.16	Orochenka
2	AB-98/8	25	1.31 ± 0.25	1.80	0.18	58.62 ± 0.18	
3	AB-100/1	14	0.96 ± 0.41	5.40	0.02	57.71 ± 0.54	
4	AB-98	25	1.18 ± 0.18	1.04	0.002	59.26 ± 0.12	
5	AB-107	25	1.30 ± 0.27	0.61	0.44	58.14 ± 0.22	Notta
6	AB-107/2	20	1.24 ± 0.25	0.21	0.65	59.03 ± 0.18	
7	AB-106/2	21	1.32 ± 0.24	0.34	0.56	60.14 ± 0.38	
8	AB-107/3	28	1.17 ± 0.17	0.88	0.35	60.55 ± 0.10	
9	AB-99	21	1.07 ± 0.25	1.16	0.28	58.75 ± 0.23	
10	AB-99/3	21	1.23 ± 0.22	0.19	0.66	59.72 ± 0.41	
11	AB-106	19	0.95 ± 0.21	0.76	0.75	55.39 ± 0.28	Karavannaya
12	AB-103	24	1.09 ± 0.46	0.43	0.51	56.34 ± 0.32	
13	AB-103/6	23	1.54 ± 0.32	0.65	0.42	57.54 ± 0.31	
14	AB-106/1	22	1.49 ± 0.55	1.70	0.19	57.16 ± 0.20	
15	AB-103/8	24	1.76 ± 0.25	0.25	0.62	57.76 ± 0.23	
16	AB-103/4	22	1.12 ± 0.45	0.07	0.79	55.91 ± 0.41	Berezovskaya
17	AB-102/3	22	1.73 ± 0.44	0.04	0.85	56.49 ± 0.30	
18	AB-105/1	23	2.00 ± 0.53	0.45	0.50	56.56 ± 0.32	
19	AB-104/4	24	1.86 ± 0.36	0.16	0.69	56.79 ± 0.30	
20	AB-102/2	21	1.46 ± 0.27	0.67	0.41	57.21 ± 0.30	
21	AB-102/4	30	1.64 ± 0.37	0.98	0.32	56.16 ± 0.21	
22	AB-104/2	28	1.71 ± 0.45	0.29	0.59	56.79 ± 0.29	

tuffs, ignimbrites, and perlites), as well as fluidal and spherulitic extrusive rhyolites, which indicate the highly explosive character of the extrusions. Dikes and substratal bodies of monzodiorite, syenite, granosyenite porphyry, and granite porphyry are subintrusive bodies that formed at a depth from a few km to direct transitions into extrusive rocks.

METHODS

In order to unravel the spatiotemporal tendencies of Early Paleogene complexes within these objects we carried out U–Pb isotope dating of zircons from representative samples of all facies varieties of VTS at the National Research Center for Geoanalysis (Beijing, China) using a Thermo Fisher Element XR ICP-MS analyzer equipped with a UP^{213}Nd: YAG (10 Hz) laser 30-μm in width. The study was carried out using the standard methods. The pattern of oscillatory zoning together with the U/Th ratios suggests a magmatic genesis of the zircons. The obtained concordant U–Pb age values at the 2 σ level calculated for zircons of each generation are given in Table 1.

DISCUSSION

According to these results, the age of the magmatic rocks of the Notta, Orochenka, Berezovskaya, and Karavannaya VTS corresponds to 60.6–55.4 Ma: Zelandian–Thanetian (Middle–Late Paleocene). New and previous (Table 2) age determinations in combination with geological and geochemical data allowed us to distinguish a peculiar Paleocene–Early Eocene magmatic stage in the southern Sikhote-Alin.

The Middle Paleocene–Early Eocene stage was predated by orogenic events at the continent–ocean boundary. The Cretaceous–Paleocene boundary was marked by the closure of the Campanian–Maastrichtian fore-arc turbidite basin in Western Sakhalin and Hokkaido. Paleocene continental coarse–clastic sediments with coal seams of the Hokkaido–Sakhalin Basin only partially inherited the Late Cretaceous subsidence area [3, 30]. It is suggested that the Late Cretaceous subduction complex of the active margin of Eastern Sikhote-Alin, which was also described in Southern Sakhalin, was deformed into an en-echelon system of flexure-like folds with initial Paleocene exhumation of high-grade complexes [6], which is also typical of the Kamuikotan belt at Hokkaido [30]. An

Table 2. The middle Paleocene–Early Eocene magmatic rocks of Sikhote-Alin and NE China

Ordinal no.	Rocks	Method	Coordinates	Age, Ma	Citations
1	Extrusive, rhyolite	LA-ICP-MS	N45°06′44″ E135°02′54″	58.12 ± 0.16	Orochenka VTS [this study]
2	Extrusive, rhyolite		N45°04′47″ E135°08′23″	58.62 ± 0.18	
3	Tuff, rhyolite		N45°06′15″ E135°11′51″	57.71 ± 0.54	
4	Tuff, rhyolite		N45°07′39″ E135°02′13″	59.26 ± 0.12	
5	Extrusive, rhyolite	LA-ICP-MS	N44°49′11″ E134°41′53″	58.14 ± 0.22	Notta VTS [this study]
6	Tuff, rhyolite		N44°49′01″ E134°43′25″	59.03 ± 0.18	
7	Extrusive, rhyolite		N45°00′36″ E135°50′22″	60.14 ± 0.38	
8	Extrusive, rhyolite		N44°54′20″ E134°42′37″	60.55 ± 0.10	
9	Ignimbrite, rhyolite		N45°05′05″ E134°52′12″	58.75 ± 0.23	
10	Ignimbrite, rhyolite		N45°03′08″ E134°54′14″	59.72 ± 0.41	
11	Extrusive, rhyolite	LA-ICP-MS	N44°45′12″ E134°55′45″	55.39 ± 0.28	Karavannaya VTS [this study]
12	Intrusive, monzodiorite		N44°47′21″ E135°04′02″	56.34 ± 0.32	
13	Intrusive, granite		N44°48′33″ E135°01′10″	57.54 ± 0.31	
14	Tuff, rhyolite		N44°44′51″ E134°57′46″	57.16 ± 0.20	
15	Tuff, rhyodacite		N44°45′07″ E135°03′52″	57.76 ± 0.23	
16	Intrusive, syenite	LA-ICP-MS	N44°49′36″ E135°01′09″	55.91 ± 0.41	Berezovskaya VTS [this study]
17	Dike, granite		N44°51′55″ E135°01′22″	56.49 ± 0.30	
18	Extrusive, rhyolite		N44°50′16″ E135°13′17″	56.56 ± 0.32	
19	Extrusive, rhyolite		N44°49′52″ E135°25′37″	56.79 ± 0.30	
20	Extrusive, rhyolite		N44°51′46″ E135°01′16″	57.21 ± 0.30	
21	Tuff, rhyolite		N44°52′35″ E135°04′37″	56.16 ± 0.21	
22	Tuff, rhyolite		N44°50′19″ E135°19′08″	56.79 ± 0.29	
23	Ignimbrite, rhyolite	Rb-Sr	N44°30′39″ E135°21′31″	59.7 ± 1.6	[24]
24	Ignimbrite, rhyolite		N44°30′55″ E135°21′28″	58.0 ± 3.6	
25	Ignimbrite, rhyolite		N44°31′16″ E135°21′08″	56.3 ± 1.2	
26	Ignimbrite, rhyolite		N44°31′40″ E135°21′26″	54.8 ± 2.6	
27	Intrusive, granite		N44°38′24″ E135°16′07″	55.3 ± 2.8	
28	Extrusive, perlite		N44°32′06″ E135°24′23″	52.9 ± 3.5	
29	Extrusive, dacite	U-Pb SHRIMP	N44°31′22″ E135°09′56″	56.6 ± 1.2	[1]
30	Intrusive, granite		N44°31′37″ E135°13′27″	57.8 ± 1.1	
31	Tuff, rhyolite	U-Pb SHRIMP	N43°21′51″ E134°34′18″	53.5 ± 0.5	[17]
32	Tuff, rhyolite		N43°21′51″ E134°34′18″	52.3 ± 0.4	
33	Intrusive, monzodiorite	LA-ICP-MS	N44°30′04″ E136°10′13″	56.3 ± 0.7	[26]
34	Intrusive, granite		N44°29′17″ E136°07′29″	57.1 ± 0.4	
35	Intrusive, granite		N49°20′33″ E137°37′26″	57.8 ± 1.1	
36	Intrusive, granodiorite	LA-ICP-MS	N50°34′52″ E139°46′07″	58.7 ± 0.4	[12]
37	Intrusive, granite		N50°35′53″ E139°47′59″	57.2 ± 0.9	
38	Intrusive, syenite		N50°05′54″ E139°48′36″	59.8 ± 0.6	
39	Tuff, rhyolite	LA-ICP-MS	N44°16′29″ E134°46′38″	60.0 ± 0.9	
40	Tuff, rhyolite		N43°49′19″ E135°16′29″	55.0 ± 1.3	[29]
41	Intrusive, granite		N43°44′09″ E135°15′56″	55.7 ± 0.7	
42	Extrusive, perlite	LA-ICP-MS	N44°14′58″ E135°27′04″	55.7 ± 0.7	[11]*
43	Tuff, rhyolite		N44°15′24″ E135°26′25″	57.5 ± 1.5	
44	Extrusive, rhyolite	LA-ICP-MS	N42°41′59″ E130°49′42″	55.5 ± 2.5	[15]
45	Intrusive, granite	LA-ICP-MS	N43°43′44″ E135°14′24″	56.0 ± 1.0	[28]
46	Tuff, rhyolite	LA-ICP-MS	N44°29′39″ E135°23′14″	57.0 ± 1.0	[32]
47	Tuff, rhyolite	LA-ICP-MS	N45°09′32″ E135°20′06″	58.0 ± 1.0	[18]
48	Intrusive, syenite		N45°06′39″ E135°20′33″	54.1 ± 2.7	
49	Tuff, rhyolite	LA-ICP-MS	N44°17′10″ E135°17′59″	54.3 ± 2.9	[5]
50	Intrusive, granodiorite	LA-ICP-MS	N47°14′60″ E132°17′60″	54.0 ± 1.0	[31]
51	Intrusive, diorite		N47°13′59″ E132°13′26″	56.3 ± 0.8	[27]
52	Intrusive, granodiorite		N47°13′44″ E132°15′12″	51.5 ± 0.3	

* The age of the Bogopol Formation in the stratotype section (Pad’ Kolobenkova R., Zerkal’nenskaya Basin).

erosion surface and a gap in sediments from the uppermost Maastrikhtian to upper Paleozoic were established in the western and central part of Hokkaido. Later (Upper Paleocene) marine and epicontinental sediments were only accumulated in separate basins [23]. These data indicates the onset of transtension along coastal line and are consistent with time interval of the Middle—Late Paleocene magmatic stage, which is widespread in Sikhote-Alin.

It should be noted that volcanogenic rocks of this magmatic stage are located in the pull-apart basins in southern Sikhote-Alin and show a well-expressed structural unconformity with Late Cretaceous magmatic complexes (e.g., [10]), whose youngest age according to U—Pb (SHRIMP) dating of diorites is 60.5 ± 0.7 Ma [1]. Their mineralogical—geochemical characteristics sharply differ from those of the Middle Paleocene—Early Eocene A-type magmatic rocks and correspond to rocks that formed in an oxidizing setting with the influence of aqueous fluids, which are typical of suprasubduction magmatism [4, 21, 26, and others].

The upper age boundary of the Paleocene—Early Eocene stage is determined by a characteristic gap in magmatism and accumulation of Early Eocene carbonaceous sediments, which with erosion rest on the Paleocene volcanic rocks and are overlain by the basalts of the Suvorovskaya (in the south) and Kuznetsovskaya (in the north) formations [9, 15]. The age of the lower carbonaceous sequences of these basins is dated back to the terminal Paleocene or Early Eocene based on spore—pollen data. The volcanic rocks of the Suvorovskaya Formation define a K—Ar age of 45.7—45.1 Ma, which corresponds to the Middle Eocene [11]. In the best-studied type sections of the volcanic rocks of the Kuznetsov Complex, andesites are dated within 49.5—47.5 Ma [22].

CONCLUSIONS

These new age data on the Early Paleogene rocks allowed us to supplement the existing material on the magmatism of the southern Far East during geodynamic reconstruction of the Sikhote-Alin orogenic belt at the Cretaceous—Paleogene boundary and to distinguish a peculiar Middle Paleocene—Early Eocene magmatic stage dated within 60.5—53.0 Ma.

ACKNOWLEDGMENTS

We are grateful to A.A. Sorokin (Institute of Geology and Nature Management, Far East Branch, Russian Academy of Science, Blagoveshchensk) for critical comments, which significantly improved our manuscript.

FUNDING

This study was supported by the Russian Foundation for Basic Research (project no. 19-05-00100)

REFERENCES

1. A. A. Alenicheva and V. G. Sakhno, “The U—Pb dating of extrusive—intrusive complexes in ore districts in the southern part of the eastern Sikhote-Alin Volcanic Belt (Russia),” Dokl. Earth Sci. **419** (2), 217—221 (2008).
2. *State Geological Map of the Russian Federation. 1 : 1000000 (Third Generation). Far East Series. Sheet M-53. Explanatory Note*, Ed. By A. F. Vas’kin (VSEGEI, St. Petersburg, 2009) [in Russian].
3. Yu. B. Gladenkov, O. K. Bazhenova, V. I. Grechin, L. S. Margulis, and B. A. Sal’nikov, Cenozoic of Sakjalin and its Petroleum Potential (GEOS, Moscow, 2002) [in Russian].
4. A. V. Grebennikov and V. K. Popov, " Petrogeochemical apects of the Late Cretaceous and Paleogene ignimbrite volcanism of East Sikhote-Alin," Russ. J. Pac. Geol. **8** (1), 38—55 (2014).
5. A. V. Grebennikov and S. O. Maksimov, “Manifestation of A-type volcanic rocks on active continental margins: evidence from southern Sikhote-Alin (Russian Far East),” Russ. Geol. Geophys. (in press).
6. A. E. Zharov, “Accretionary tectonics and geodynamics of Southern Sakhalin,” Geotectonics, **38** (4), 277—293 (2004).
7. L. P. Zonenshain, M. I. Kuz’min, and L. P. Natapov, *Tectonics of Lithospheric Plates of the USSR Territory* (Nedra, Moscow, 1990) [in Russian].
8. S. V. Kovalenko, *State Geological Map of the Russian Federation. 1 : 1000000 (Third Generation). Far East Series* (VSEGEI, St. Petersburg, 2007) [in Russian].
9. *Geological Map of the Russian Federation. 1 : 1000000 (Third Generation). Sheet (L-(52), 53; (K-52, 53). Lake Khanka: Explanatory Notes* Ed. By S. V. Kovalenko (VSEGEI, St. Petersburg, 2011) [in Russian].
10. V. A. Mikhailov, *Magmatism of Volcanotectonic Structures of the Southern Eastern Sikhote-Alin Volcanic Belt* (Vladivostok, 1989) [in Russian].
11. B. I. Pavlyutkin, I. Yu. Chekryzhov, and T. I. Petrenko, “Problems of Paleogene—Neogene stratigraphy of the Zerkal’naya Depression, East Sikhote-Alin,” Russ. J. Pac. Geol. **10** (4), 283—298 (2016).
12. O. V. Petrov, A. F. Morozov, T. V. Chepkasova, and S. S. Shevchenko, *Geochronological Atlas—Reference Book of Main Lithotectobic Compelxes of Russia*, Ed.by O. V. Petrov, A. F. Morozov, T. V. Chepkasova, and S. S. Shevchenko (VSEGEI, St. Petersburg, 2015). http://geochronatlas.vsegei.ru
13. V. K. Popov and A. V. Grebennikov, “New age data on the volcanic rocks of the Bogopol Formation in Primorye,” Tikhookean Geol. **20** (3), 47—54 (2001).
14. V. K. Popov and A. V. Grebennikov, “Khasan—Amur Area (Paleocene—Miocene): Felsic Volcanism,” in Geodynamics, Magmatism, and Metallogeny of East Russia, Ed. by A. I. Khanchuk (Dal’nauka, Vladivostok, 2006) **vol. 1**, pp. 354—361 [in Russian].
15. V. K. Popov, A. A. Chashchin, Y. Tsutsumi, I. Yu. Chekryzhov, and S. Yu. Budnitskii, “New geochronological data on the Eocene—Oligocene volcanism of the Kraskinskaya rift basin (Southwestern Primorye),” Mezhdunar. Nauch.-Issled. Zhurn **12** (78), 75—78 (2018).

16. G. V. Roganov and O. I. Suprunenko, *State Geological Map of the Russian Federation. 1 : 1000000 (Third Generation). Far East Series. Sheet N-54. Nikolevsk-on-Amur. Explanatory Note,* (VSEGEI. St. Petersburg, 2014) [in Russian].
17. V. G. Sakhno, F. I. Rostovskii, and A. A. Alenicheva, "Pb isotope dating of igneous complexes from the Milogradovo gold–silver deposit (Southern Primor'e)," Dokl. Earth Sci. **433** (1), 879–886 (2010).
18. V. G. Sakhno and S. V. Kovalenko, "Igneous compólexes of the Orochenka caldera of the East Sikhote-Alin Belt: U–Pb (SHRIMP) age, trace and rare earth element composition, and Au–Ag mineralization," Dokl. Earth Sci. **479** (4), 420–424 (2018).
19. A. I. Khanchuk, V. V. Golozubov, Yu. A. Martynov, and V. P. Simanenko, "Early Cretaceous and Paleogene transform margins (Californian type) of the Russian Far East," in *Tecctonics of Asia: Proc. of 30th Tectonic Coference, Moscow, Russia* (GEOS, Moscow, 1997), pp. 240–243 [in Russian].
20. A. I. Khanchuk and V. V. Ivanov, "Mesocenozoic geodynamic settings and gold mineralization of the Russian Far East," Geol. Geofiz.**40** (11), 1635–1645 (1999).
21. *Geodynamics, Magmatism, and Metallogeny of Russian East*, Ed. by A. I. Khanchuk, (Dal'nauka, Vladivostok, **200**) [in Russian].
22. A. A. Chashchin and V. K. Popov, "Cenozoic volcanism in rift basins of the Eastern Sikhote-Alin: results of new geochronological studies," *Proc. 3rd All-Russian Coference with International Participation "Geologocal Processes in Subduction, Collisionl and Transform Settings"* (Dal'nauka, Vladivostok, 2016) [in Russian].
23. H. Ando and T. Tomosugi, "Unconformity between the Upper Maastrichtian and Upper Paleocene in the Hakobuchi Formation, North Hokkaido, Japan: a major time gap within the Yezo Forearc Basin Sediments," Cretaceous Res **26**, 85–95 (2005).
24. A. V. Grebennikov and S. O. Maksimov, "Fayalite rhyolites and a zoned magma chamber of the Paleocene Yakutinskaya volcanic depression in Primorye, Russia," J. Mineral. Petrol. Sci. **101** (2), 69–88 (2006).
25. A. V. Grebennikov, A. I. Khanchuk, V. G. Gonevchuk, and S. V. Kovalenko, "Cretaceous and Paleogene granitoid suites of the Sikhote-Alin Area (Far East Russia): geochemistry and tectonic implications," Lithos **261**, 250–261 (2016).
26. B. M. Jahn, G. Valui, N. Kruk, V. Gonevchuk, M. Usuki, and J. T. J. Wu, "Emplacement ages, geochemical and Sr-Nd-Hf isotopic characterization of Mesozoic to Early Cenozoic granitoids of the Sikhote-Alin Orogenic Belt, Russian Far East: crustal growth and regional tectonic evolution," J. Asian Earth Sci. **111**, 872–918 (2015).
27. P.-C. Li, Z.-H. Liu, S.-C. Li, Q.-Y. Zhao, Q. Shi, C.-H. Li, and X. -H. Yang, "Late Paleocene–Early Eocene granitoids in the Jiamusi Massif, NE China: zircon U-Pb ages, geochemistry, and tectonic implications," Int. Geol. Rev. **61** (4), 1–16 (2018).
28. J. Tang, W. Xu, Y. Niu, F. Wang, W. Ge, A. A. Sorokin, and I. Y. Chekryzhov, "Geochronology and geochemisìtry of Late Cretaceous–Paleocene granitoids in the Sikhote-Alin Orogenic Belt: petrogenesis and implications for the oblique subduction of the Paleo-Pacific Plate," Lithos **266–267**, 202–212 (2016).
29. Y. Tsutsumi, K. Yokoyama, S. A. Kasatkin, and V. V. Golozubov, "Ages of igneous rocks in the southern part of Primorye, Far East Russia," Mem. Nat. Mus. Nat. Sci. **51**, 71–78 (2016).
30. H. Ueda, "Hokkaido", *The Geology of Japan*, Ed. by T. Moreno, S. Wallis, T. Kojima, and W. Gibbons, (Geol. Soc. London, London, 2016), pp. 201—221.
31. Z. H. Wang, H. Yang, W. C. Ge, J. H. Bi, Y. L. Zhang, W. L. Xu, "Discovery and geological significance of the Eocene granodiorites in the Sanjiang Basin, NE China: evidence from zircon U-Pb chronology, geochemistry and Sr-Nd-Hf isotopes," Acta Petrol. Sinica **32** (6), 1823–1838 (2016).
32. P. Zhao, B-M. Jahn, and B. Xu "Elemental and Sr-Nd isotopic geochemistry of Cretaceous to Early Paleogene granites and volcanic rocks in the Sikhote-Alin Orogenic Belt (Russian Far East) and their implication on regional tectonic evolution," J. Asian Earth Sci. **146**, 383–401 (2017).

Recommended for publishing by G.L. Kirillova

Translated by M. Bogina