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

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**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  $40 \times 20$  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

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

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

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<sup>213</sup>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  $\sigma$  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

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$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$	Ordinal no.	Rocks	Method	Coordinates	Age, Ma	Citations
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	1	Extrusive, rhyolite	LA-ICP-MS	N45°06′44″ E135°02′54″	$58.12 \pm 0.16$	Orochenka VTS [this
3       Tuff, rhyolite       N45'06'15" E135'11'1" $57.71 \pm 0.54$ 4       Tuff, rhyolite       N45'06'15" E135'02'13" $59.26 \pm 0.12$ 5       Extrusive, rhyolite       N44'49'11" E134'41'53" $58.14 \pm 0.22$ Notta VTS [this         6       Tuff, rhyolite       N44'49'11" E134'43'25" $59.03 \pm 0.38$ study]         7       Extrusive, rhyolite       N44'49'11" E134'43'25" $50.03 \pm 0.38$ study]         10       Ignimbrite, rhyolite       LA-ICP-MS       N44'49'11" E134'43'25" $53.92 \pm 0.23$ Notta VTS         11       Extrusive, rhyolite       LA-ICP-MS       N44'45'12" E135'04'02" $55.39 \pm 0.23$ Karavannaya VTS         12       Intrusive, granite       N44'45'07" E135'01'0" $57.54 \pm 0.31$ Karavannaya VTS         13       Intrusive, symite       LA-ICP-MS       N44'45'07" E135'01'0" $57.54 \pm 0.31$ Karavannaya VTS         14       Tuff, rhyolite       LA-ICP-MS       N44'45'07" E135'01'0" $55.54 \pm 0.23$ Karavannaya VTS         15       Tuff, rhyolite       N44'45'07" E135'01'0" $55.94 \pm 0.30$ Karavannaya VTS         16       Intrusive, granite       N44'50'0" E135'01'27" $56.54 \pm 0.21$ Karavannaya VTS <t< td=""><td>2</td><td>Extrusive, rhyolite</td><td></td><td>N45°04'47" E135°08'23"</td><td><math>58.62 \pm 0.18</math></td><td>study]</td></t<>	2	Extrusive, rhyolite		N45°04'47" E135°08'23"	$58.62 \pm 0.18$	study]
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$	3	Tuff, rhyolite		N45°06'15" E135°11'51"	$57.71 \pm 0.54$	• •
5         Extrusive, rhyolite         LA-ICP-MS         N44*49/11"         E134*41'33"         \$8.14 ± 0.23         Nota VTS [this study]           6         Tuff, rhyolite         N44*69/01"         E134*32'25"         \$9.03 ± 0.18         \$study]           7         Extrusive, rhyolite         N44*69/01"         E134*32'12"         \$8.75 ± 0.23         \$study]           9         Ignimbrite, rhyolite         N44*69/01"         E134*54'14"         \$9.72 ± 0.41         \$study]           11         Extrusive, monzodiorite         N44*6172"         E134*54'14"         \$9.72 ± 0.41         \$study]           12         Intrusive, granite         N44*451'21"         E134*54'14"         \$9.72 ± 0.41         \$study]           13         Intrusive, spranite         N44*451'21"         E135*01'0"         \$5.34 ± 0.31         \$this study]           14         Tuff, rhyolite         N44*451'51"         E135*057'46"         \$7.76 ± 0.23         \$this study]           15         Tuff, rhyolite         N44*450'35"         E135*051'10"         \$6.79 ± 0.30         \$this study]           18         Extrusive, rhyolite         N44*30'39"         E135*01'2"         \$6.79 ± 0.20         \$this study]           21         Tuff, rhyolite         N44*30'30"         E135*21'28" </td <td>4</td> <td>Tuff. rhvolite</td> <td></td> <td>N45°07'39″ E135°02'13″</td> <td><math>59.26 \pm 0.12</math></td> <td></td>	4	Tuff. rhvolite		N45°07'39″ E135°02'13″	$59.26 \pm 0.12$	
6         Tuff, rhyolite         N44*34'00"         E134*34'23" $50.33 \pm 0.18$ study           7         Extrusive, rhyolite         N45*00'36"         E135*50'22" $60.14 \pm 0.38$ study           8         Extrusive, rhyolite         N44*05'20"         E134*22'37" $60.55 \pm 0.10$ study           9         Ignimbric, rhyolite         N45*05'05"         E134*22'12" $85.75 \pm 0.23$ study           11         Extrusive, monzodiorite         N44*45'12"         E135*01'0" $57.54 \pm 0.31$ study           12         Intrusive, granite         N44*45'12"         E135*01'0" $57.54 \pm 0.31$ Berzzowkaya VTS           13         Intrusive, syonite         LA-ICP-MS         N44*45'15"         E135*01'10" $57.54 \pm 0.31$ 14         Tuff, rhyolite         N44*45'15"         E135*01'10" $57.54 \pm 0.31$ Berzzowkaya VTS           15         Tuff, rhyolite         N44*5'16"         E135*01'10" $56.79 \pm 0.29$ E135*01'16" $57.21 \pm 0.30$ 16         Intrusive, rhyolite         N44*3'05'19"         E135*01'16" $53.3 \pm 1.2$ Itis study           21         Tuff, rhyolite         N44*30'30"         E135*01'11" <td>5</td> <td>Extrusive, rhyolite</td> <td>LA-ICP-MS</td> <td>N44°49'11″ E134°41'53″</td> <td><math>58.14 \pm 0.22</math></td> <td>Notta VTS [this</td>	5	Extrusive, rhyolite	LA-ICP-MS	N44°49'11″ E134°41'53″	$58.14 \pm 0.22$	Notta VTS [this
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	9	Ignimbrite, rhyolite		N45°05′05″ E134°52′12″	$58.75 \pm 0.23$	
	10	Ignimbrite, rhyolite		N45°03′08″ E134°54′14″	$59.72 \pm 0.41$	
12Intrusive, monzodiorite Intrusive, granite $N4^{42}721''$ E135°04'02'' E135°04'02'' $56.34 \pm 0.32$ $57.54 \pm 0.31$ [this study]13Intrusive, granite Intrusive, symite $N44'45''$ $184''57'46''$ 	11	Extrusive, rhyolite	LA-ICP-MS	N44°45′12″ E134°55′45″	$55.39 \pm 0.28$	Karavannava VTS
13Intrusive, granite $N44^248'3^2$ $25.25^{-10}$ $57.54\pm0.31$ 14Tuff, rhyolacite $N44^244'3'$ $E135^{-0}1'0''$ $57.54\pm0.31$ $57.54\pm0.31$ 15Tuff, rhyolacite $N44^245'1''$ $E135^{-0}1'0''$ $57.54\pm0.31$ $57.54\pm0.31$ 16Intrusive, syenite $LA-ICP-MS$ $N44^245'1''$ $E135^{-0}1'0''$ $55.9\pm0.32$ 17Dike, granite $N44^25'1'' E135''13'''$ $56.39\pm0.30$ [this study]18Extrusive, rhyolite $N44^25'1'E'$ $E135^{-0}1'0''$ $56.39\pm0.30$ 20Extrusive, rhyolite $N44^25'1'E'$ $E135^{-0}1'16''$ $57.2\pm0.30$ 21Tuff, rhyolite $N44^25'1'E'$ $E135^{-0}1'16''$ $57.2\pm0.30$ 22Tuff, rhyolite $N44^23'3''E''' E135''21'2''''56.79\pm0.2923Ignimbrite, rhyoliteN44^23'14'''E135''21'20''''''''''''''''''''''''''''''''$	12	Intrusive monzodiorite	2.1101 110	N44°47′21″ E135°04′02″	$56.34 \pm 0.32$	[this study]
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15       Tur, fryodacite       N44*4507"       E135*03*52"       57.76 $\pm$ 0.23         16       Intrusive, syenite       LA-ICP-MS       N44*4936"       E135*03*52"       57.76 $\pm$ 0.23         17       Dike, granite       N44*936"       E135*0121"       56.49 $\pm$ 0.30       Berezovskaya VTS         18       Extrusive, rhyolite       N44*9512"       E135*0171"       56.76 $\pm$ 0.32       [this study]         19       Extrusive, rhyolite       N44*9512"       E135*0171"       56.76 $\pm$ 0.30       [this study]         21       Tuff, rhyolite       N44*9514"       E135*0171"       56.76 $\pm$ 0.21       [this study]         22       Tuff, rhyolite       N44*3014"       E135*0171"       56.79 $\pm$ 0.30         23       Ignimbrite, rhyolite       N44*30155"       E135*21728"       58.0 $\pm$ 3.6         24       Ignimbrite, rhyolite       N44*30455"       E135*2160"       55.7 $\pm$ 1.6       [24]         24       Ignimbrite, rhyolite       N44*3140"       E135*21607"       55.3 $\pm$ 2.8       2.6         27       Intrusive, granite       N44*3124"       E135*0560"       56.6 $\pm$ 1.2       [11]         30       Intrusive, granite       SHRIMP       N44*31271"       E135*313*10"       51.75       57.8	13	Tuff rhyolite		N44°44′51″ F134°57′46″	$57.0 \pm 0.01$ $57.16 \pm 0.20$	
16       Intrusive, synite       LA-ICP-MS       N44*393" E135°01'02"       55.91 ± 0.41       Berezovskaya VTS         17       Dike, granite       N44*91'55" E135°01'22"       56.49 ± 0.30       [this study]         18       Extrusive, rhyolite       N44*91'55" E135°01'27"       56.79 ± 0.30       [this study]         19       Extrusive, rhyolite       N44*91'46" E135°01'16"       57.21 ± 0.30       [this study]         20       Extrusive, rhyolite       N44*91'46" E135°01'16"       56.79 ± 0.30       [this study]         21       Tuff, rhyolite       N44*91'46" E135°10'16"       56.79 ± 0.29       [24]         23       Ignimbrite, rhyolite       N44*30'57" E135°21'26"       56.3 ± 1.2       [24]         26       Ignimbrite, rhyolite       N44*31'40" E135*21'26"       56.4 ± 1.2       [24]         26       Ignimbrite, rhyolite       N44*31'40" E135*21'26"       54.8 ± 2.6       [17]         27       Intrusive, granite       N44*31'37" E135°09'56"       56.6 ± 1.2       [1]         30       Intrusive, granite       SHRIMP       N44*31'37" E135°1'127"       53.5 ± 0.5       [17]         31       Tuff, rhyolite       U-Pb       N44*30'14" E136*01'13"       53.5 ± 0.5       [17]         32       Tuff, rhyolite	15	Tuff rhyodacite		N44°45′07″ F135°03′52″	$57.10 \pm 0.20$ $57.76 \pm 0.23$	
17       Dike, granite       N44*51'55"       E135*01'22"       56.49 ± 0.30       [this study]         18       Extrusive, rhyolite       N44*51'55"       E135*01'22"       56.56 ± 0.32         19       Extrusive, rhyolite       N44*51'46"       E135*01'16"       56.56 ± 0.32         20       Extrusive, rhyolite       N44*951'46"       E135*01'16"       57.21 ± 0.30         21       Tuff, rhyolite       N44*50'16"       E135*01'37"       56.16 ± 0.21         22       Tuff, rhyolite       Rb-Sr       N44*30'39"       E135*21'28"       58.0 ± 3.6         23       Ignimbrite, rhyolite       N44*31'16"       E135*21'28"       58.0 ± 3.6       124         24       Ignimbrite, rhyolite       N44*31'31'6"       E135*21'28"       58.0 ± 3.6       124         26       Ignimbrite, rhyolite       N44*31'37"       E135*24'23"       58.0 ± 3.6       124         27       Intrusive, granite       N44*31'37"       E135*24'23"       55.2 ± 3.5       135         28       Extrusive, cacite       U-Pb       N43*21'51"       E13*3'418"       53.3 ± 0.5       117         30       Intrusive, granite       LA-ICP-MS       N44*3'3'37"       E136*07'37"       57.1 ± 0.4         31 <th< td=""><td>16</td><td>Intrusive svenite</td><td>LA-ICP-MS</td><td>N44°49′36″ E135°01′09″</td><td><math>57.70 \pm 0.23</math> <math>55.91 \pm 0.41</math></td><td>Berezovskava VTS</td></th<>	16	Intrusive svenite	LA-ICP-MS	N44°49′36″ E135°01′09″	$57.70 \pm 0.23$ $55.91 \pm 0.41$	Berezovskava VTS
18Extrusive, rhyolite Extrusive, rhyolite Extrusive, rhyolite Inff, rhyolite $N44^{+50}'16''$ E135°11'' $56.56 \pm 0.32$ $5.79 \pm 0.30$ $57.2 \pm 0.30$ 20Extrusive, rhyolite Tuff, rhyolite Ignimbrite, rhyolite Ignimbrite, rhyolite Ignimbrite, rhyolite Ignimbrite, rhyolite Ignimbrite, rhyolite 	17	Dike granite	Lat let wib	N44°51′55″ F135°01′22″	$56.49 \pm 0.30$	[this study]
19Extrusive, inyolite Extrusive, inyolite 17ff, rhyolite $N44^{29}52'' E135^{21}3'''$ $56.3^{2} \pm 0.30$ $57.21 \pm 0.30$ 20Extrusive, inyolite Tuff, rhyolite 12 $N44^{25}2'35''' E135^{20}4'37''$ $56.16 \pm 0.21$ $56.79 \pm 0.29$ 23Ignimbrite, rhyolite Ignimbrite, rhyolite Strustive, granite SHRIMP $N44^{23}0'39'' E135^{21}28''N44^{23}2'06''' 55.3 \pm 2.8$ N44^{23}2'16''' E135^{20}24'23'' S5.3 \pm 2.8[24]29Extrusive, granite SHRIMP Intrusive, granite Intrusive, granite Intrusive, granite Intrusive, granite Intrusive, granite Intrusive, graniteU-Pb N44^{23}1'37'' E135^{21}3'27'' S5.3 \pm 0.5 S5.3 \pm 0.4[17]31Tuff, rhyolite Intrusive, granite Intrusive, granite Intrusive, graniteLA-ICP-MS N44^{23}0'04'' E136^{21}0'13''' N44^{22}1'1'' E134^{23}4'18'' S5.3 \pm 0.4[17]34Intrusive, granite Intrusive, granite Intrusive, granite Intrusive, graniteLA-ICP-MS N44^{23}0'04'' E136^{20}0'7'' N50^{23}5'3'' E139^{24}5''' S5.3 \pm 1.1[17]35Intrusive, granite Intrusive, granite Intrusive, graniteLA-ICP-MS N44^{20}1'2'' E134^{20}4'18'' S5.5 \pm 1.5[26]44Extrusive, rhyolite Intrusive, granite Intrusive, graniteLA-ICP-MS N44^{21}5'2'' E139^{24}6'3''' S5.5 \pm 1.5[27]44Extrusive, prelite Intrusive, granite Intrusiv	18	Extrusive rhyolite		N44°50′16″ F135°13′17″	$56.19 \pm 0.30$ 56.56 ± 0.32	
10Extrusive, infyolite $144^{\circ}51'46'' E135'01'16''$ $57.2\pm 0.30$ 21Tuff, rhyolite $N44^{\circ}51'46'' E135'01'16''$ $57.2\pm 0.30$ 22Tuff, rhyolite $N44^{\circ}51'46'' E135'01'16''$ $56.16\pm 0.21$ 23Ignimbrite, rhyolite $N44^{\circ}30'55'' E135'21'28''$ $56.0\pm 0.29$ 24Ignimbrite, rhyolite $N44^{\circ}30'55'' E135'21'28''$ $58.0\pm 3.6$ 25Ignimbrite, rhyolite $N44^{\circ}31'46'' E135'01'08'''$ $56.3\pm 1.2$ 26Ignimbrite, rhyolite $N44^{\circ}31'20'' E135'21'28'''$ $56.3\pm 1.2$ 27Intrusive, granite $N44^{\circ}31'20'' E135'21'28'''$ $56.6\pm 1.2$ 28Extrusive, daciteU-Pb $N44^{\circ}31'27'' E135'01'27'''''' 57.8\pm 1.1$ $51.5\pm 0.5$ 29Extrusive, graniteU-Pb $N44^{\circ}31'27'' E135'01'27''''''''''''''''''''''''''''''''''$	10	Extrusive, rhyolite		N44°49'52" F135°25'37"	$56.30 \pm 0.32$ 56.79 ± 0.30	
1111111111111121Tuff, rhyoliteRb-Sr $N44^232'35''$ E135'04'37''56.790.2923Ignimbrite, rhyoliteRb-Sr $N44^230'35''$ E135'21'28''58.03.616.02124Ignimbrite, rhyolite $N44^430'55''$ E135'21'28''58.03.616.02125Ignimbrite, rhyolite $N44^430'55''$ E135'21'28''58.03.616.02126Ignimbrite, rhyolite $N44^430'55''$ E135'21'08''56.31.25.32.827Intrusive, granite $N44'31'40''$ E135'21'28''53.22.93.528Extrusive, perlite $N44'31'40''$ E135'24'23''52.9 $3.5$ 5.31.130Intrusive, graniteSHRIMP $N44'31'37''$ E135'04'37''53.35.0.5[17]31Tuff, rhyoliteU-Pb $N44'30'37''$ E136'01'31''53.35.0.5[17]32Tuff, rhyoliteLA-ICP-MS $N44'30'04''$ E136'01'31''56.35.71.733Intrusive, granite $N44'20'17''$ E136'01'37''57.81.1134Intrusive, granite $N40'20'37'''$ E136'01'37'''57.81.1135Intrusive, granite $N50'35'5''''''''''''''''''''''''''''''''$	20	Extrusive, myolite		N44°51′46″ E135°01′16″	$50.77 \pm 0.30$ 57 21 ± 0.30	
121Tuff, rhyoliteN44*50'19' E135*19'08"56.79 ± 0.2923Ignimbrite, rhyoliteRb-SrN44*30'39" E135*21'31"59.7 ± 1.6[24]24Ignimbrite, rhyoliteN44*30'16" E135*21'08"56.3 ± 1.256.3 ± 1.226Ignimbrite, rhyoliteN44*31'40" E135*21'26"54.8 ± 2.627Intrusive, graniteN44*31'40" E135*21'26"55.4 ± 2.528Extrusive, perliteN44*31'27" E135*01'07"55.3 ± 2.829Extrusive, daciteU-PbN44*31'27" E135*01'27"57.8 ± 1.131Tuff, rhyoliteU-PbN44*31'27" E135*01'27"57.8 ± 1.133Intrusive, graniteSHRIMPN44*31'37" E134*34'18"52.3 ± 0.534Intrusive, graniteLA-ICP-MSN44*20'17" E136*07'29"57.1 ± 0.435Intrusive, graniteLA-ICP-MSN44*20'37" E139*47'59"57.2 ± 0.938Intrusive, graniteN50*35'53" E139*47'59"57.2 ± 0.938Intrusive, graniteN44*0'29'17" E136*07'29"55.7 ± 0.739Tuff, rhyoliteLA-ICP-MSN44*16'29" E134*46'38"60.0 ± 0.940Tuff, rhyoliteLA-ICP-MSN44*16'29" E135*15'56"55.7 ± 0.741Intrusive, graniteN44*24'09" E135*15'56"55.7 ± 0.742Extrusive, rhyoliteLA-ICP-MSN44*24'59" E130*49'42"55.5 ± 1.544Extrusive, rhyoliteLA-ICP-MSN44*24'59" E135*21'24"55.0 ± 1.045Tuff, rhyoliteLA-ICP-MSN44*24'59" E135*21'24"55.0 ± 1.	20	Tuff rhyolite		N44°52'35″ F135°04'37″	$57.21 \pm 0.30$ 56.16 ± 0.21	
23Ignimbrite, rhyolite Ignimbrite, rhyolite 	21	Tuff rhyolite		N44°50′19″ F135°19′08″	$56.70 \pm 0.21$ 56.79 ± 0.29	
24Ignimotic, thyoliteINF 30 PLD 21/28"57.7 ± 1.5 $[24]$ 24Ignimbrite, thyoliteN44*30'55" E135*21'28"56.3 ± 1.226Ignimbrite, thyoliteN44*31'16" E135*21'28"56.3 ± 1.227Intrusive, graniteN44*31'27" E135*21'28"55.3 ± 2.828Extrusive, perliteN44*31'22" E135*02'23"52.9 ± 3.529Extrusive, graniteSHRIMPN44*31'22" E135*02'27"57.8 ± 1.130Intrusive, graniteSHRIMPN44*31'27" E134*34'18"53.5 ± 0.5[17]31Tuff, thyoliteU-PbN44*30'04" E136*01'13"56.3 ± 0.7[26]33Intrusive, graniteSHRIMPN43*21'51" E134*34'18"53.5 ± 0.5[17]34Intrusive, graniteLA-ICP-MSN44*20'17" E136*07'29"57.1 ± 0.435Intrusive, graniteLA-ICP-MSN50*34'52" E139*4'07"58.7 ± 0.4[12]36Intrusive, graniteLA-ICP-MSN50*05'54" E139*4'59"57.2 ± 0.9[29]38Intrusive, graniteLA-ICP-MSN44*16'29" 153*016'29"55.0 ± 1.3[29]41Intrusive, graniteLA-ICP-MSN44*14'58" E135*270'4"55.5 ± 2.5[15]42Extrusive, perliteLA-ICP-MSN44*14'52'4"56.0 ± 1.0[28]44Intrusive, graniteLA-ICP-MSN44*21'52"57.5 ± 0.7[11]*43Tuff, thyoliteLA-ICP-MSN44*21'52"55.5 ± 2.5[15]44Extrusive, graniteLA-ICP-MSN44*21'52"5	22	Ignimbrite rhvolite	Rh-Sr	N44°30'39" E135°1)'08	$50.77 \pm 0.27$ 59 7 + 1 6	[24]
25Ignimbrite, rhyolite Ignimbrite, rhyolite Ignimbrite, rhyolite Ignimbrite, rhyolite Ignimbrite, rhyolite Improved the status of the stat	23	Ignimbrite, myolite	<b>K</b> 0-51	N44' 30' 57' E135' 21' 51' N/40' 30' 55'' E135' 21' 28''	$59.7 \pm 1.0$ 58.0 ± 3.6	[27]
25Ignimbrite, hyolite Ignimbrite, hyolite144*3 110* E135*21'26"54.8 $\pm$ 2.626Ignimbrite, hyolite Intrusive, graniteN44*31'47" E135*21'26"54.8 $\pm$ 2.627Intrusive, granite Intrusive, graniteN44*31'47" E135*21'26"55.3 $\pm$ 2.829Extrusive, dacite U-PbV-PbN44*31'37" E135*01'27"57.8 $\pm$ 1.130Intrusive, granite Intrusive, graniteSHRIMP SHRIMPN44*31'37" E135*01'27"57.8 $\pm$ 1.131Tuff, rhyolite U-PbU-PbN43*21'51" E134*34'18"52.3 $\pm$ 0.433Intrusive, granite Intrusive, graniteLA-ICP-MSN44*0'04" E136*01'29" 	24	Ignimbrite, myolite		N44 50 55 E155 21 28 N/40°31′16″ E135°21′08″	$56.0 \pm 5.0$	
20Intrusive, graniteN44°30'40"E135°16'00"55.3 $\pm$ 2.827Intrusive, graniteN44°33'20"E135°16'00"55.3 $\pm$ 2.828Extrusive, daciteU-PbN44°31'22"E135°09'56"56.6 $\pm$ 1.2[1]30Intrusive, graniteSHRIMPN44°31'22"E135°09'56"56.6 $\pm$ 1.2[1]31Tuff, rhyoliteU-PbN44°31'27"E135°13'27"57.8 $\pm$ 1.1[1]32Tuff, rhyoliteU-PbN43°21'51"E134°34'18"52.3 $\pm$ 0.433Intrusive, graniteSHRIMPN44°30'04"E136°10'13"56.3 $\pm$ 0.7[26]34Intrusive, graniteLA-ICP-MSN44°20'37"E137°37'26"57.8 $\pm$ 1.135Intrusive, graniteN50°35'53"E139°47'59"57.2 $\pm$ 0.938Intrusive, graniteN50°35'54"E139°46'079"57.2 $\pm$ 0.938Intrusive, syeniteN44°16'29"E135°16'29"55.5 $\pm$ 1.3[29]40Tuff, rhyoliteLA-ICP-MSN44°16'29"E135°16'29"55.5 $\pm$ 0.7[11]*41Intrusive, graniteLA-ICP-MSN44°15'24"E135°21'04"55.5 $\pm$ 0.7[11]*43Tuff, rhyoliteLA-ICP-MSN44°15'24"E135°21'04"55.5 $\pm$ 1.5[29]44Extrusive, perliteLA-ICP-MSN42°41'59"E135°21'04"55.7 $\pm$ 0.7[11]*44Extrusive, rapatiteLA-ICP-MSN42°41'59"E135°21'04"55.5 $\pm$ 2.5[15]44Extrusive, gra	25	Ignimbrite, myolite		N44°31′40″ F135°21′26″	$50.3 \pm 1.2$ 54 8 + 2 6	
21Initiatic, granite $N44^{\circ}30^{\circ}6^{\circ}$ $50.5^{\circ}24^{\circ}3^{\circ}$ $50.5^{\circ}24^{\circ}.5^{\circ}$ 28Extrusive, daciteU-Pb $N44^{\circ}32^{\circ}6^{\circ}$ $52.9^{\circ}4.3.5^{\circ}$ $56.6^{\circ}\pm1.2^{\circ}$ [1]30Intrusive, graniteSHRIMP $N44^{\circ}31^{\circ}3^{\circ}$ $51.3^{\circ}27^{\circ}$ $57.8^{\circ}\pm1.1^{\circ}$ [1]31Tuff, rhyoliteU-Pb $N44^{\circ}31^{\circ}3^{\circ}$ $53.5^{\circ}\pm0.5^{\circ}$ [17]32Tuff, rhyoliteU-Pb $N43^{\circ}21^{\circ}51^{\circ}$ $53.5^{\circ}\pm0.5^{\circ}$ [17]33Intrusive, graniteSHRIMP $N44^{\circ}30^{\circ}04^{\circ}$ $51.3^{\circ}\pm0.7^{\circ}$ [26]34Intrusive, graniteLA-ICP-MS $N44^{\circ}20^{\circ}17^{\circ}$ $57.3^{\circ}\pm0.7^{\circ}$ [26]35Intrusive, graniteN49^{\circ}20^{\circ}3^{\circ} $51.3^{\circ}\pm0.7^{\circ}$ [26]36Intrusive, graniteN50^{\circ}34^{\circ}52^{\circ} $51.3^{\circ}\pm0.7^{\circ}$ [26]37Intrusive, graniteN50^{\circ}34^{\circ}52^{\circ} $57.8^{\circ}\pm1.1$ [12]38Intrusive, graniteLA-ICP-MS $N44^{\circ}20^{\circ}13^{\circ}$ $59.8^{\circ}\pm0.6^{\circ}$ [29]38Intrusive, graniteLA-ICP-MS $N44^{\circ}16^{\circ}29^{\circ}$ $55.0^{\circ}\pm1.3^{\circ}$ [29]41Intrusive, graniteLA-ICP-MS $N44^{\circ}14^{\circ}18^{\circ}$ $60.0^{\circ}\pm0.9^{\circ}$ [11]*43Tuff, rhyoliteLA-ICP-MS $N44^{\circ}14^{\circ}15^{\circ}$ $55.5^{\circ}\pm5.7^{\circ}\pm0.7^{\circ}$ [11]*44Extrusive, perliteLA-ICP-MS $N44^{\circ}15^{\circ}24^{\circ}$ $55.5^{\circ}\pm5.5^{\circ}\pm5.5^{\circ}\pm5.5^{\circ}$ [15]44Extrusive, gr	20	Intrusive granite		N44°38′24″ F135°16′07″	$54.0 \pm 2.0$ $55.3 \pm 2.8$	
25Extrusive, prainte1.441.4421.001.24.271.51.051.21.529Extrusive, daciteU-PbN44 $31'22''$ E135°04'56''56.6 ± 1.2[1]30Intrusive, graniteSHRIMPN44°31'22''E135°04'18''53.5 ± 0.5[17]31Tuff, rhyoliteSHRIMPN44°31'21'S1''E134°34'18''53.5 ± 0.5[17]32Tuff, rhyoliteSHRIMPN44°31'21'S1''E134°34'18''56.3 ± 0.7[26]33Intrusive, graniteLA-ICP-MSN44°20'17''E136°0'29''57.8 ± 1.1[1]34Intrusive, graniteLA-ICP-MSN50°34'52''E139°46'07''58.7 ± 0.4[12]35Intrusive, graniteLA-ICP-MSN50°35'53''E139°47'59''57.2 ± 0.9[11]36Intrusive, graniteLA-ICP-MSN44°16'29''E139°46'07''58.7 ± 0.4[12]37Intrusive, graniteLA-ICP-MSN44°16'29''E139°46'38''60.0 ± 0.940Tuff, rhyoliteLA-ICP-MSN44°16'29''E135°16'29''55.7 ± 0.7[11]*41Intrusive, graniteLA-ICP-MSN44°14'58''E135°26'25''57.5 ± 1.5[15]42Extrusive, perliteLA-ICP-MSN44°21'3''E135°14'24''56.0 ± 1.0[28]44Extrusive, graniteLA-ICP-MSN44°29'39''E135°23'14''57.0 ± 1.0[32]45Intrusive, graniteLA-ICP-MSN44°29'39''E135°20'06''58.0 ± 1.0[18] <td>28</td> <td>Extrusive perlite</td> <td></td> <td>N44°32′06″ F135°24′23″</td> <td><math>53.3 \pm 2.0</math> <math>52.9 \pm 3.5</math></td> <td></td>	28	Extrusive perlite		N44°32′06″ F135°24′23″	$53.3 \pm 2.0$ $52.9 \pm 3.5$	
25Extrusive, graniteCF10N44° 3127E135° 130° 50° 5050° 122[11]30Intrusive, graniteSHRIMPN44° 3127E135° 1327757.8 $\pm$ 1.1[17]31Tuff, rhyoliteU-PbN43° 21′ 51″E135° 1327757.8 $\pm$ 1.1[17]32Tuff, rhyoliteSHRIMPN43° 21′ 51″E136° 10′ 13″56.3 $\pm$ 0.7[26]33Intrusive, monzodioriteLA-ICP-MSN44° 30′ 04″E136° 10′ 13″56.3 $\pm$ 0.7[26]34Intrusive, graniteN49° 20′ 33″E137° 37′ 26″57.8 $\pm$ 1.11135Intrusive, graniteLA-ICP-MSN50° 34′ 52″E139° 46′ 07″58.7 $\pm$ 0.4[12]36Intrusive, graniteLA-ICP-MSN50° 34′ 52″E139° 44′ 53″59.8 $\pm$ 0.6[12]37Intrusive, syeniteN50° 05′ 54″E139° 44′ 53″60.0 $\pm$ 0.9[29]38Intrusive, syeniteLA-ICP-MSN44° 16′ 29″E135° 16′ 29″55.0 $\pm$ 1.3[29]41Intrusive, graniteLA-ICP-MSN44° 14′ 58″E135° 15′ 56″55.7 $\pm$ 0.7[11]*42Extrusive, preliteLA-ICP-MSN44° 14′ 58″E135° 21′ 04″55.5 $\pm$ 2.5[15]44Extrusive, graniteLA-ICP-MSN44° 21′ 24″E135° 15′ 25″57.5 $\pm$ 1.545Intrusive, graniteLA-ICP-MSN44° 14′ 58″E135° 21′ 24″56.0 $\pm$ 1.0[28]46Tuff, rhyoliteLA-ICP-MSN44° 29′ 39″E135° 23′ 14″57.0 $\pm$ 1.0[32]<	20	Extrusive dacite	∐_Ph	N44°31′22″ E135°09′56″	$52.9 \pm 5.3$ 56.6 + 1.2	[1]
30Initiative, graniteSTRIAT $[N43^\circ 13')^{5}1'' = [134^\circ 34'18'']$ $57.3 \pm 1.1$ 31Tuff, rhyoliteSHRIMP $N43^\circ 21'51'' = [134^\circ 34'18'']$ $53.5 \pm 0.5$ [17]32Tuff, rhyoliteSHRIMP $N43^\circ 21'51'' = [134^\circ 34'18'']$ $53.5 \pm 0.5$ [17]33Intrusive, monzodioriteLA-ICP-MS $N44^\circ 30'04'' = [136^\circ 07'29'']$ $57.1 \pm 0.4$ 34Intrusive, granite $N49^\circ 20'33'' = [139^\circ 46'07'']$ $58.7 \pm 0.4$ [12]35Intrusive, graniteLA-ICP-MS $N50^\circ 34'52'' = [139^\circ 46'07'']$ $58.7 \pm 0.4$ [12]36Intrusive, graniteLA-ICP-MS $N50^\circ 34'52'' = [139^\circ 46'38'']$ $60.0 \pm 0.9$ 38Intrusive, syenite $N50^\circ 35'54'' = [139^\circ 46'38'']$ $60.0 \pm 0.9$ 39Tuff, rhyoliteLA-ICP-MS $N44^\circ 16'29'' = [134^\circ 46'38'']$ $60.0 \pm 0.9$ 40Tuff, rhyoliteLA-ICP-MS $N44^\circ 16'29'' = [135^\circ 16'29'']$ $55.0 \pm 1.3$ [29]41Intrusive, graniteLA-ICP-MS $N44^\circ 14'58'' = [135^\circ 27'04'']$ $55.7 \pm 0.7$ [11]*42Extrusive, perliteLA-ICP-MS $N44^\circ 14'58'' = [135^\circ 24'24'']$ $55.5 \pm 2.5$ [15]44Extrusive, graniteLA-ICP-MS $N44^\circ 29'39'' = [135^\circ 24'24'']$ $55.5 \pm 2.5$ [15]45Intrusive, graniteLA-ICP-MS $N44^\circ 29'39'' = [135^\circ 20'06'']$ $58.0 \pm 1.0$ [28]46Tuff, rhyoliteLA-ICP-MS $N44^\circ 29'39'' = [135^\circ 20'06'']$ $58.0 \pm 1.0$ [18]48Intrusive, syenite <td>30</td> <td>Intrusive granite</td> <td>SHRIMP</td> <td>N/A°31'37" E135°13'27"</td> <td><math>50.0 \pm 1.2</math> <math>57.8 \pm 1.1</math></td> <td>[1]</td>	30	Intrusive granite	SHRIMP	N/A°31'37" E135°13'27"	$50.0 \pm 1.2$ $57.8 \pm 1.1$	[1]
31Tuff, rhyoliteCorr of SHRIMPN43° 21' 31'E134° 34' 18'' E134° 34' 18''5.5.3 ± 0.5.3 ± 0.7 5.2.3 ± 0.433Intrusive, monzodioriteLA-ICP-MSN44° 20' 17''E136° 10' 13'' E136° 07' 29''56.3 ± 0.7 57.1 ± 0.434Intrusive, graniteN44° 29' 17''E136° 07' 29'' E130° 04''57.1 ± 0.435Intrusive, graniteLA-ICP-MSN50° 34' 52''E139° 46' 07'' E130° 46' 07''58.7 ± 0.4 58.7 ± 0.436Intrusive, graniteLA-ICP-MSN50° 34' 52''E139° 46' 07'' E130° 48' 36''59.8 ± 0.639Tuff, rhyoliteLA-ICP-MSN44° 16' 29''E136° 16' 29'' E130° 48' 36''59.8 ± 0.639Tuff, rhyoliteLA-ICP-MSN44° 16' 29''E135° 15' 56'' 55.7 ± 0.755.7 ± 0.740Tuff, rhyoliteLA-ICP-MSN44° 15' 24''E135° 27' 04'' E135° 25' 55''55.7 ± 0.741Intrusive, graniteLA-ICP-MSN44° 15' 24''E135° 27' 04'' E135° 26' 25''55.7 ± 0.742Extrusive, preliteLA-ICP-MSN42° 41' 59''E135° 26' 25'' E130° 49' 42''55.5 ± 2.5[15]44Extrusive, graniteLA-ICP-MSN44° 29' 39''E135° 21' 14''50.0 ± 1.0[28]46Tuff, rhyoliteLA-ICP-MSN44° 29' 39''E135° 23' 14''57.0 ± 1.0[32]47Tuff, rhyoliteLA-ICP-MSN44° 29' 39''E135° 20' 33''54.1 ± 2.748Intrusive, granodioriteLA-ICP-MSN44° 17' 10''E132° 17' 59''' <t< td=""><td>31</td><td>Tuff rhyolite</td><td>JI Ph</td><td>N/44 31 37 E135 13 27 <math>N/3^{\circ}21'51'' E137^{\circ}37'18''</math></td><td><math>57.8 \pm 1.1</math> 53.5 ± 0.5</td><td>[17]</td></t<>	31	Tuff rhyolite	JI Ph	N/44 31 37 E135 13 27 $N/3^{\circ}21'51'' E137^{\circ}37'18''$	$57.8 \pm 1.1$ 53.5 ± 0.5	[17]
32InfiniteSTRAT $(N45^{\circ}21')^{16}$ $(D45^{\circ}21')^{16}$ $(D45^{\circ}21')^{17}$ 36Intrusive, graniteLA-ICP-MS $N44^{\circ}15'2'^{17}$ $E135^{\circ}15'5'^{17}$ $(D45^{\circ}21')^{17}$ $(D45^{\circ}21')^{17$	32	Tuff, rhyolite	SHRIMP	$N/3^{\circ}21'51'' E134^{\circ}34'18''$	$53.3 \pm 0.3$	[1/]
34Infrusive, infinizodionic Intrusive, granite Intrusive, granite Intrusive, granite 35IN44*30'17'' E136*07'29'' E139*46'07'' S7.1 $\pm$ 0.4 S7.1 $\pm$ 0.4 S7.2 $\pm$ 0.4 	33	Intrusive monzodiorite	I A ICP MS	$N4/^{\circ}30'0/''$ E136°10'13"	$52.3 \pm 0.4$ 56 3 ± 0.7	[26]
35Intrusive, granite $N49^{\circ}20'33''$ E137°37'26'' $57.8 \pm 1.1$ 36Intrusive, granodioriteLA-ICP-MS $N50^{\circ}34'52''$ $E137^{\circ}37'26''$ $57.8 \pm 1.1$ 37Intrusive, granite $N50^{\circ}34'52''$ $E139^{\circ}46'07''$ $58.7 \pm 0.4$ $[12]$ 38Intrusive, granite $N50^{\circ}35'53''$ $E139^{\circ}46'07''$ $58.7 \pm 0.4$ $[12]$ 39Tuff, rhyoliteLA-ICP-MS $N44^{\circ}16'29''$ $E134^{\circ}46'38''$ $60.0 \pm 0.9$ 40Tuff, rhyoliteLA-ICP-MS $N44^{\circ}16'29''$ $E135^{\circ}16'29''$ $55.0 \pm 1.3$ $[29]$ 41Intrusive, graniteLA-ICP-MS $N44^{\circ}14'58''$ $E135^{\circ}15'56''$ $55.7 \pm 0.7$ $[11]^*$ 42Extrusive, perliteLA-ICP-MS $N44^{\circ}14'58''$ $E135^{\circ}26'25''$ $57.5 \pm 1.5$ $55.5 \pm 2.5$ $[15]$ 44Extrusive, rhyoliteLA-ICP-MS $N42^{\circ}41'59''$ $E135^{\circ}23'14'''$ $56.0 \pm 1.0$ $[28]$ 46Tuff, rhyoliteLA-ICP-MS $N44^{\circ}29'39''$ $E135^{\circ}23'14'''$ $57.0 \pm 1.0$ $[32]$ 47Tuff, rhyoliteLA-ICP-MS $N45^{\circ}06'39''$ $E135^{\circ}20'33''''$ $54.1 \pm 2.7$ 49Tuff, rhyoliteLA-ICP-MS $N45^{\circ}06'39'''''''''''''''''''''''''''''''''''$	33	Intrusive granite	LA-ICI -IVIS	N44°29'17" E136°07'29"	$50.3 \pm 0.7$ $57.1 \pm 0.4$	[20]
35Intrusive, granite $144^{\circ} 20^{\circ} 35^{\circ} E139^{\circ} 46^{\circ} 07^{\circ}$ $57.3 \pm 1.1$ 36Intrusive, granite $150^{\circ} 34^{\circ} 52^{\circ} E139^{\circ} 46^{\circ} 07^{\circ}$ $58.7 \pm 0.4$ [12]37Intrusive, granite $150^{\circ} 34^{\circ} 52^{\circ} E139^{\circ} 44^{\circ} 07^{\circ}$ $58.7 \pm 0.4$ [12]38Intrusive, syenite $150^{\circ} 03^{\circ} 53^{\circ} 53^{\circ} E139^{\circ} 44^{\circ} 59^{\circ}$ $59.8 \pm 0.6$ 39Tuff, rhyoliteLA-ICP-MS $N44^{\circ} 16^{\prime} 29^{\circ} E134^{\circ} 46^{\prime} 38^{\circ}$ $60.0 \pm 0.9$ 40Tuff, rhyoliteLA-ICP-MS $N44^{\circ} 44^{\prime} 09^{\circ} E135^{\circ} 15^{\prime} 55^{\circ}$ $55.7 \pm 0.7$ 41Intrusive, graniteLA-ICP-MS $N44^{\circ} 44^{\prime} 58^{\circ} E135^{\circ} 27^{\circ} 04^{\circ}$ $55.7 \pm 0.7$ 42Extrusive, perliteLA-ICP-MS $N44^{\circ} 41^{\prime} 58^{\circ} E135^{\circ} 27^{\circ} 04^{\circ}$ $55.7 \pm 0.7$ 43Tuff, rhyoliteLA-ICP-MS $N42^{\circ} 41^{\prime} 59^{\circ} E130^{\circ} 49^{\prime} 42^{\circ}$ $55.5 \pm 2.5$ [15]44Extrusive, rhyoliteLA-ICP-MS $N42^{\circ} 41^{\prime} 59^{\circ} E135^{\circ} 23^{\circ} 14^{\circ}$ $56.0 \pm 1.0$ [28]46Tuff, rhyoliteLA-ICP-MS $N44^{\circ} 29^{\prime} 39^{\circ} E135^{\circ} 20^{\prime} 33^{\circ}$ $54.1 \pm 2.7$ 49Tuff, rhyoliteLA-ICP-MS $N44^{\circ} 17^{\circ} 10^{\circ} E135^{\circ} 17^{\circ} 59^{\circ}$ $54.3 \pm 2.9$ [5]50Intrusive, granodioriteLA-ICP-MS $N47^{\circ} 13^{\prime} 59^{\circ} E132^{\circ} 13^{\prime} 60^{\circ}$ $54.0 \pm 1.0$ [31]51Intrusive, diorite $N47^{\circ} 13^{\prime} 44^{\prime} E132^{\circ} 15^{\prime} 20^{\circ}$ $54.3 \pm 0.8$ [27]52Intrusive, granodiorite $N47^{\circ} 13^{\prime} 44^$	35	Intrusive, granite		$N/49^{\circ}20'33'' = F137^{\circ}37'26''$	$57.1 \pm 0.4$ $57.8 \pm 1.1$	
30Intrusive, granite Intrusive, graniteLAFICITINS $1030\ 34\ 52^{\circ}\ E139\ 40\ 07^{\circ}\ 53.7\ \pm0.7\ 10.7\ 102^{\circ}\ 57.2\ \pm0.9\ 57.2\ \pm0.9\ 57.2\ \pm0.9\ 57.2\ \pm0.9\ 59.8\ \pm0.6\ 60.0\ \pm0.9\ 10.7\ 100\ 59.8\ \pm0.6\ 60.0\ \pm0.9\ 10.7\ 100\ 59.8\ \pm0.6\ 60.0\ \pm0.9\ 10.7\ 100\ 59.7\ \pm0.7\ 100\ 59.8\ \pm0.6\ 60.0\ \pm0.9\ 100\ 59.8\ \pm0.6\ 100\ \pm0.9\ 100\ 50.7\ \pm0.7\ 100\ 59.8\ \pm0.6\ 100\ \pm0.9\ 100\ 50.7\ \pm0.7\ 100\ 100\ 100\ 100\ 100\ 100\ 100\ 10$	36	Intrusive granodiorite	LA ICP MS	N50°34′52″ E13° 57 20	$57.8 \pm 1.1$ 58 7 ± 0.4	[12]
37Intrusive, granite $130^{\circ} 33^{\circ} 33^{\circ} 513^{\circ} 4139^{\circ} 4336^{\circ}$ $57.2 \pm 0.3^{\circ}$ 38Intrusive, syenite $N50^{\circ} 05' 54^{\circ}$ $E139^{\circ} 48' 36^{\circ}$ $59.8 \pm 0.6$ 39Tuff, rhyolite $N44^{\circ} 16' 29^{\circ}$ $E139^{\circ} 48' 38^{\circ}$ $60.0 \pm 0.9$ 40Tuff, rhyolite $N43^{\circ} 49' 19^{\circ}$ $E135^{\circ} 16' 29^{\circ}$ $55.0 \pm 1.3$ $[29]$ 41Intrusive, granite $N43^{\circ} 44' 09^{\circ}$ $E135^{\circ} 15' 56^{\circ}$ $55.7 \pm 0.7$ $[11]^{*}$ 42Extrusive, perliteLA-ICP-MS $N44^{\circ} 14' 58^{\circ}$ $E139^{\circ} 26' 25^{\circ}$ $57.5 \pm 1.5$ 44Extrusive, rhyoliteLA-ICP-MS $N42^{\circ} 41' 59^{\circ}$ $E130^{\circ} 49' 42^{\circ}$ $55.5 \pm 2.5$ $[15]$ 45Intrusive, graniteLA-ICP-MS $N42^{\circ} 41' 59^{\circ}$ $E130^{\circ} 49' 42^{\circ}$ $56.0 \pm 1.0$ $[28]$ 46Tuff, rhyoliteLA-ICP-MS $N44^{\circ} 29' 39^{\circ}$ $E135^{\circ} 23' 14^{\circ}$ $57.0 \pm 1.0$ $[32]$ 47Tuff, rhyoliteLA-ICP-MS $N44^{\circ} 09' 32^{\circ}$ $E135^{\circ} 20' 06^{\circ}$ $58.0 \pm 1.0$ $[18]$ 48Intrusive, syenite $N45^{\circ} 06' 39^{\circ}$ $E132^{\circ} 17' 59^{\circ}$ $54.3 \pm 2.9$ $[5]$ 50Intrusive, granodioriteLA-ICP-MS $N44^{\circ} 14' 60^{\circ}$ $E132^{\circ} 17' 60^{\circ}$ $54.0 \pm 1.0$ $[31]$ 51Intrusive, granodiorite $N47^{\circ} 13' 24^{\circ}$ $E132^{\circ} 15' 20^{\circ}$ $56.3 \pm 0.8$ $[27]$ 50Intrusive, granodiorite $N47^{\circ} 13' 44^{\circ}$ $E132^{\circ} 15' 12^{\circ}$ $51.5 \pm 0.3$ $51.5 \pm 0.3$	37	Intrusive, granite	LA-ICI -INIS	N50°35′53″ E130°47′50″	$57.7 \pm 0.4$	[12]
36Initiality, syntheIA-ICP-MS $N44^{\circ}16'29''$ $E139^{\circ}48'30''$ $53.5 \pm 0.0$ 39Tuff, rhyoliteIA-ICP-MS $N44^{\circ}16'29''$ $E135^{\circ}16'29''$ $60.0 \pm 0.9$ 40Tuff, rhyolite $N43^{\circ}49'19''$ $E135^{\circ}16'29''$ $55.0 \pm 1.3$ $[29]$ 41Intrusive, graniteIA-ICP-MS $N44^{\circ}14'58''$ $E135^{\circ}27'04''$ $55.7 \pm 0.7$ $[11]^*$ 42Extrusive, perliteIA-ICP-MS $N44^{\circ}14'58''$ $E135^{\circ}26'25''$ $57.5 \pm 1.5$ $[11]^*$ 43Tuff, rhyoliteIA-ICP-MS $N44^{\circ}15'24''$ $E135^{\circ}26'25''$ $57.5 \pm 1.5$ $[15]$ 44Extrusive, rhyoliteIA-ICP-MS $N42^{\circ}41'59''$ $E135^{\circ}23'14''$ $56.0 \pm 1.0$ $[28]$ 46Tuff, rhyoliteIA-ICP-MS $N44^{\circ}29'39''$ $E135^{\circ}23'14'''$ $57.0 \pm 1.0$ $[32]$ 47Tuff, rhyoliteIA-ICP-MS $N44^{\circ}29'39''$ $E135^{\circ}20'06'''$ $58.0 \pm 1.0$ $[18]$ 48Intrusive, syeniteIA-ICP-MS $N44^{\circ}17'10''$ $E135^{\circ}17'59''$ $54.3 \pm 2.9$ $[5]$ 50Intrusive, granodioriteIA-ICP-MS $N47^{\circ}13'59''$ $54.3 \pm 2.9$ $[5]$ 51Intrusive, diorite $N47^{\circ}13'44''$ $E132^{\circ}15'12''$ $56.3 \pm 0.8$ $[27]$ 52Intrusive, granodiorite $N47^{\circ}13'44''$ $E132^{\circ}15'12''$ $51.5 \pm 0.3$ $51.5 \pm 0.3$	38	Intrusive svenite		N50°05′54″ E130°48′36″	$57.2 \pm 0.9$ 59.8 ± 0.6	
37Tuff, rhyoliteEATION MS $A444 10 29^{-} E135^{+}10 30^{-} = 50.0 \pm 0.9^{-}$ 40Tuff, rhyolite $N43^{\circ}44'09'' E135^{\circ}16'29'' = 55.0 \pm 1.3 = [29]$ 41Intrusive, granite $N43^{\circ}44'09'' E135^{\circ}15'56'' = 55.7 \pm 0.7 = 0.7 = 55.7 \pm 0.7$	39	Tuff rhyolite	I A-ICP-MS	N44°16′29″ F134°46′38″	$59.0 \pm 0.0$ $60.0 \pm 0.9$	
401 un, myone $143 + 9 + 9 + 19 + 1135 + 10 + 27 + 353.6 \pm 1.35 + 1135 + $	40	Tuff rhyolite	LATION MD	N43°49′19″ F135°16′29″	$55.0 \pm 1.3$	[20]
41Infrusive, graniteLA-ICP-MS $N44^\circ 14' 58'' E135^\circ 27'04''$ $55.7 \pm 0.7$ [11]*43Tuff, rhyoliteLA-ICP-MS $N44^\circ 14' 58'' E135^\circ 26' 25''$ $57.5 \pm 1.5$ [11]*44Extrusive, rhyoliteLA-ICP-MS $N42^\circ 41' 59'' E130^\circ 49' 42''$ $55.5 \pm 2.5$ [15]45Intrusive, graniteLA-ICP-MS $N43^\circ 43' 44'' E135^\circ 14' 24''$ $56.0 \pm 1.0$ [28]46Tuff, rhyoliteLA-ICP-MS $N44^\circ 29' 39'' E135^\circ 23' 14''$ $57.0 \pm 1.0$ [32]47Tuff, rhyoliteLA-ICP-MS $N45^\circ 09' 32'' E135^\circ 20' 06''$ $58.0 \pm 1.0$ [18]48Intrusive, syeniteN45^\circ 06' 39'' E135^\circ 20' 33'' $54.1 \pm 2.7$ [49]49Tuff, rhyoliteLA-ICP-MS $N44^\circ 17' 10'' E135^\circ 17' 59''$ $54.3 \pm 2.9$ [5]50Intrusive, granodioriteLA-ICP-MS $N47^\circ 13' 59'' E132^\circ 13' 26''$ $56.3 \pm 0.8$ [27]51Intrusive, diorite $N47^\circ 13' 44'' E132^\circ 15' 12''$ $51.5 \pm 0.3$ [27]	40	Intrusive granite		N43°44′09″ F135°15′56″	$55.0 \pm 1.3$ $55.7 \pm 0.7$	[27]
42Extrusive, printeExtrem PMS $R44 + 14 + 38 = E135 + 27 + 64$ 53.7 $\pm$ 6.7[11]43Tuff, rhyoliteN44°15'24" E135°26'25"57.5 $\pm$ 1.5[15]44Extrusive, rhyoliteLA-ICP-MSN42°41'59" E130°49'42"55.5 $\pm$ 2.5[15]45Intrusive, graniteLA-ICP-MSN43°43'44" E135°14'24"56.0 $\pm$ 1.0[28]46Tuff, rhyoliteLA-ICP-MSN44°29'39" E135°23'14"57.0 $\pm$ 1.0[32]47Tuff, rhyoliteLA-ICP-MSN44°19'32" E135°20'06"58.0 $\pm$ 1.0[18]48Intrusive, syeniteN45°06'39" E135°20'33"54.1 $\pm$ 2.7[49]49Tuff, rhyoliteLA-ICP-MSN44°17'10" E135°17'59"54.3 $\pm$ 2.9[5]50Intrusive, granodioriteLA-ICP-MSN47°14'60" E132°17'60"54.0 $\pm$ 1.0[31]51Intrusive, dioriteN47°13'59" E132°13'26"56.3 $\pm$ 0.8[27]52Intrusive, granodioriteN47°13'44" E132°15'12"51.5 $\pm$ 0.3	42	Extrusive perlite	LA ICP MS	$N4/^{\circ}1/^{\prime}58'' = F135^{\circ}27'0A''$	$55.7 \pm 0.7$	[11]*
43Full, flyonc $1444 1524 E135 2025$ $57.5 \pm 1.5$ 44Extrusive, rhyoliteLA-ICP-MS $N42^\circ 41'59'' E130^\circ 49'42''$ $55.5 \pm 2.5$ [15]45Intrusive, graniteLA-ICP-MS $N43^\circ 43'44'' E135^\circ 14'24''$ $56.0 \pm 1.0$ [28]46Tuff, rhyoliteLA-ICP-MS $N44^\circ 29'39'' E135^\circ 23'14''$ $57.0 \pm 1.0$ [32]47Tuff, rhyoliteLA-ICP-MS $N44^\circ 29'39'' E135^\circ 20'06''$ $58.0 \pm 1.0$ [18]48Intrusive, syeniteN45°06'39'' E135°20'33'' $54.1 \pm 2.7$ [18]49Tuff, rhyoliteLA-ICP-MS $N44^\circ 17'10'' E135^\circ 17'59''$ $54.3 \pm 2.9$ [5]50Intrusive, granodioriteLA-ICP-MS $N47^\circ 14'60'' E132^\circ 17'60''$ $54.0 \pm 1.0$ [31]51Intrusive, diorite $N47^\circ 13'59'' E132^\circ 13'26''$ $56.3 \pm 0.8$ [27]52Intrusive, granodiorite $N47^\circ 13'44'' E132^\circ 15'12''$ $51.5 \pm 0.3$	42	Tuff rhyolite	LA-ICI -IVIS	N44 14 56 E155 27 04 $N44^{0}15'24'' E135^{0}26'25''$	$57.7 \pm 0.7$	[11]
44ExtremeEx	43	Fytrusive rhyolite	LA ICP MS	N44 15 24 E155 20 25 $N/2^{\circ}/1'50'' E130^{\circ}/0'/2''$	$57.5 \pm 1.5$ 55.5 + 2.5	[15]
45Intrusive, granuleEA-ICP-MS $IA43 43 44^{\circ}$ E135 14 2450.0 ± 1.0[23]46Tuff, rhyoliteLA-ICP-MS $N44^{\circ}29'39''$ $E135^{\circ}23'14''$ $57.0 \pm 1.0$ [32]47Tuff, rhyoliteLA-ICP-MS $N45^{\circ}09'32''$ $E135^{\circ}20'06''$ $58.0 \pm 1.0$ [18]48Intrusive, syeniteN45^{\circ}06'39'' $E135^{\circ}20'33''$ $54.1 \pm 2.7$ [18]49Tuff, rhyoliteLA-ICP-MS $N44^{\circ}17'10''$ $E135^{\circ}17'59''$ $54.3 \pm 2.9$ [5]50Intrusive, granodioriteLA-ICP-MS $N47^{\circ}14'60''$ $E132^{\circ}17'60''$ $54.0 \pm 1.0$ [31]51Intrusive, dioriteN47^{\circ}13'59'' $E132^{\circ}15'12''$ $56.3 \pm 0.8$ [27]52Intrusive, granodioriteN47^{\circ}13'44'' $E132^{\circ}15'12''$ $51.5 \pm 0.3$	45	Intrusive granite	LA-ICP MS	$N/3^{\circ}/3'/4''$ E135°14'24''	$55.5 \pm 2.5$ 56.0 ± 1.0	[13]
40Tuff, myolicEXPICT M/S $14442537$ $E1352514$ $57.0\pm1.0$ $[132]$ 47Tuff, rhyoliteLA-ICP-MS $N45^{\circ}09'32''$ $E135^{\circ}20'06''$ $58.0\pm1.0$ $[18]$ 48Intrusive, syenite $N45^{\circ}06'39''$ $E135^{\circ}20'33''$ $54.1\pm2.7$ $[18]$ 49Tuff, rhyoliteLA-ICP-MS $N44^{\circ}17'10''$ $E135^{\circ}17'59''$ $54.3\pm2.9$ $[5]$ 50Intrusive, granodioriteLA-ICP-MS $N47^{\circ}14'60''$ $E132^{\circ}17'60''$ $54.0\pm1.0$ $[31]$ 51Intrusive, diorite $N47^{\circ}13'59''$ $E132^{\circ}13'26''$ $56.3\pm0.8$ $[27]$ 52Intrusive, granodiorite $N47^{\circ}13'44''$ $E132^{\circ}15'12''$ $51.5\pm0.3$	45	Tuff rhyolite	LA-ICI -MIS	N/1/20/30" F135023'11"	$50.0 \pm 1.0$ 57.0 ± 1.0	[20]
47Full, InyoliteEA-ICF-MS $1443 0532$ $E135 2000$ $38.0 \pm 1.0$ $[18]$ 48Intrusive, syenite $N45^\circ06'39''$ $E135^\circ20'33''$ $54.1 \pm 2.7$ 49Tuff, rhyoliteLA-ICP-MS $N44^\circ17'10''$ $E135^\circ17'59''$ $54.3 \pm 2.9$ $[5]$ 50Intrusive, granodioriteLA-ICP-MS $N47^\circ14'60''$ $E132^\circ17'60''$ $54.0 \pm 1.0$ $[31]$ 51Intrusive, diorite $N47^\circ13'59''$ $E132^\circ13'26''$ $56.3 \pm 0.8$ $[27]$ 52Intrusive, granodiorite $N47^\circ13'44''$ $E132^\circ15'12''$ $51.5 \pm 0.3$	40	Tuff, rhyolite	LA-ICI -MIS	$N45^{\circ}00'32'' E135^{\circ}20'06''$	$57.0 \pm 1.0$	[32]
43Influsive, symile $143\ 00\ 39\ E133\ 20\ 35\ 13\ 4.1\ \pm\ 2.7\ 13\ 2.7\ 13\ 13\ 13\ 13\ 13\ 13\ 13\ 13\ 13\ 13$	47	Intrusive svenite	LA-ICI-WIS	N45 07 52 E135 20 00 N45°06'30″ E135°20'33″	$58.0 \pm 1.0$ $54.1 \pm 2.7$	[10]
50       Intrusive, granodiorite       LA-ICP-MS $N47^{\circ}14'60''$ E135' 17'57' $54.3 \pm 2.7$ [5]         51       Intrusive, diorite       LA-ICP-MS $N47^{\circ}14'60''$ E132°17'60'' $54.0 \pm 1.0$ [31]         52       Intrusive, granodiorite       N47°13'59''       E132°13'26'' $56.3 \pm 0.8$ [27]	то 40	Tuff rhvolite	I A-ICP MS	N44°17′10″ F135°17′50″	$57.1 \pm 2.7$ 54 3 + 2 0	[5]
50       Intrusive, granodiorite $LA-1C1^{-1V15}$ $1470^{-14}$ $E152^{-17}$ $54.0 \pm 1.0$ $[51]$ 51       Intrusive, diorite $N47^{\circ}13'59''$ $E132^{\circ}13'26''$ $56.3 \pm 0.8$ $[27]$ 52       Intrusive, granodiorite $N47^{\circ}13'44''$ $E132^{\circ}15'12''$ $51.5 \pm 0.3$ $[27]$	50	Intrusive granodiorite		N47°14'60" E132°17'60"	$54.0 \pm 2.9$	[3]
52 Intrusive, granodiorite $N47^{\circ}13'44'' E132^{\circ}15'12'' = 51.5 \pm 0.3$	51	Intrusive, granoulonite		N47°13′59″ F132°13′26″	$57.0 \pm 1.0$ 56 3 + 0 8	[ <sup>31</sup> ] [27]
	52	Intrusive, granodiorite		N47°13′44″ E132°15′12″	$51.5 \pm 0.3$	L=, ]

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

\* 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  $60.5 \pm 0.7$  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.

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