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OCEANOLOGY

Petrology of the Hubert Miller Seamount, Marie Byrd Seamounts Province, West Antarctic, Southern Ocean

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The Marie Byrd Seamounts are located at the foot of the continental slope of Marie Byrd Land (MBL) in the Amundsen Sea, in the Pacific sector of the Southern Ocean. The basement of the continental slope in this region is broken, but its surface is smoothed by a thick sedimentary cover [1]. In the lower part of the slope, the cover resembles an accumulative apron. The chain of the Marie Byrd Seamounts extends nearly in a latitudinal direction within 69°–70° N, where the apron enveloping the base of the seamounts passes into a deepwater abyssal plain of the Amundsen Sea floor [2].

The Hubert Miller Seamount (hereafter, Miller Seamount), one of the largest seamounts in the province, was studied in detail for the first time in 2001 during Cruise ANT-18/5a of the R/V *Polarstern* (see Fig. 1 in [12]). In terms of morphology, this seamount is a slightly NW–SE elongated large block with an even (almost flat) summit surface and steep slopes. The seamount top is outlined by an 1500-m isobath and rises over the surrounding floor about 2000 m. Multibeam echo sounding revealed dozens of small (100- to 200-m-high) parasitic volcanic cones on the flat summit surface and slopes of the seamount.

The attempt to recover samples from the northeastern slope of the seamount in 2001 failed due to breakage of the dredge, but rock fragments were collected on the upper part of the western slope by a grab sampler and corers at five stations: PS 58/259-1SL (69°20.17′ S, 121°28.93′ W, depth 1260 m); PS 58/259-2GKG (69°19.98′ S, 121°28.87′ W, depth 1265 m); PS 58/261-1GKG (69°19.68′ S, 121°29.04′ W, depth 1259 m); PS 58/262-1SL (69°21.45′ S, 121°31.9′ W, depth 1138 m); and PS 58/263-1SL (69°18.30′ S, 121°28.44′ W, depth 1153 m). During Cruise ANT-23/4 of the R/V *Polarstern* (February–April 2006), four successful dredgings were carried out on the southwestern and southeastern slopes of the Miller Seamount at the following stations (Fig. 1): P 69/320 (69°21.09′ S, 121°52.12′ W, depth 2500–2432 m); P 69/321, 69°21.53′ S, 121°31.94′ W, depth 1670–1431 m; P 69/324 (69°30.07′ S, 121°04.00′ W, depth 2622–2205 m); and P 69/325 (69°27.23′ S, 120°55.38′ W, depth 1560–1527 m). Although the material recovered cannot be unambiguously interpreted as in situ rocks (an ice drift cannot be ruled out), it is of interest because of the shape of samples (mainly nonrounded angular fragments with fresh detachment surfaces). We believe that the material represents debris of hard rocks exposed on slopes.

Numerous volcanic parasitic cones found on the seamount and samples of in situ basalts indicate the volcanic origin of the seamount. This inference is confirmed by the analysis of the gravity field carried out by Teterin (Fig. 2). A positive anomaly (160 mGal) with the shape following contours the seamount is recorded above the seamount. The anomaly is conjugated at the seamount foot with the negative minimum (5–25 mGal) characteristic for crustal blocks of isostatic compensation. The density model of the NE–SW profile of the seamount shows that the positive anomaly is related to a lenticular body on the submerging surface of the crustal layer (density of 2.63 g/cm) compensated by the Moho surface submergence. The central part of the lenticular body includes a vertical isometric block (10 km across, density 2.8 g/cm). Such a profile is typical of submarine volcanoes composed of alkaline basalts. According to this interpretation, the volcanic origin of the Miller Seamount is related to the northward advancement of the continental volcanic province of MBL.

The recovered samples included the following rock types: hornfels (sample 259-2r), arkosic sandstone (sample 259-2p), quartz diorite (samples 259-am, 261-1am), mica schist (sample 261-1), granite (sample 259-gr), granosyenite (sample 261-1s) gabbro, rhyolite, and dacite (sample 259-1z), andesite (samples 259-2bp,

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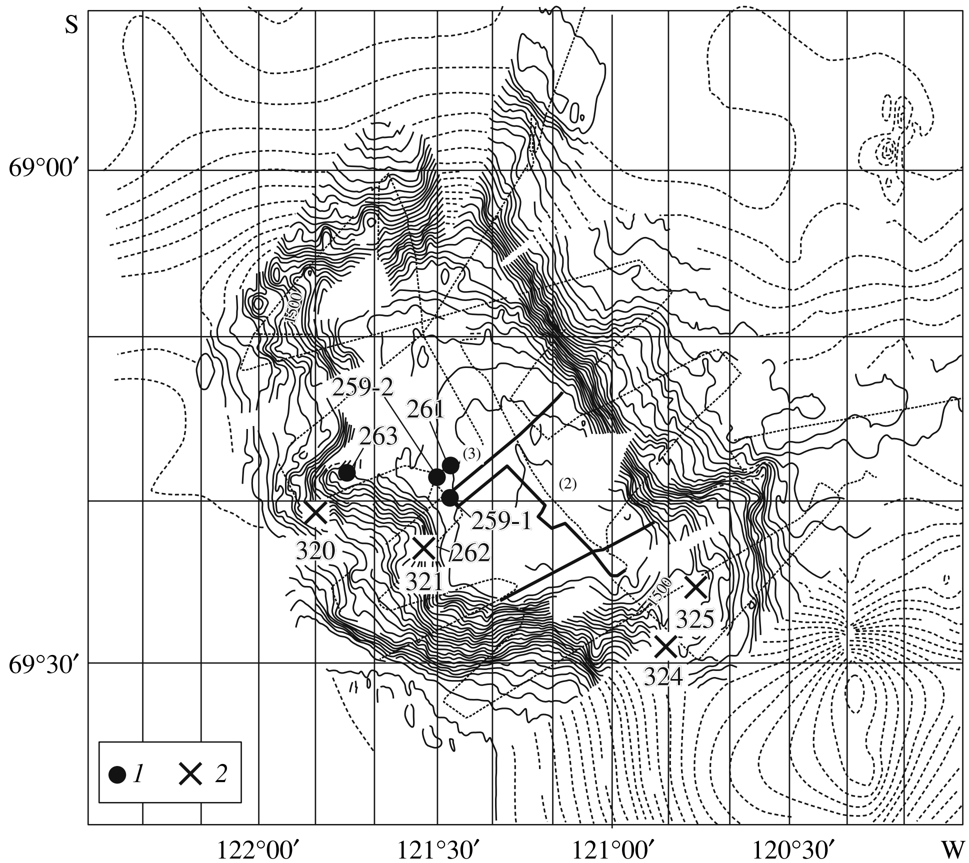

Fig. 1. Topography of the Miller Seamount based on surveying in Cruise ANT-18/5a of the R/V *Polarstern*. (*1*) Geological stations (259–263) in Cruise ANT-18/5a, 2001; (*2*) geological stations (320–325) in Cruise ANT-23/4, 2006.

261-1p), alkaline basalt (samples 259-2vz, 321-1), basaltic andesite (samples 325-2, 324-1), trachybasalt (sample 320-1-1), and fresh tholeiitic olivine basalt (sample 259-2b) (Table 1).

An angular sample (14 × 13 × 12 cm) of biotite–plagioclase hornfels was recovered from the zone of contact metamorphism during injection of quartz–biotite–pyroxene dioritic porphyrite into arkosic sandstone. The arkosic sandstone comprises large (0.15–0.20 mm) rounded zircon grains. The hornfels contains acicular elongated (0.035 × 0.004 mm) zircons formed in the course of metamorphism. Based on the U–Pb isotope dating of zircons collected from arkosic sandstone (sample 259-2p, 14 grains, >0.15 mm) and the $^{206}Pb/^{238}U$–$^{207}Pb/^{235}U$ relationship, the absolute age of sandstone is estimated at 148.2 ± 7.5 Ma (Late Jurassic). The U–Pb dating of zircons collected from hornfels (sample 259-2r, 10 grains, 0.15–0.10 mm) yielded 47 ± 15 Ma (Eocene–Paleocene, Table 2).

The granolepidoblastic quartz–two-mica schist formed after metapelite consists of garnet, biotite, muscovite, chlorite, cordierite, and sillimanite grains. Based on low contents of Ti and Na and a high Fe content, the two-mica schists of the Miller Seamount are similar to amphibole schists from the Eltanin Fracture Zone (East Pacific Rise) [3, 4], as well as schists and amphibolites of the Southern Andes and Antarctic Peninsula (Stonington Island).

Volcanic rocks of the Miller Seamount belong to the early (calc-alkaline and alkaline) and late (tholeiitic) genetic series [5]. The early series comprises basaltic andesite, andesite, dacite, and rhyolite altered to greenstones (Table 1). In Fig. 3a, their data points lie in the field of island arcs and Andean-type active continental margins. This field also includes data points of rhyolite recovered from the seamount in the central Amundsen Sea (station PS 58/251-1MUC, 68°37.28′ S, 97°07.11′ W, depth 2860 m, 22 samples) and of trachyandesite of the calc-alkaline series recovered from Peter I Island. Intrusions of leucocratic granitoids associate with effusives of the calc-alkaline series on the Miller Seamount. Alkaline olivine basalt associated with gabbro and granosyenite belongs to the subalkaline (K–Na) series. The tholeiitic series include fresh vesicular olivine basalts (Table 1) most likely related to epiorogenic rifting, which is widespread on MBL [6], in the central

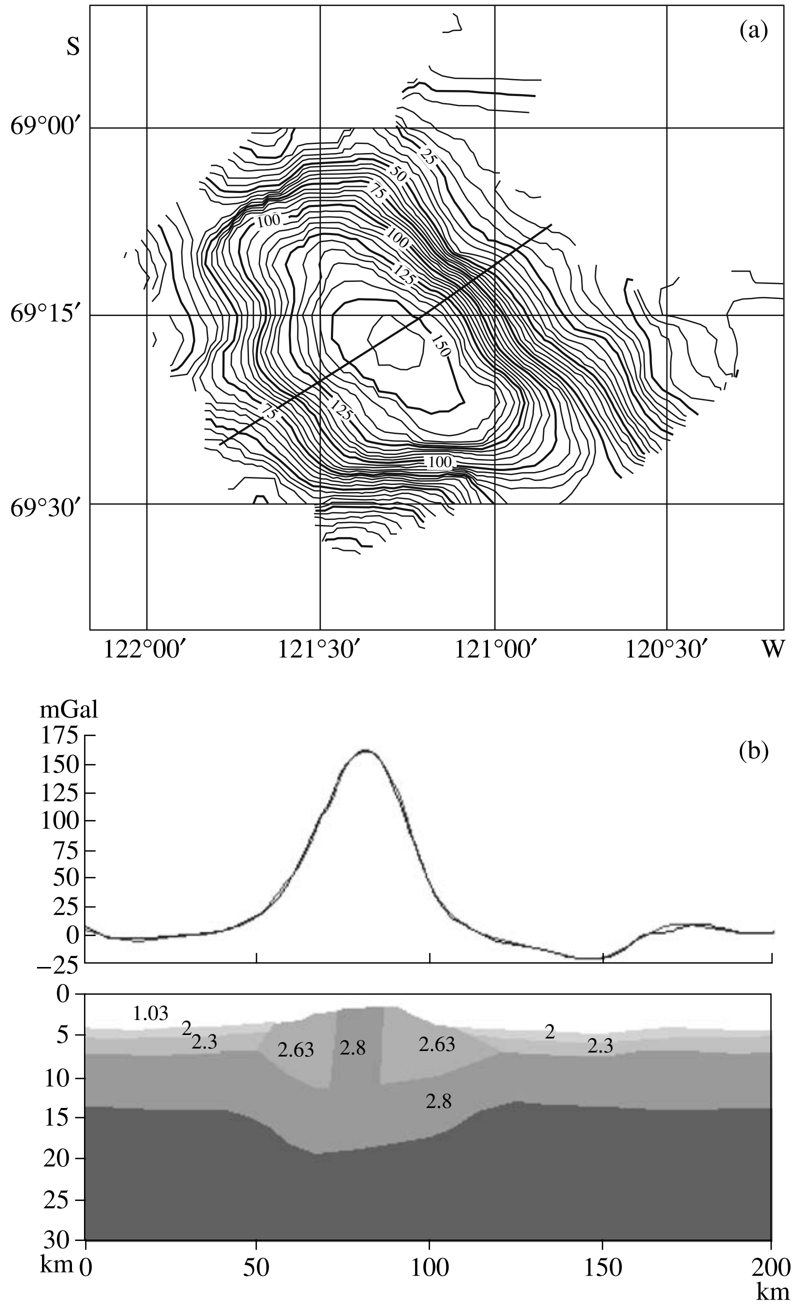

Fig. 2. (a) Map of the Faye gravity anomaly in the Miller Seamount region based on onboard gravimetric survey data in Cruise ANT-18/5a of the R/V *Polarstern*. Full line shows the position of profile AW1 2 001 002. (b) Model of the Earth's crust and uppermost mantle along the Miller Seamount profile (see Fig. 2a for the profile position).

part of the Amundsen Sea (station PS 58/257-1 GRG, 69°09.77′ S, 102°20.77′ W, depth 4332 m), on the Jones Seamount [7], and along the entire Andes foldbelt [5]. As is evident from Fig. 3a, the data point of the composition of tholeiitic olivine basalt from the Miller Seamount lies in the band of enriched within-plate oceanic basalts, near olivine basalts of the Jones Seamount, MBL, Peter I Island, and the central Amundsen Sea. Magmatic rocks of the Miller Seamount are enriched in TiO_2, Na_2O, K_2O, and P_2O_5 and depleted in Ca (Table 1). Thus, the chemical composition of the olivine basalt is similar to that of volcanic rocks from Andean-type active continental margins.

High contents of LILE (K, Rb, Ba, Sr, Th), and elements with high ion potential (Ta, Nb, Ce, Zr, P, Hf, Sm, Y, Yb, Cr) in volcanics of the Miller Seamount (Table 1) make them comparable with volcanic rocks of the Andean-type active continental margin [5]. The diagram with microelement contents normalized to N-MORB shows Rb, Ba, Sr, and Th maximums and Nb

Table 1. Chemical composition of rocks of the Miller Seamount (MBL, Amundsen Sea), wt %

Component	1	2	3	4	5	6	7	8	9	10	11
SiO_2	52.21	51.52	63.50	55.85	41.68	65.88	51.66	44.08	44.81	47.06	46.88
TiO_2	0.70	0.91	0.99	1.10	2.59	0.78	2.19	1.73	3.50	3.62	2.17
Al_2O_3	15.24	17.56	15.34	18.33	12.60	17.85	15.84	14.81	16.38	16.68	13.82
FeO	8.43	8.20	5.76	7.00	10.75	6.74	12.07	9.51	12.30	10.55	12.59
MnO	0.17	0.32	0.14	0.10	0.19	0.09	0.21	0.76	0.20	0.14	0.19
MgO	6.75	5.41	1.82	3.76	11.25	1.98	1.78	1.65	3.04	3.91	9.98
CaO	10.75	8.85	4.13	5.98	8.63	2.32	6.76	8.80	9.17	8.64	9.88
Na_2O	3.04	3.69	3.41	2.60	1.30	1.50	4.45	4.03	3.30	3.59	1.56
K_2O	0.40	1.22	1.70	1.54	1.35	2.08	1.75	1.99	1.19	1.83	0.66
P_2O_5	0.13	0.29	0.34	0.31	0.52	0.21	1.09	6.64	0.65	0.76	0.39
L.O.I.	1.45	0.98	1.87	3.11	8.66	0.25	1.16	5.5	4.62	2.80	1.53
Total	99.27	98.95	100.8	99.68	99.52	99.68	98.96	99.50	99.16	99.58	99.65
Rb	10	38	36	46	24	84	48	28	21	49	15
Ba	162	233	478	596	359	313	769	846	440	458	252
Sr	461	752	355	933	476	188	621	865	967	923	634
La	9	19	17	27	43	21	75	94	52	49	24
Ce	21	44	40	61	87	45	157	143	107	104	47
Nd	12	24	22	29	46	20	79	86	53	50	25
Sm	3	5	5	5	9	4	15	16	10	10	6
Eu	0.92	1.55	1.50	1.40	3	1.13	5.00	5.01	3.28	3.03	1.77
Tb	0.45	0.67	0.86	0.56	1.13	0.55	1.98	2.13	1.23	1.16	0.82
Yb	1.59	1.95	3.12	1.11	2.06	1.13	4.52	5.56	2.74	2.51	1.77
Y	15	19	35	16	32	18	49	77	32	29	32
Zr	81	104	172	164	308	19	447	394	332	318	195
Nb	1.84	3.47	7.80	9.20	13	11.46	89	110	80	76	35.35
Hf	2.18	2.57	4.44	3.98	7.06	0.48	10.20	9.17	7.03	6.74	3.86
Th	3.23	5.33	3.61	4.70	5.73	9.37	9.00	7.71	5.54	5.13	2.89
U	0.90	1.24	0.93	1.07	1.33	1.89	2.04	0.99	1.08	0.95	4.20
Ta	0.12	0.19	0.72	0.73	0.29	0.95	5.82	7.03	5.13	5	1.67
Cr	200	121	36	114	854	79	37	13	4	13	348
Ni	32	169	13	70	321	24	121	179	3	33	243
Pb	12	29	15	13	3	11	14	15	10	9	7

Note: (1) Basaltic andesite (sample 325-1-1); (2) basalt (sample 324-1-5); (3) dacite (sample 259-1z); (4) andesite (sample 259-2bp); (5) alkaline basalt (sample 259-2vz); (6) hornfels (sample 259-2am); (7) trachybasalt (sample 320-1-1); (8–10) alkaline basalts (samples 321-1-1, 321-1-3, and 321-1-5); (11) tholeiitic basalt (sample 259-2b). (1, 2, 7–10) Rocks recovered by dredge in Cruise ANT 18/4 cruise, (3–6, 11) rocks recovered by grab sampler in Cruise ANT 18/5a of the R/V *Polarstern*.

and Ta minimums that reflect the composition of the enriched source during magma generation.

As seen in Fig. 3a, the absolute values of both Th and Ta are higher in volcanics of the Miller Seamount. Increase in the Th content is related to an increase in the content of fluid components and degree of contamination, while increase in the Ta content is associated with magma melting in a more enriched mantle source. Both processes also make the Miller Seamount comparable with the Andean-type active continental margin. The high alkalinity of volcanics in the region is reflected in enrichment with LREE (Table 1).

Isotopic–geochemical studies of tholeiitic olivine basalt (sample 259-2b) yielded the following composition (ppm): Rb 14.56, Sr 591.4, Sm 5.213, Nd 16.98, Pb 7.0084, U 3.8607. The isotope ratios are as follows: $^{87}Rb/^{86}Sr$ 0.07118, $^{87}Sr/^{86}Sr$ 0.703854 ± 11, $^{147}Sm/^{144}Nd$ 0.18622, $^{143}Nd/^{144}Nd$ 0.512796 ± 13, $^{206}Pb/^{204}Pb$ 18.799, $^{207}Pb/^{204}Pb$ 15.623, and $^{208}Pb/^{204}Pb$ 38.602. In the $^{143}Nd/^{144}Nd$–$^{87}Sr/^{86}Sr$ diagram for tholeiitic olivine basalt (sample 259-2b), data points of radiogenic isotopes lie in the field of rocks of the southern Andes segment [5] and near the Jones Seamount [7]. They exhibit high values of the $^{143}Nd/^{144}Nd$ ratio (0.5128) and relatively low values of the $^{87}Sr/^{86}Sr$ ratio (0.7038). As evident from Fig. 3b, tholeiitic basalts of the Miller Seamount and MBL [6] occupy different positions: basalts of the Marie Byrd Seamount were affected by fluids within or near the MORB field, whereas basalts from the Miller Seamount were affected by fluids near the Jones Seamount and within the northern segment of the Andes and Colorado Plateau at the DM/EM boundary. This is likely to suggest an initial stage of the continental crust destruction. Volcanic rocks of MBL indicate a more advanced process of the continental crust destruction. They are similar to the HIMU reservoir [8], a fluid diffusion halo generated after vigorous destruction of the continental crust. In this case, the energy of radioactive efficiency during the alpha decay of U and Th played a leading role in mobilization of radiogenic isotopes by fluid flows.

The data presented suggest a continental mode of rocks of the Miller Seamount. Therefore, we assume that this structure represents a relict fragment of the continental crust of the Antarctic segment of the Andes foldbelt that was destructed, altered by the mantle plume, and submerged. The existence of such a segment was assumed previously [9].

Traces of such relict blocks of the continental margins, which underwent destruction and submergence,

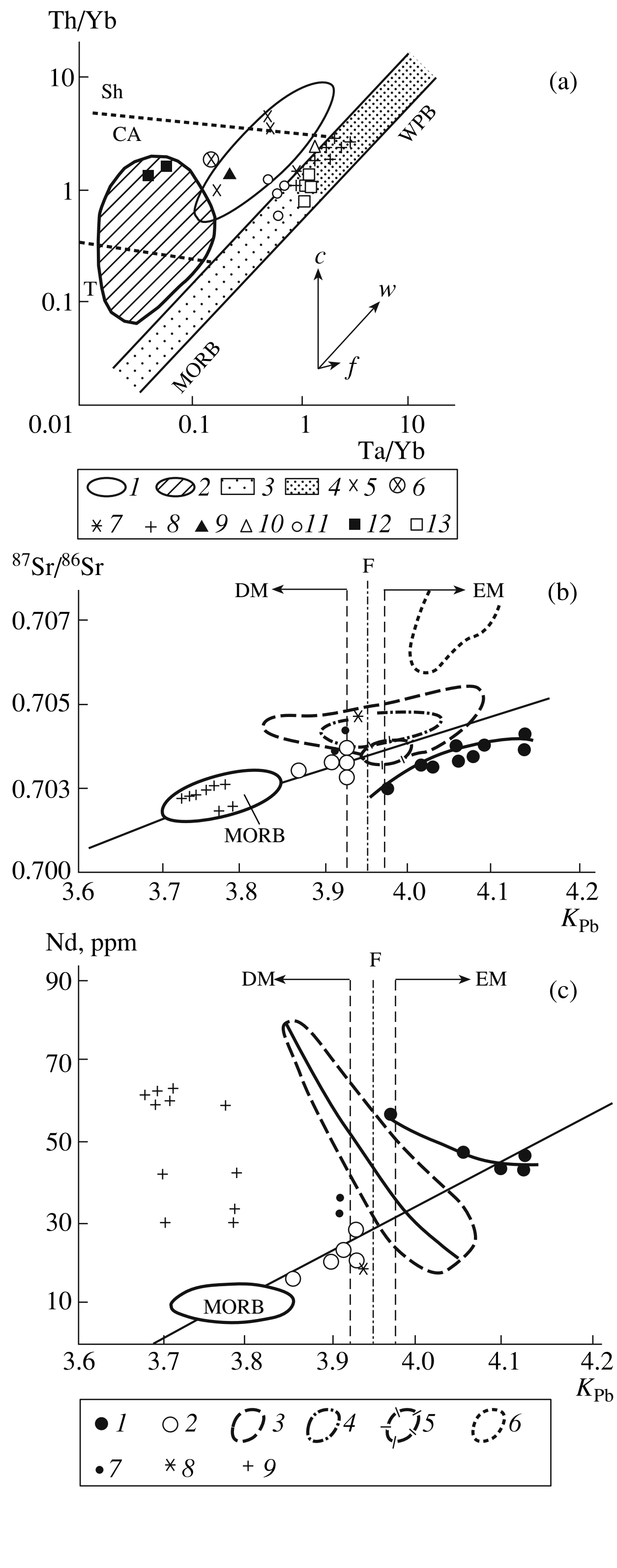

Fig. 3. (a) Th/Yb–Ta/Yb diagram for volcanics of the Miller Seamount. (*1*) Active continental margins; (*2*) island arcs; (*3, 4*) depleted and enriched mantle source, respectively; (*5–7*) volcanic series of the Miller Seamount: (*5*) calc-alkaline, (*6*) subalkaline, and (*7*) tholeiitic; (*8*) basalts of MBL; (*9, 10*) rhyolite and tholeiitic basalt, respectively, of the central Amundsen Sea; (*11*) basalts of the Jones Seamount; (*12, 13*) basalts at stations 324, 325, and 321 recovered in Cruise ANT-23/4. (MORB) depleted mantle; (WPB) enriched mantle. Vectors show the influence of the following factors: (*w*) within-plate enrichment with lithophile elements, (*c*) crustal contamination, (*f*) fractional crystallization. Dashed lines separate fields of tholeiitic (T), calc-alkaline (CA), and shoshonite (Sh) rocks. (b) $^{86}Sr/^{87}Sr$–K_{Pb} diagram for volcanics of the Miller Seamount and MBL. (c) Nd–K_{Pb} diagram. (*1*) Tholeiitic basalt of the Miller Seamount; (*2*) basalts of the MBL; (*3*) basalts of the Jones Seamount; (*4*) volcanics of the Colorado Plateau; (*5–7*) volcanics of the (*5*) northern, (*6*) southern, and (*7*) central segments of the Andes; (*8*) tholeiitic basalts of the Miller Seamount; (*9*) basalts of the MBL. (DM, EM) Depleted oceanic mantle and enriched continental mantle, respectively; (F) DM/EM transitional zone. K_{Pb} designates $(Th/U)_{Pb}$.

Table 2. Results of the U–Pb isotopic dating of zircons from hornfels of the Miller Seamount, Amundsen Sea

Nos.	Weight, mg	Pb	U	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{206}Pb$	$^{208}Pb/^{206}Pb$	$^{207}Pb/^{235}U$ (2σ%)	$^{206}Pb/^{238}U$ (2σ%)	*Rho*	Age, Ma		
		ppm								$^{207}Pb/^{235}U$	$^{206}Pb/^{238}U$	$^{207}Pb/^{206}Pb$
1	0.02	7.378	476.4	674.67	0.04867 ± 9	0.18279	0.11523 (0.372)	0.01717 (0.316)	0.87	110.7 ± 0.4	109.8 ± 0.3	131.8 ± 4.5
2	0.01	9.110	502.2	978.14	0.04717 ± 6	0.11974	0.05173 (0.315)	0.00795 (0.313)	0.93	51.2 ± 0.2	51.1 ± 0.2	58.2 ± 3.1

Note: Zircon fractions: (1) >0.15 mm (14 grains), (2) <0.15 + 0.1 mm (10 grains) from hornfels (sample 259-2am). (2σ) confidence interval of error, %, (*Rho*) error correlation coefficient along coordinate axes.

were also revealed in eastern Antarctica [10] and along the southern underwater periphery of Australia [11].

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