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New K-Ar Ages for Basalts from Franz Josef Land

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Abstract. New K-Ar age determinations on basalt samples from three drillholes and outcrops on Franz Josef Land suggest that flood volcanism throughout the archipelago fits in a very narrow age interval (116±5 Ma). For 95% of the samples we studied, age scatter is within analytical uncertainty. New data on basaltic bulk-rock, trace element, and REE compositions point to mantle plume affinity for the Early Cretaceous magmatism on Franz Josef Land, which preceded the onset of seafloor spreading in the Canada Basin.

A key to the geological history of the Arctic Basin is provided by the timing of magmatism on islands adjacent to the Eurasian and Amerasian basins of the Arctic Ocean. In this context, a central role is played by the Franz Josef Land (FJL) archipelago, which has long been a focus of study [*Geology of the USSR,* 1970]. Thus far, there has been much controversy concerning the dating of the flood basalts, dikes that cut through sedimentary rocks, and sills occurring in the Mesozoic sedimentary cover and more ancient Carboniferous and Vendian strata. The latest review on the timing of magmatism on Franz Josef Land, compiled by V. D. Dibner with co-workers [*Dibner,* 1998], points to a wide scatter of radiometric (K-Ar) determinations ranging from 200 to 60 Ma (see also the list of references for other publications). Biostratigraphic data constrain the main igneous phase to the Middle to Late Jurassic, and its cessation is timed, rather tentatively, as post-Cenomanian based on a basaltic dike reportedly cutting through Cenomanian deposits on Hoffman I. [*Dibner,* 1998].

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We studied 14 basalt samples collected at various depths from three drillholes on Alexandra Land (Nagurskaya 1 Hole), Hays I. (Hays 1 Hole), and Graham Bell I. (Severnaya 1 Hole) and eight samples from exposures on other six islands (Figure 1). This collection characterizes the entire spectrum of volcanic facies: extrusive (lava flows), subvolcanic (sills), and feeder (dikes), and it is thus fairly representative.

The rocks we sampled are quartz-normative (Table 1) and display a tholeiitic differentiation trend, features typical of plume basalts [*Grachev,* 1987, 2000]. A peculiarity of the major-element composition of Franz Josef Land basalts is their high TiO_2 (up to 4.37%) and FeO^* (ave. 13.74%) contents combined with low K_2O abundances. Another remarkable feature of the FJL basalt chemistry is that the rocks are virtually undifferentiated, as illustrated not solely by our own data (including the REE spectra), but also by previous studies [*Lupanova,* 1953; *Ntaflos and Richter,* 1998; *Vlodavets,* 1934]. Taken together, these features classify FJL basalts with the Fe-Ti basalts of mantle plume affinity [*Grachev,* 1987, 2000].

For all the basalt samples that we studied, K-Ar radiometric ages were obtained. Radiogenic Ar abundances were measured on a specialized mass spectrometric unit at IGEM RAS

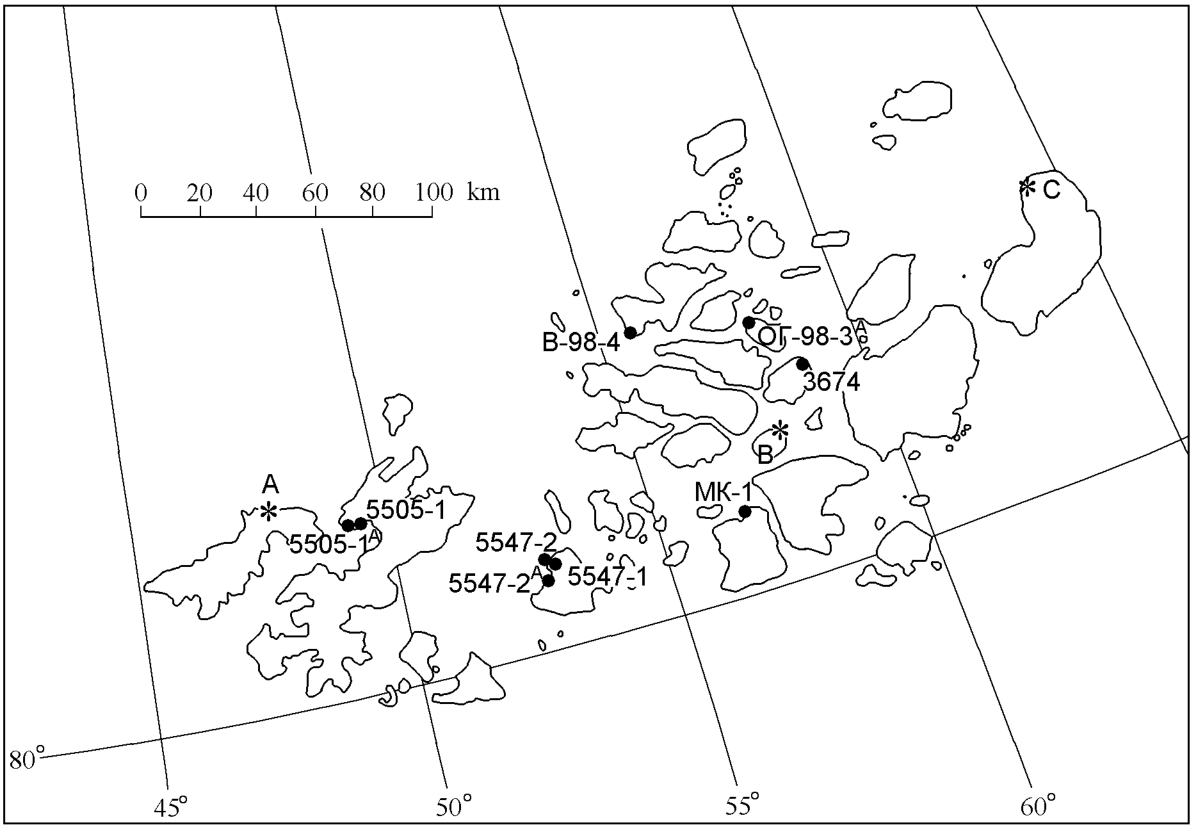

Figure 1. Scheme showing location of drillholes and surface samples. A – Nagurskaya 1 Hole, B – Hays 1 Hole, C – Severnaya 1 Hole.

using isotopic dilution with ^{38}Ar as a spike, and K abundances were measured by flame photometry [*Chernyshev et al.,* 1999]. The constants used in age calculations were: $\lambda_K=0.581\times 10^{-10}$yr.$^{-1}$, $\lambda_\beta=4.962\times10^{-10}$yr.$^{-1}$,$^{40}K=0.01167$ (at.%). The results obtained are reported in Table 2.

These data show magmatic rocks from five islands (Alexandra Land, Graham Bell I., Jackson I., and Wiener Neustadt I.) to fall in a rather narrow age interval, 116±5 Ma, which is within analytical uncertainty. Measurements from two samples collected from lava sheets on George Land yield a somewhat younger age of 95 Ma, but the potassium content of these samples is so low that these figures must be treated

Table 1. Comparison of average chemical compositions and CIPW norms (%) for Franz Josef Land basalts and typical mantle plume basalts

Component	1	2	3	4	5	6	7	Component	1	2	3	4	5	6	7
SiO_2	48.87	48.72	48.60	48.82	47.37	50.71	49.04	Q	3.65	2.07	2.93	4.34	0.51	1.06	2.68
TiO_2	2.39	2.38	1.98	2.21	2.46	1.90	2.45	Or	6.29	7.83	2.08	3.64	2.07	2.00	2.54
Al_2O_3	13.75	15.10	14.21	14.39	14.63	13.00	15.08	Ab	19.66	21.07	20.35	19.97	21.01	17.69	19.26
FeO*	14.84	13.90	13.72	13.74	13.00	11.23	11.46	An	23.96	26.13	26.95	26.86	27.74	25.09	29.66
MgO	4.64	4.02	5.21	5.20	6.79	10.27	7.49	Hy	16.85	15.32	16.67	14.81	15.37	28.13	18.13
CaO	9.21	9.41	10.37	9.88	10.89	9.61	9.96	Di	16.35	15.20	19.01	16.81	19.83	18.22	15.86
Na_2O	2.32	2.49	2.40	2.36	2.48	2.09	2.28	Mt	5.55	4.90	5.02	6.47	6.60	3.35	5.39
K_2O	1.06	1.33	0.35	0.62	0.35	0.34	0.43	Il	4.53	4.52	3.75	4.19	4.68	3.60	4.65
P_2O_5	0.32	0.36	0.23	0.25	0.27	–	–	Ap	0.75	0.84	0.55	0.60	0.64	–	–
								N	17	2	6	127	21	23	52

Note: Franz Josef Land: 1 - sills, 2 - dikes, 3 - flows, 4 - average, 5 - eastern Iceland (Ng_1); Hawaii: 6 - Mauna Loa, 7 - Waianae, Oahu I.

Table 2. K-Ar age determinations from Franz Josef Land basalts

Sampling interval, meters	Mode of occurrence	Potassium, %±σ	$^{40}Ar_{rad}$ (ppb)±σ	Age, Ma±σ
Graham Bell I. (Severnaya 1 Hole)				
2652.2–2656.4	Sill	0.31±0.015	2.37±0.09	108±6
1897.0–1902.9	Sill	0.49±0.02	4.04±0.14	116±6
754.6–756.1	Sill	0.55±0.02	4.55±0.15	116±6
Hays I. (Hays 1 Hole)				
2128.0–2125.0	Sill	0.48±0.02	3.86±0.15	112±6
1626.0–1618.4	Sill	0.51±0.02	4.40±0.15	121±7
932.9–925.9	Sill	0.27±0.015	2.10±0.09	110±7
Alexandra Land (Nagurskaya 1 Hole)				
2944.3–2947.6	Sill	0.40±0.015	3.27±0.15	114±6
2899.6–2900.0	Sill	0.69±0.02	6.04±0.20	121±5
2805.5–2812.5	Sill	0.80±0.02	7.53±0.24	131±5
2607.3–2609.9	Sill	0.68±0.02	6.06±0.20	124±5
2198.5–2205.3	Dike	1.15±0.02	9.84±0.30	119±5
1985.2–1990.2	Sill	0.84±0.02	6.99±0.23	117±8
1839.1–1843.0	Sill	0.75±0.02	6.56±0.22	122±5
1351.6–1367.6	Sill	0.47±0.02	3.84±0.15	115±6
George Land				
5534-1	Flow	0.165±0.02	1.11±0.2	95±5
5505-1A	Flow	0.110±0.005	0.74±0.03	95±5
Hooker I.				
5547-1	Sill	0.161±0.005	1.30±0.05	113±5
5542-2A	Sill	0.975±0.02	7.2±0.2	103±5
Jackson I.				
V-98-4	Flow	1.07±0.02	8.7±0.2	114±5
Greeley I.				
OG-98-3A	Flow	0.72±0.02	4.950±0.15	96±5
Wiener Neustadt I.				
3674	Sill	0.34±0.01	2.94±0.15	121±6
McClintock I.				
MK-1	Flow	0.160±0.005	1.24±0.05	108±6

with caution. As for the dating of the one basalt sample from Greeley I. (96±5 Ma), further studies are required to prove that this age is meaningful.

It thus follows that, despite the facies diversity of the volcanites ranging from flow units of the extrusive lava-flow facies to dikes and sills of the subvolcanic (vent) facies, age determinations from all the samples fall in a narrow time interval of 116±5 Ma. Such a feature of the development of flood basalts is known to be characteristic of mantle plumes [*Grachev,* 2000].

Implications of the above results suggest themselves. Phanerozoic manifestations of mantle plume magmatism (Siberian craton, Deccan Plateau, Parana River, etc. flood volcanics) are known to fit in extremely narrow time intervals (based on precision measurements, no longer than 2 or 3 m.y. and, in many cases, less than 1 m.y.) [*Grachev,* 2000]. The fact that Franz Josef Land basalts, which display the entire set of geochemical fingerprints of mantle plume magmatism, formed over a brief interval of 115±10 Ma and not from 200 to 60 Ma, as was believed earlier [*Dibner,* 1998], suggests conclusions that are pivotal to paleogeodynamic reconstructions in the Arctic.

Cretaceous magmatic rocks have been reported from many areas across the Arctic region. On the New Siberian

Is. (Kotelnyi and Stolbovoi islands), dolerite dikes as thick as tens of meters have been reported. Their age is determined tentatively as Late Cretaceous [*Dorofeev et al.,* 1999]. On Bennett I., Lower to Upper Cretaceous (?) basalts make up two sequences as thick as 360 m. Tuffaceous mudstones occurring at the base of the upper basaltic sequence host a palinologic assemblage based on which the basalts have been dated to the Lower Cretaceous (Aptian?) [*Geology of the USSR,* 1970]. According to *Drachev* [1999], K-Ar measurements on two samples yielded 112–115±5 Ma, values virtually identical with the Franz Josef Land basalt age. Cretaceous basalts are also reported from the Canadian Arctic Archipelago [*Christie,* 1980; *Donovan,* 1964; *Tozer,* 1964; et al.].

Even this plainly incomplete evidence demonstrates that basaltic magmatism in the Arctic region at the Early/Late Cretaceous boundary was probably much more widespread than had been believed. Importantly, this temporal boundary coincides with the most significant angular unconformity observed throughout the Arctic region [*Embry,* 1998]. Paleotectonic reconstructions drawing on magnetic lineations in the Arctic Basin suggest that, at that time, Franz Josef Land along with the Canadian Arctic Islands and Svalbard were located closely together [*Rowley and Lottes,* 1989]. Within that framework, the area of basaltic magmatism was near the locus of the Icelandic hot spot for the same interval of time [*Drachev,* 1999; *Lawver and Muller,* 1994].

Because mantle plume activity is known to precede continental breakup and inception of oceanic basins, it follows that mantle plume magmatism at 116±5 Ma on Franz Josef Land was a direct precursor of the onset of seafloor spreading in the Canada Basin. This conclusion agrees with the latest results from the analysis of magnetic lineations in this basin [*Grantz et al.,* 1998].

References

Chernyshev, I. V., et al., K-Ar isotope systematics and age of the recent volcanism of the Kazbek volcanic area, Greater Caucasus, *Dokl. Ross. Akad. Nauk, 367,* 810–814, 1999 (in Russian).

Christie, R. L., The Arctic Archipelago, in: *Encyclopedia of World Regional Geology,* Dowden, Hutchison and Ross, Stroudsbury, 1975.

Dibner, V. D., Ed., *Geology of Franz Josef Land,* Norsk Polarinstitutt, 190 pp., Meddelelser, 146, Oslo, 1998.

Donovan, D. T., The Cretaceous Deposits of Eastern Greenland, in: *Geology of the Arctic,* Toronto University Press, 1964.

Dorofeev, V. K., M. G. Blagoveshchensky, A. N. Smirnov, and V. I. Ushakov, *The New Siberian Islands: Geological Structure and Metallogeny,* 130 pp., VNIIOkeanologiya, St. Petersburg, 1999 (in Russian).

Drachev, S. S., *Tectonics of the rifted continental margin of northeastern Eurasia in the Arctic (the Laptev and East Siberian seas),* Ph. D. thesis, 40 pp., Moscow, 1999 (in Russian).

Embry, A. F., Tectonic Implications of Large-scale Jurassic-Cretaceous Sequence Boundaries in the Circum-Arctic, III Inter. Conference on Arctic Margins, 54–55, 1998.

Geology of the USSR, vol. XXVI, The Islands of the Soviet Arctic: A Geological Description, Nedra, Moscow, 1970 (in Russian).

Grachev, A. F., *Rift Zones of the Earth,* 2-nd edition, supplemented and revised, Nedra, Moscow, 1987 (in Russian).

Grachev, A. F., Mantle plumes and the problems of Geodynamics, *Physics Solid Earth, 36,* (4), 263, 2000.

Grantz, A., D. L. Clark, R. L. Phillips, S. P. Srivastava, et al., Phanerozoic stratigraphy of Northwind Ridge, magnetic anomalies in the Canada Basin and the geometry and timing of rifting in the Amerasia Basin, Arctic Ocean, *Geol. Soc. Am. Bull., 110,* 801–820, 1998.

Jackson, H. R., A. Grantz, I. Reid, S. D. May, and P. E. Hart, Observations of anomalous oceanic crust in the Canada Basin, Arctic Ocean, *Earth Planet. Sci. Lett., 134,* 99–106, 1995.

Komarnitsky, V. M., and E. V. Shipilov, New geological data on the magmatism of the Barents Sea, *Dokl. Akad. Nauk SSSR, 320,* 1203–1206, 1991 (in Russian).

Komarova, A. E., and L. P. Pirozhkov, Basalt sheets on Champ and Wiener Neustadt islands, Franz Josef Land, *Dokl. Akad. Nauk SSSR, 131,* (2), 409–411, 1960 (in Russian).

Lawver, L. A., and R. D. Muller, Iceland hotspot track, *Geology, 22,* 311–314, 1994.

Lupanova, N. P., On the Petrography of Franz Josef Land, *Tr. Nauch.-Issl. Inst. Geol. Arktiki, LVII,* 73 pp., 1953 (in Russian).

Masurenkov, Yu. P., and G. B. Flerov, Basalts of the Bennett Island, the Soviet Arctic, *Vulkanol. Seismol.,* (1), 36–53, 1989 (in Russian).

Northwind Ridge, Magnetic Anomalies in the Canada Basin and the Geometry and Timing of Rifting in the Amerasia Basin, *Arctic Ocean, Geol. Soc. Am. Bull., 110,* 801–820, 1998.

Ntaflos, Th., and W. Richter, Continental flood basalts from Franz Josef Land, Arctic Russia: Evidence for bimodal magmatism, III Inter. Conference on Arctic Margins, 131–132, 1998.

Rowley, D. B., and A. L. Lottes, Plate-kinematic Reconstructions of the North Atlantic and Arctic: Late Jurassic to Present, in: *Mesozoic and Cenozoic Plate Reconstructions,* edited by Scotese, C. R., and W. W. Sager, 73–120, Elsevier, Amsterdam, 1989.

Solheim, A., E. Musatov, and N. Heintz, Eds., *Geological aspects of Franz Josef Land and the northernmost Barents Sea,* Norsk Polarinstitutt, Meddelelser, 151, Oslo, 1998.

Tarakhovsky, A. N., I. V. Shkola, and V. L. Andreichev, Age of flood basalts from Franz Josef Land, *Dokl. Akad. Nauk SSSR,* 965–969, 1983 (in Russian).

Tarnugo, J. A., The high Arctic large igneous province, III Inter. Conference on Arctic Margins, 184, 1998.

Test, B. I., On the Materials on Basalts from Franz Josef Land, *Tr. Arktich. Inst., 76,* 1937 (in Russian).

The Northern Land: Geological Structure and Metallogeny, 187 pp., VNIIOkeanologiya, St. Petersburg, 2000 (in Russian).

Tozer, E. T., A Stratigraphic Summary of Mesozoic and Tertiary Deposits of the Canadian Arctic Archipelago, in: *Geology of the Arctic,* Toronto University Press, 1964.

Vlodavets, V. I., On the petrography of the Hooker Island, *Tr. Arktich. Inst., XIII,* 87–113, 1934 (In Russian).

Vogt, P., P. Taylor, L. Kovacs, and G. L. Johnson, Detailed aeromagnetic investigation of the Arctic Basin, *J. Geophys. Res., 84,* 1071–1089, 1979.

Vogt, P., C. Bernero, L. Kovacs, and P. Taylor, Structure and plate tectonic evolution of the marine Arctic as revealed by aeromagnetics, *Oceanol. Acta,* SP, 25–40, 1981.

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