New findings of alkaline-ultramafic dykes in the Prince Charles Mountains: Age and composition

A. A. Laiba,[1] B. V. Belyatsky,[2] and N. V. Rodionov[3]

[1]Polar Marine Geological Expedition, St.-Petersburg, Russia (laibageo@peterlink.ru)
[2]Institute for Geology and Mineral Resources of the World Ocean (VNIIOkeangeologia), St.-Petersburg, Russia (bbelyatsky@mail.ru)
[3]All-Russian Geological Institute (VSEGEI), Center of Isotopic Research (CIR), St.-Petersburg, Russia (Nickolay_Rodionov@vsegei.ru)

Summary Dykes of phlogopite-bearing alkaline picrite discovered in 2004 in the southern part of Mt. Meredith are comparable through their mineralogy and geochemistry with typical mica-bearing kimberlites and distinctive from the well-known alkaline-ultramafic bodies in Jetty Peninsula and along the shores of Radok Lake. At the same time, temperature and pressure estimations of their crystallization - 990˚C and 18-26 kbar and the time of intrusion – 122 Ma and primary isotope signatures ($^{87}Sr/^{86}Sr_i$ = 0.7048 – 0.7051, ε_{Nd} = -1.0 – -0.6) lead us to infer a similarity to the rocks of the Beaver Lake Province. Taking into consideration this fact and supposing that their formation is connected with development of Lambert-Amery rift in Mesozoic time and mantle activity under the influence of the mantle plume (Kerguelen plume?) which caused Gondwana breakup, we suggest that these alkaline-ultramafic bodies make up a single magmatic province, similar in time and development to the alkaline-ultramafic-carbonatite Shillong Province in India.

Citation: Laiba, A.A., B.V. Belyatsky and N.V. Rodionov (2007), New findings of alkaline-ultramafic dykes in the Prince Charles Mountains: Age and composition, in Antarctica: A Keystone in a Changing World – Online Proceedings of the 10th ISAES, edited by A.K. Cooper and C.R. Raymond et al., USGS Open-File Report 2007-1047, Extended Abstract 195, 5 p.

Introduction

Small bodies of alkaline–ultramafic rocks were found in the northern part of the Prince Charles Mountains in 1970 – 1980s (Laiba et al., 1987; Egorov, 1994; Mikhalsky et al., 1998; Mikhalsky et al., 2001). Dykes, stocks and sills, supposed to be connected with Amery rift propagation during Mesozoic time, crop out within Jetty Peninsula and on the southern shore of Radok Lake, where they cut Meso–Neoproterozoic metamorphic rocks and Permian sediments (Fig. 1). Stock bodies are from 10 x 25 to 80 x 120 m in size, dykes are about 180 m long with thickness about 2 m. K–Ar age estimations by whole–rock samples and phlogopite vary from 150 ± 5 to 113 ± 5 Ma (Laiba et al., 1987). The inner stock structure can be divided into three stages of intrusion: 1) tuffisite breccias, 2) biotite-pyroxene alkaline picrites and melanephelinites, 3) polzenites (these rocks are not wide spread). All the phases contain different ultramafic nodules of mantle origin. Accessory minerals are represented by chromium diopside, chrome–spinel, pyrope, several small diamond crystals were found in the tuffisite from one of this stock. Detail description of petrologic peculiarities of the ultramafic bodies and mantle inclusions can be find in a number of special papers (Andronikov and Egorov, 1993; Egorov, 1994; Andronikov 1997; Foley et al., 2006). On the basis of these detail investigations there has been carried out reconstruction of composition up to the depth of 100 - 150 km and evolution of mantle segment for this part of Antarctic lithosphere from Proterozoic till Mesozoic time. At the same time, the problem of precise age and relationship of magmatic bodies of this alkaline – ultramafic province still remain understudied. Bodies localization at the intersection of deep meridianal structures connected with Paleozoic rift of Beaver Lake and submeridianal fracture zones, spatial proximity, similarity in mineralogical-geochemical composition could evidence to closeness in time of intrusion and crystallization of these bodies. But, the age estimations suppose the considerable gap in time - from 40 to 50 Ma for formation of alkaline-ultramafic bodies of Beaver Lake province which is higher than the known age characteristics for the other similar regions of the world. Absence of precise age estimations does allow correlate this province with the other Mesozoic alkaline-ultramafic provinces of the other Gondwana continents – India, Australia and Africa. Considering that age estimations for the these bodies were carried out by means of K-Ar method mainly for whole rock samples, many of which had undergone the influence of carbonate metasomatism and included different xenogenic mantle minerals which make data interpretation and comparison more difficult, we have tried on the basis of more convenient isotope systems to estimate the time of intrusion of alkaline-ultramafic rocks of Beaver province and to compare their age with the same characteristics for kimberlite dykes discovered within the Fisher Massif and Mt. Meredith.

Mineralogical and chemical composition

In 2004 in the southern part of Mt. Meredith (central part of the Prince Charles Mountains, Fig. 1) there was found a new dyke of phlogopite-alkaline picrites (Laiba and Kudryavtsev, 2006). Not thick dyke (15 – 20 cm) is 50 m long, has north-east strike and cuts Proterozoic biotite paragneisses. Moreover, in Cenozoic glacial sediments on the south-eastern slope of Meredith massif there have been found the fragments and boulders (about 0.5 m in size) made up by alkaline pyroxene picrites of a different petrochemical type. Dyke rocks are fresh and have clear porphyritic texture. Phlogopite-

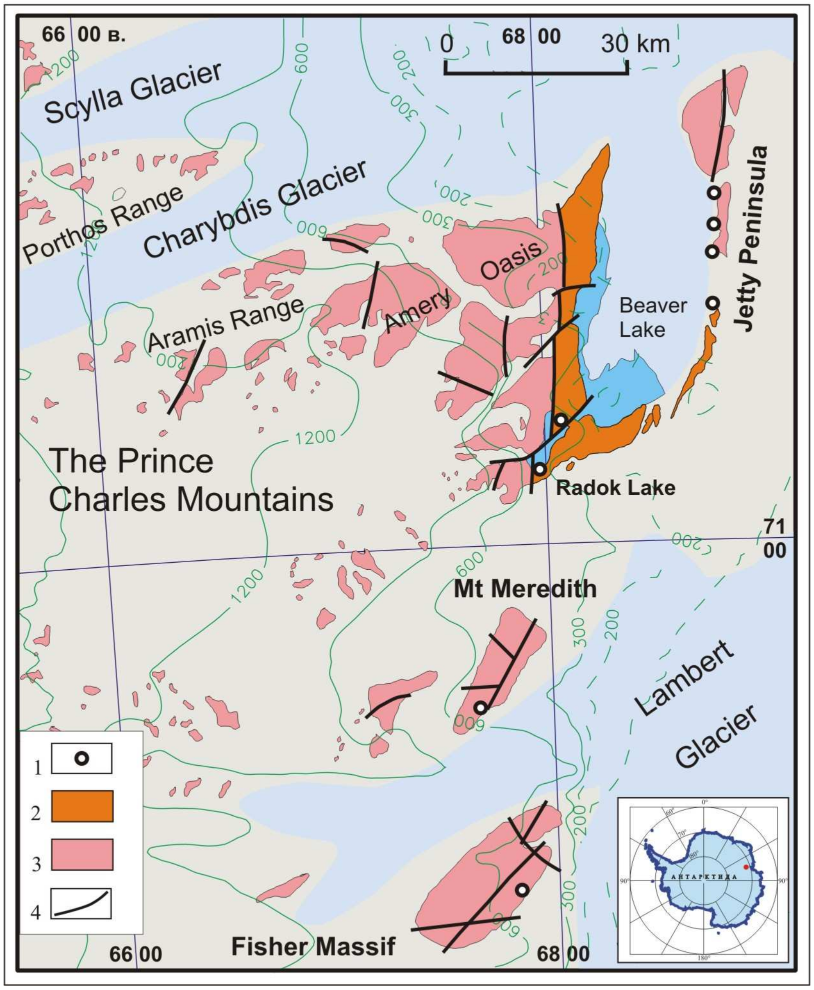

Figure 1. Geological sketch map showing occurrences of alkaline-ultramafic rocks in the northern and central parts of the Prince Charles Mountains: 1 – Jurassic-Cretaceous alkaline picrites; 2 – Permian-Triassic coal-bearing deposits; 3 – Precambrian rocks; 4 – faults.

olivine microlitic matrix contain disintegrated mantle nodules represented by olivine, phlogopite and orthopyroxene megacrystals with the size up to 3 x 5 cm, their general share is 20 – 25 %. The main rock–forming minerals are olivine (20 – 25 %) and phlogopite (40 – 55 %), minor minerals are Ti–magnetite (about 5 %), and pyroxene (1 – 2 %), accessory minerals are represented by apatite, ilmenite, monazite, pyrite. In picrites there are parts made up by volcanic glass. Rocks are not deformed but rather strongly altered and contain not less than 10 – 20 % of secondary carbonate. By mineral and chemical composition phlogopite picrites are close to typical mica kimberlites and represent a new type among the known alkaline-ultramafic rocks developed in Jetty Peninsula and on Radok Lake shores (Table 1).

The studied phlogopite megacrystals (phlogopite – I) have zoned structure with rims which are close to matrix phlogopite by their composition. Higher Mg content in rims could be caused by Ti–magnetite crystallization due to the rise of oxygen activity in the course of picrite melt rising. Heterogeneity of early (mantle) phlogopite is proved by corroded outer parts of megacrystals' nuclei. Crystallization temperature of olivine-orthopyroxene equilibrium was estimated as about 990° C (Mori and Green, 1978). Corresponding pressure is about 18 – 19 kbar according to (Perchuk, 1977) or about 25 – 29 kbar according (McGregor, 1974) geobarometers. The obtained parameters are within graphite stability field and on the whole correspond to the early calculated P – T conditions for lherzolite inclusions from alkaline-ultramafic bodies of Jetty Peninsula.

In the central part of the Prince Charles Mountains – Fisher massif, in 1989 there was discovered a dyke of "carbonatite kimberlites" (Egorov et al., 1993). Thin (20 – 25 cm) kimberlite dyke outcrops on the south-eastern slope of the massif where it makes an interrupted band about 450 m long and it cuts Meso-Proterozoic metadiorites of the Fisher complex. General dyke strike is of meridianal direction with the dip angle about 20 – 25 to the west. By paleomagnetic data (Q > 1) and chemical affinity to alkaline-ultramafic rocks of Jetty oasis the age of kimberlites is estimated as possibly Cretaceous. Carbonate kimberlites are composed by phlogopite inclusions (up to 10 %), single grains of green mica, olivine and magnetite, all these minerals are placed into fine-grained phlogopite-magnetite-calcite-olivine matrix with an admixture of apatite, chromite and serpophite. The rock has lens–striped texture represented by alteration of light and dark stripes with different amount of calcite and dark minerals which have different morphology and size. The interstices are made up mainly by calcite. Its share is 25 – 60 % in light layers and 80 – 90 % in schlieren of globular texture. There are distinguished primary magmatic and metasomatic types of calcite (Egorov et al., 1993). Chemical composition of rocks is characterized by considerable variations of the main components (wt% for 5 analysis): SiO_2: 8 – 22, Fe_2O_3: 8 – 15, MgO: 4 – 19, CaO: 20 – 43, CO_2: 15 – 32, K_2O: 0.2 – 1.3, Na_2O: 0.01 – 0.3, P_2O_5: 1.6 – 3.3 (Table 1). It could be explained by heterogeneity of mineral composition within magmatic layered rocks. Kimberlites from the Fisher massif in their general features are similar to the rocks of the kimberlitic sill belonging to Benfontein group, South Africa (Dawson, 1973).

Table 1. Representative compositions of alkaline-ultramafic rocks from the Prince Charles Mountains (wt % and ppm)

	1	2	3	4	5	6	7	8	9	10	11
SiO_2	31.1	30.5	30.7	34.9	33.83	35.55	38.93	24.19	20.54	35.20	31.1
TiO_2	2.29	2.73	2.83	1.47	2.21	2.28	1.62	2.00	1.25	2.32	2.03
Al_2O_3	4.58	5.14	5.42	4.13	8.36	8.62	6.51	4.70	2.24	4.40	4.90
Fe_2O_3	5.29	7.52	7.55	9.76*	4.04	4.46	3.21	2.66	12.40*	9.8*	10.50*
FeO	4.76	3.13	3.20		6.39	6.13	5.99	5.41			
MnO	0.16	0.19	0.18	0.15	0.18	0.18	0.14	0.14	0.19	0.11	0.10
MgO	24.4	20.5	20.4	23.20	14.08	16.50	20.92	15.17	17.06	27.9	23.90
CaO	11.4	12.9	12.6	12.80	14.75	13.88	9.67	15.56	22.10	7.6	10.60
Na_2O	< 0.05	< 0.05	< 0.05	0.19	1.71	2.08	1.69	0.52	0.28	0.32	0.31
K_2O	2.91	2.24	2.07	2.20	2.67	1.94	1.65	3.01	0.58	0.98	2.1
P_2O_5	0.66	2.15	1.56	0.41	0.86	0.91	0.61	1.38	1.56	0.70	0.70
LOI	11.6	12.2	12.5	10.60	11.00			24.47	22.13		
Total	99.6	99.5	99.3	99.80	100.08			99.21	100.33		
Rb	90	87.5	85.4	61.1	95 – 125	38 – 125	37.9 – 64.4	119		0 – 350	
Sr	1340	1670	1500	913	578 – 119	578 – 1674	733 – 908	1407	1502 – 1997	40 – 1900	
Zr	378	542	536	173	39 – 303	39 – 303	186 – 223	423	141 – 177	84 – 700	
Y	17.4	26.7	28.3	9.2	21 – 29	21 – 29	16.3 – 21.6	27	22 – 4	4 – 75	
U	< 2	6.47	6.52	< 2	1 – 2	1.5 – 3.6	< 2 – 2.19	2	219 - 243	0.6 – 18.3	
Pb	10.4	29.3	20.2	8.98	5 – 10	5 – 10	5.78 – 3.40	26		0.9 –50.0	
Nb	153	205	208	103	21 – 144	21 – 144	78.3 – 130	161		32 – 450	
Th	30.3	31.1	35.2	10.6	14 – 22	14 – 23	8.78 – 13.00	25		4 – 54	

Note: * – total Fe as Fe_2O_3
1 – 4: phlogopite picrites from Mt. Meredith (1 – 3: from a dyke; 4: from moraine); 5 – 9: alkaline ultramafics from the Prince Charles Mountains (5: polzenites from Radok lake, average of 2 samples; 6: melilite picrites (polzenites) from Jetty Peninsula, average of 13 samples; 7: pyroxene picrites from Jetty Peninsula, average of 34 samples; 8: carbonatite kimberlite from Mt. Meredith (Mikhalsky et al., 2001), 9: carbonatite kimberlite from Fisher Massif (Egorov et al., 1993)); 10: average olivine kimberlites (Dawson, 1967; Muramatsu, 1977); 11: average mica kimberlites (Dawson, 1967).

Age estimation

For the oldest according to K–Ar age estimations (Laiba et al., 1987) rocks (alkaline picrite) from Yuzhnoe stock there have been obtained Sm–Nd and Rb–Sr isochrons for fractions of rock–forming minerals (n = 6) by the method of selective acid separation which reveal the age trends of 125 ± 7.5 and 122 ± 3.2 Ma, correspondingly (with primary isotope compositions: ε_{Nd} = -0.73, $^{87}Sr/^{86}Sr_i$ = 0.705105). These age estimations coincide within the error for the three measured samples from this body and time of it crystallization estimated as the average value from these estimations corresponds to 124 ± 2.2 Ma and differs considerably from the earlier obtained data for this object.

To estimate the age of carbonatite kimberlite dyke from Fisher Massif there has been carried separation of zircon from one sample by traditional method of separation in heavy liquids. Total amount of separated zircon grains was about 20 from the sample about 1.5 - 2 kg. They were represented by particles of large transparent and weakly colored crystals of typical magmatic habitus (Fig. 2a, b). CL images are typical for zircons of alkaline-ultramafic rocks and kimberlites (Belousova et al., 1998, 2001) and are characterized by large block structure caused by repetition of dark and light zones (Fig. 2a, b) corresponding to considerable fluctuation in U, Th, Pb and REE content (Fig. 2c) which is connected with peculiarities of zircon crystallization under conditions of fluid saturated kimberlite melt. U-Pb isotope compositions were measured in the 6 largest zircon grains by SIMS SHRIMP–II (Fig. 2d). The obtained results, in spite of considerable variations of element content [U]: 18 – 348 ppm, [Th]: 5 – 1069 ppm, [Pb]: 0.3 – 5.9 ppm and the presence of unradiogenic Pb up to 12 %, have allowed to construct discordia and evaluate the age of zircon crystallization as 122.1 ± 1.3 Ma. The obtained crystallization age estimation, without any doubt, characterizes magmatic event, because not only Th/U ratio 0.3 – 3.2 is typical for magmatic zircons (more over, values > 1.0 are usually connected with kimberlite zircons (Belousova et al., 1998)), but REE distributions in the studied zircons correspond to the typical magmatic fractionation at zircon crystallization from a melt (point 1.3, Fig. 2c). At the same time, as it has been already mentioned, crystallization peculiarity, first of all, interaction of crystallizing zircon matter with the enriched in lithophile elements fluid results in formation of separate zones within the zircon grains characterized by metasomatic carbonatite distribution of REE (Fig. 3c, points 1.1, 3.1). Also, for this kimberlite sample by three points there has been built inner mineral Rb-Sr isochron (whole–rock sample, phlogopite, carbonate) which corresponds to the age 118.4 ± 3.2 Ma with primary isotope composition $^{87}Sr/^{86}Sr_i$ = 0.704870 (ε_{Nd} = -0.96) which coincides well with the results of U-Pb zircon dating. At last, for the dyke of phlogopite alkaline picrites of Mt. Meredith there have been obtained Rb–Sr age estimation (two–points isochron: whole-rock–phlogopite) corresponding to 119.8 ± 1.5 Ma with primary isotope composition: $^{87}Sr/^{86}Sr_i$ = 0.705052 (ε_{Nd} = -0.6).

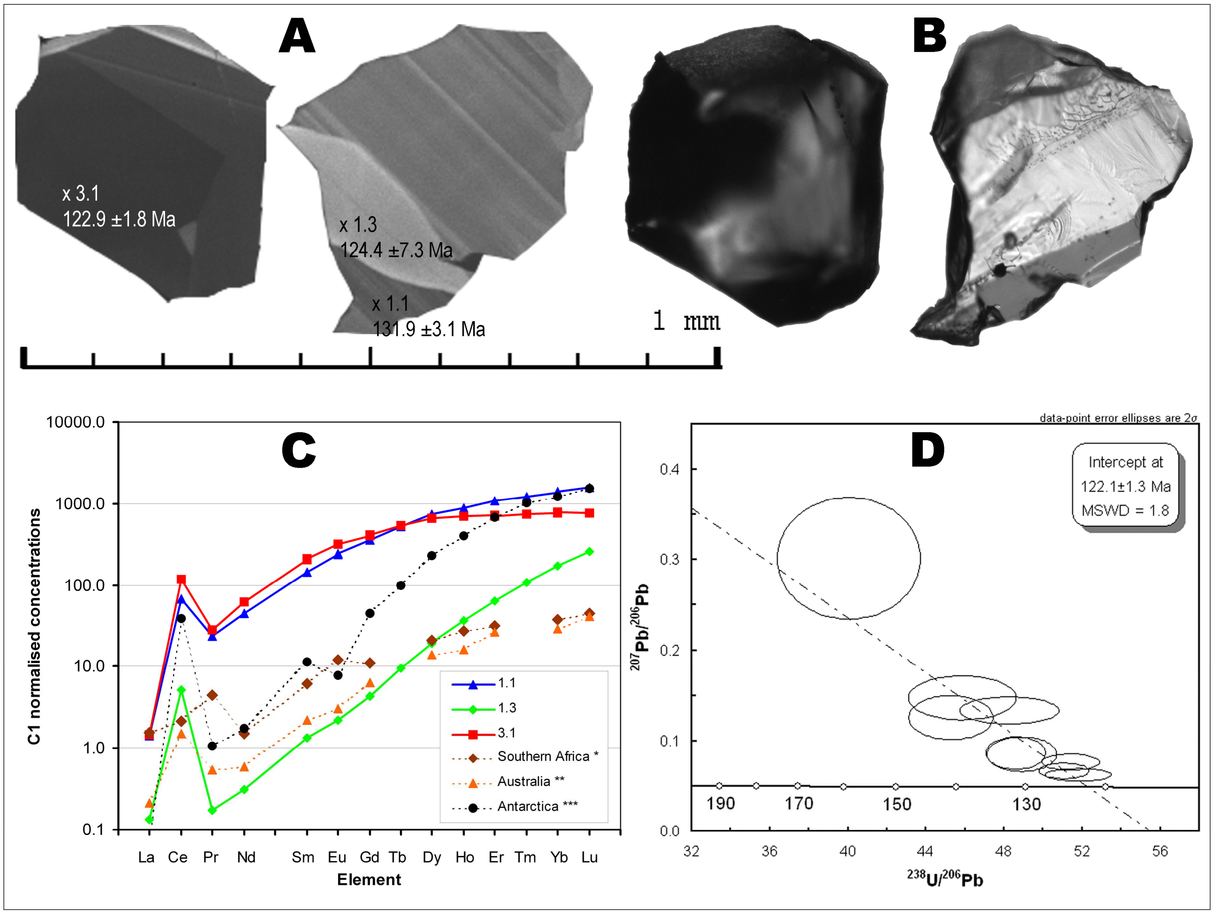

Figure 2. Studied zircons from carbonatite kimberlite dyke, Fisher Massif.
A – CL images; B – optic images; C – REE patterns, numbers correspond to analytical-points of A, *, ** - kimberlite zircons from (Belousova et al., 1998, 2001), *** - Mawson charnockite zircon from (Hoskin and Ireland, 2000); D – Tera-Wasserburg concordia diagram.

Thus, the carried out age estimations and isotope composition of alkaline-ultramafic bodies of the Prince Charles Mountains allow to suppose their close in time intrusion and crystallization under conditions of developing in Mesozoic time Lambert–Amery rift and similar primary isotope composition of mantle source (or its similar evolution) and, as a result, to consider these geologic objects as products of a single alkaline-ultramafic province.

Acknowledgements. This research was supported by Federal Program “World Ocean” – subprogram “Antarctica”. We thank to I. V. Kudryavtsev (PMGE, VSEGEI) for help in the first stage of this research, valuable and fruitful discussion with E. Mikhalsky and A. Andronikov, and all colleagues in the Center of Isotopic Research (VSEGEI) who conducted a lot of work in careful preparation of zircon material and studied under different analytical devices.

References

Andronikov, A. V., and L. S. Egorov (1993), Mesozoic alkaline-ultrabasic magmatism of Jetty Peninsula, in Gondwana Eight: Assembly, Evolution and Dispersal, edited by R.H. Findlay, R. Unrug, M.R. Banks, and J.J. Veevers, pp. 547–557, Balkema, Rotterdam.

Andronikov, A. V. (1997), Varying glass compositions in deep-seated inclusions from alkaline-ultramafic rocks of Jetty Peninsula)East Antarctica): evidence for mantle metasomatism, in The Antarctic Region: Geological Evolution and Processes, edited by C. A. Ricci, pp. 901-910, University of Siena.

Belousova, E. A., W. L. Griffin, and N. J. Pearson (1998), trace element composition and cathodoluminescence properties of southern African kimberlitic zircons, Mineralogical Magazine, 62(3), 355–366.

Belousova, E. A., W. L. Griffin, S. R. Shee, S. E. Jackson, and S. Y. O’Reilly (2001), Two age populations of zircons from the Timber Creek kimberlites, Northern Territory, as determined by laser-ablation ICP-MS analysis, Australian Journal of Earth Sciences, 48, 757–765.

Dawson, J. B. (1967), Geochemistry and origin of kimberlite, in Ultramafic and related rocks, edited by P.J. Wyllie, pp. 269–278, Wiley, New York.

Egorov, L. S., A. Yu. Melnik, and A. V. Ukhanov (1993), First finding of a kimberlite dyke containing syngenetic calcite carbonatite schlieren in Antarctica, Reports of USSR Academy of Sciences, 328, 230–233.

Egorov, L. S. (1994), Some petrologic, geochemical and genetic peculiarities of the hypabyssal alkaline-ultramafic rocks with the example of the polzenite-alkaline picrite complex of Jetty Peninsula (Prince Charles Mountains, East Antarctica), Geochemistry International, 1, 24–39.

Foley, S. F., A. V. Andronikov, and S. Melzer (2002), Petrology of ultramafic lamprophyres from the Beaver Lake area of Eastern Antarctica and their relation to the breakup of Gondwanaland, Mineralogy and Petrology, 74, 361–384.

Foley, S. F., A. V. Andronikov, D. E. Jacob, and S. Melzer (2006), Evidence from Antarctic mantle peridotites xenoliths for changes in mineralogy, geochemistry and geothermal gradients beneath a developing rift, Geochim. Cosmochim. Acta, 70, 3096–3120.

Hoskin, P. W. O., and T. R. Ireland (2000), Rare earth element chemistry of zircon and its use as a provenance indicator, Geology, 28, 627–630.

Laiba, A. A., A. V. Andronikov, L. S. Egorov, and L. V. Fedorov (1987), Stock and dyke bodies of alkaline-ultrabasic composition at Jetty Peninsula (Prince Charles Mountains, East Antarctica), in Geological–geophysical investigations in Antarctica, edited by V. L. Ivanov, and G. E. Grikurov, pp. 35–47, “Sevmorgeologia”, Leningrad.

Laiba, A. A., and I. V. Kudriavtsev (2006), Geological observations on the eastern fringe of the Amery Ice Shelf during the 49th Russian Antarctic Expedition, in Russian Earth Science Research in Antarctica, edited by G. L. Leitchenkov and A. A. Laiba, pp. 33–53, VNIIOkeangeologia, St.-Petersburg.

McGregor, I. D. (1974), The system MgO-Al2O3-SiO2: solubility of Al2O3 in enstatite for spinel and garnet peridotite compositions, American Mineralogist, 59, 261–279.

Mikhalsky, E. V., J. W. Sheraton, A. A. Laiba, R. J. Tingey, D. E. Thost, E. N. Kamenev, and L. V. Fedorov (2001), Geology of the Prince Charles Mountains, Antarctica, Geoscience Australia Bulletin, 247, Canberra, AGSO, Australia.

Mikhalsky, E. V., A. A. Laiba, and N. P. Surina (1998), The Lambert Province of alkaline-basic and alkaline-ultrabasic rocks in East Antarctica: geochemical and genetic characteristics of igneous complexes, Petrology, 6, 466–479.

Mitchell, R. H. (1991), Kimberlites and lamproites: primary sources of diamond, Geoscience Canada, 18(1), 1–16.

Mori, T., and D. H. Green (1978), Laboratory duplication of phase equilibria observed in natural garnet lherzolites, Journal of Geology, 86, 83–97.

Muramatsu, Y. (1977), Geochemische Untersuchungen an Kimberliten, einen Granat-peridotit und einen Eklogit-Einschlu? aus Kimberleg, Sudafrika, Dr. Dissertation, University of Göttingen, Germany.

Perchuk, L. L. (1977), Pyroxene barometer and “pyroxene geotherms”, Reports of USSR Academy of Sciences, 233, 1196–1200.