

Petrology, Geochemistry and K-Ar Age Constraints of the Eastern De Gerlache Seamount Alkaline Basalts (Bellingshausen Sea, Southeast Pacific)

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Abstract: Abstract: The De Gerlache Seamounts are two topographic highs in the Bellingshausen Sea, southeastern Pacific. Petrological and geochemical studies together with K-Ar age determinations were carried out on four dredged basalt samples collected during a RV "Polarstern" expedition (ANT-XII/4) in 1995. Minor and trace element composition suggest alkaline basalt compositions. Compared to alkaline basalts of adjacent West Antarctica (the Jones Mountains) and of Peter I Island, the samples have lower mg-numbers, lower Ni and Cr contents and lower high field-strength elements (HFSE)/Nb and large-ion lithophile elements (LILE)/HFSE ratios. Three of the four samples have low K, Rb, and Cs concentrations relative to alkaline basalts. The K-depletion and other elemental concentrations may be explained by 1.1% melting of amphibole bearing mantle material. Additionally, low Rb and Ba values suggest low concentrations of these elements in the mantle source. K-Ar age determinations yield Miocene ages (20-23 Ma) that are similar in age to other alkaline basalts of West Antarctica (Thurston Island, the Jones Mountains, Antarctic Peninsula) and the suggested timing of onset of Peter I Island volcanism (~10-20 Ma). The occurrence of the DGS and Peter I Island volcanism along an older but reactivated tectonic lineation suggests that the extrusions exploited a zone of pre-existing lithospheric weakness. The alkaline nature and age of the DGS basalts support the assumption of plume activity in the Bellingshausen Sea.

Zusammenfassung: Die De-Gerlache-Seamounts (DGS) sind zwei topographische Erhebungen im Bellingshausenmeer des südöstlichen Pazifiks. Petrologische und geochemische Untersuchungen sowie K-Ar-Altersbestimmungen wurden an vier Gesteinsproben, die während der „Polarstern“-Expedition ANT-XII/4 (1995) mit einer Gesteinsdredge am östlichen Seamount gesammelt wurden, durchgeführt. Die Neben- und Spurenelementzusammensetzung und die Anreicherung der inkompatiblen Elemente Ti, P, Nb und Zr zeigen eine alkalische Natur der Basalte an. Im Vergleich zu den alkalischen Basalten des nahen westantarktischen Kontinents (Jones Mountains) und der Peter-I-Insel haben die Basalte geringe mg-Werte, geringe Ni- und Cr-Konzentrationen und geringe HFSE (High Field Strength Element)/Nb- und LILE (Light Incompatible Elements)/HFSE-Verhältnisse. Diese Abweichungen in der geochemischen Zusammensetzung kann durch Fraktionierung einer Mantelphase bei geringem Aufschmelzgrad erklärt werden. Ein weiteres Merkmal der geochemischen Zusammensetzung sind sehr geringe K-, Rb- und Cs-Konzentrationen im Vergleich zu den alkalischen Inselbasalten. Während die K-Verarmung und die anderen Elementkonzentrationen gut durch eine 1.1%-ige Aufschmelzung von primitivem Mantelmaterial mit Amphibol als Restphase modelliert werden kann, können die geringen Rb- und Ba-Konzentrationen nur auf kleine Konzentrationen dieser Elemente in der primären Zusammensetzung des Mantelmaterials selbst zurückgeführt werden. Die K-Ar-Altersbestimmungen ergaben ein miozänes Alter (20-23 Ma) und stimmen mit dem Altersbereichen der alkalischen Basalte der Westantarktis (Thurston Island, Marie Byrd Land und Antarktische Halbinsel) wie auch mit der angenommenen initialen Platznahme der Basalte der Peter-I-Insel (~10-20 Ma) überein. Das Auftreten des Vulkanismus der DGS und Peter-I-Insel entlang eines älteren, aber reaktivierten tektonischen Lineaments legt den Schluss nahe, dass bei den Extrusionen eine lithospärische Schwächezone ausgenutzt wurde. Der alkalische Charakter und das Alter der DGS-Basalte erhärten die Annahme, dass die Vulkanite im Bellingshausenmeer auf einen Mantel-Plume zurückgeführt werden können.

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INTRODUCTION

The identification and interpretation of magnetic anomaly patterns suggest a complex tectonic history of the Bellingshausen Sea in the southeastern Pacific (HERRON & TUCHOLKE 1976, STOCK & MOLNAR 1987, CANDE et al. 1989, MAYES et al. 1990, LARTER et al. 2002, EAGLES et al. 2004). The existence of a Phoenix (or Aluk) Plate that was subducted almost completely below the Antarctic Peninsula since the Cretaceous is well established and is reflected by the emplacement of Late Jurassic to Early Cretaceous calc-alkaline basalts on Thurston Island. Satellite-derived gravity data show a set of north – south striking, large-amplitude gravity anomalies (MCADOO & LAXON 1997). One of the two dominant anomaly branches is in alignment with the De Gerlache Seamounts (DGS) and Peter I Island and has been discussed as the signature of a possible scar after a ridge jump of the Phoenix-Antarctic ridge at chron C27n (about 61 Ma) (LARTER et al. 2002). The second branch intersects with the first one at the location of the DGS and is interpreted as a result of compressional and transtensional tectonics (GOHL et al. 1997, CUNNINGHAM et al. 2002, EAGLES et al. 2004).

Cenozoic alkaline volcanic rocks throughout West Antarctica occur in diverse tectonic environments. Significant differences in the abundance of large-ion lithophile elements (LILE) divide the West Antarctic basalts in two groups. Basalts from the Antarctic Peninsula have high K/Ba and K/Rb ratios (50-140 and 500-1500, respectively) and marked Ba depletion (Ba/Nb 2.5-8.0); their origin is mainly attributed to slab window formation following the cessation of subduction (HOLE 1988, 1990). Basalts from West Antarctica (Marie Byrd Land, the Jones Mountains, and Thurston Island), and Peter I Island in the Bellingshausen Sea have LILE distributions within the range of ocean island basalts (OIB) (K/Ba <50, Ba/Nb 5-20) and their origin is mainly attributed to plume activity which also explains tectonic doming and associated spatial patterns of volcanism in the area (FUTA & LEMASURIER 1982, HART et al. 1995, HOLE et al. 1994, LEMASURIER & REX 1989). K-Ar ages of basalts of Peter I Island from PRESTVIK et al. (1990) and PRESTVIK & DUNCAN (1991) yield 0.33-0.1 Ma, but based on estimated volume and eruption rate, volcanism may have started around 10 to 20 Ma ago (PRESTVIK et al. 1990). BASTIEN et al. (1976) determined K-Ar ages of 13 Ma, but these results may be erroneous due to analyses of an older xenolith (PRESTVIK & DUNCAN 1991).

The DGS are two topographic highs with typical guyot morphology (LECOINTE & BELGICA, HAGEN et al. 1998)

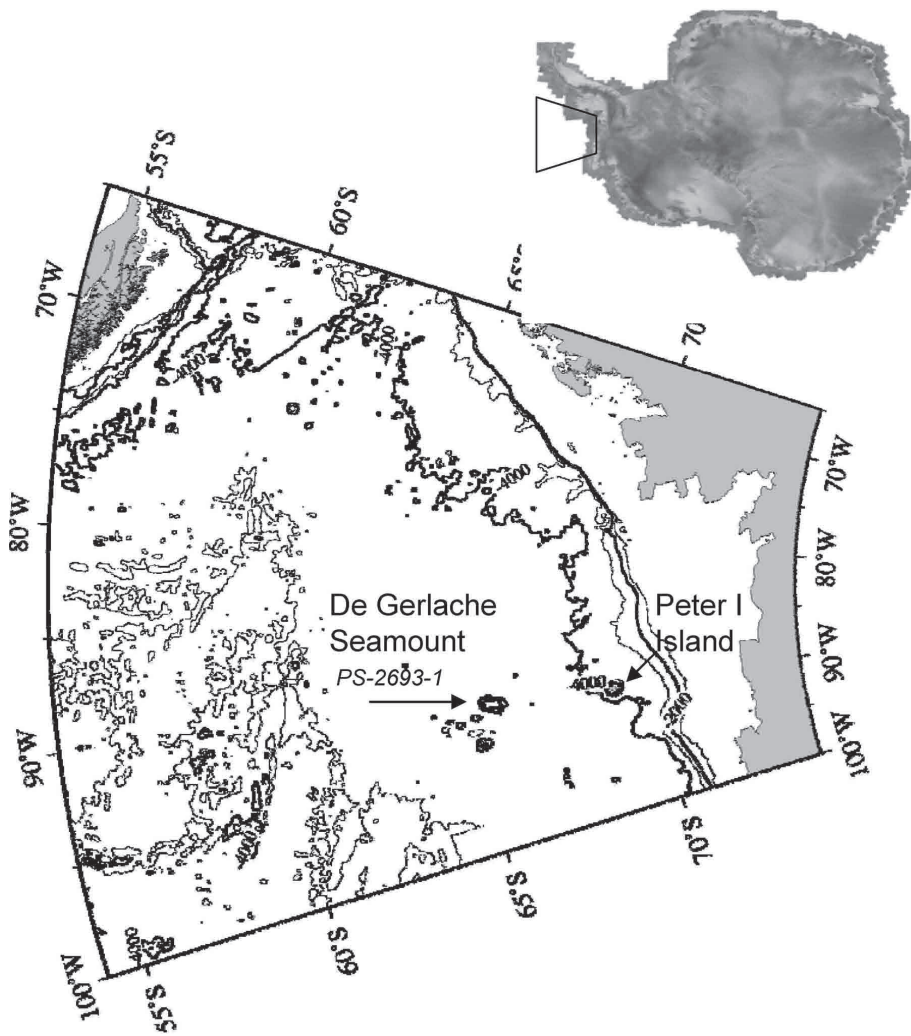


Fig. 1: Map of the Bellingshausen Sea and location of the De Gerlache Seamounts. Samples were dredged from the eastern Seamount (see arrow).

Abb. 1: Karte vom Bellingshausenmeer mit Lage der De-Gerlache-Seamounts. Die Proben wurden vom östlichen Seamount genommen (siehe Pfeil).

located in the Bellingshausen Sea (southeast Pacific, 64°30' to 66° S and between 90° to 94° W, Fig. 1). The eastern Seamount, the Belgica Guyot is approximately 60 km east – west and 90 km north – south at its base, and 17 km by 46 km at its summit (HAGEN et al. 1998). The summit area is a heavily eroded, flat plain in about 400 to 500 m water depth. PARASOUND data across the summit reveal a rough microtopography, extremely high reflection amplitudes and no significant signal penetration that suggests the volcanic basement is exposed at surface. The position of DGS and Peter I Island along the fracture zone termination of the earlier Phoenix-Antarctic ridge extends to the Jones Mountain volcanic province (HART et al. 1995). The alignment of basaltic provinces may suggest genetic and tectonic relationships of DGS basalts with Peter I Island and the Jones Mountains that can be confirmed from geochemistry and age determination of the DGS. The establishment of genetic/tectonic relationships may assist in the interpretation of the complex tectonic structure of this region. This study presents results of the first petrological and geochemical investigations along with K-Ar age determinations of so far unknown DGS basalts. The results are compared to chemical composition of the well known alkaline basalts from Peter I Island and Jones Mountains to evaluate their genetic relationship.

SAMPLES AND METHODS

Dredge samples along with other measurements were taken from the DGS during the RV “Polarstern” cruise (ANT-XII/4) in 1995. The basalt samples were recovered in 800 m to 600 m water depth at the upper north-eastern slope of the eastern seamount (location PS2693, 65°18.3' S; 90°35.2' W; Fig. 1) using a chain-dredge. The rocks are fresh basaltic scree and well rounded basaltic conglomerates cemented with a sandy groundmass.

Unaltered samples were selected for geochemical analysis and any altered parts and manganese crusts were removed prior to analysis. Cleaned samples were crushed and pulverized to a grain size smaller 0.63 mm in an agate mortar. X-ray fluorescence (XRF) analyses were performed on fused glass beads of lithium tetraborate (1:4) for major elements and on pellets of pulverized samples for trace elements. Trace element concentrations were analyzed with ICP-MS in 1:500 and 1:1000 dilution of autoclave-digests (mixture of suprapure HF (40 %) – HNO₃ (65 %) – H₃PO₄ (70 %) at 180 °C). Coulometric titration provided estimates of H₂O and CO₂. Ferrous iron was analyzed by manganometric titration; in the following text FeO* refers to total iron reported as FeO. Measurement performance, digestion-techniques, and calibration solutions were checked with international reference material and duplicate analyses were carried out routinely. XRF, CO₂, H₂O, and FeO analysis were

performed at the Institute of Mineralogy and Geochemistry, University of Karlsruhe, Germany, and ICP-MS measurements were performed at the Geoforschungszentrum, Potsdam, Germany.

For K-Ar age determination, whole rocks were crushed in a

Sample	PS-2693-1 (1)	PS-2693-1 (2)	PS-2693-1 (3)	PS-2693-1 (5)
SiO ₂	44.20	43.70	43.50	47.30
TiO ₂	4.77	4.82	4.81	4.04
Al ₂ O ₃	15.20	15.30	15.30	15.70
FeO ^{a)}	7.35	7.02	7.20	4.65
Fe ₂ O ₃	7.93	8.92	8.19	6.73
MnO	0.17	0.17	0.16	0.12
MgO	4.24	4.21	4.15	3.66
CaO	9.78	9.74	9.96	9.45
Na ₂ O	3.16	3.19	3.17	3.88
K ₂ O	0.47	0.51	0.48	1.27
P ₂ O ₅	1.03	1.15	1.26	1.01
CO ₂ ^{b)}	0.15	0.15	0.17	0.12
H ₂ O ^{b)}	1.12	1.21	1.17	0.72
mg-number	0.38	0.37	0.37	0.42
Total	99.57	100.09	99.52	98.65
<i>XRF</i> Cr	64	64	70	119
Ni	33	34	37	52
Cu	30	31	32	32
Zn	202	192	200	168
Ga	25	25	23	26
Sr	582	591	599	741
Y	45	45	50	40
Zr	336	335	334	388
Nb	48	48	48	55
Ba	177	178	192	268
<i>ICP MS</i> Sc	20	21	21	17
Co	32	36	35	35
Rb	1.8	2.5	1.6	12
Cs	0.05	0.07	0.05	0.17
La	25	26	26	29
Ce	59	62	61	66
Pr	8.3	8.7	8.6	9.9
Nd	37	39	38	43
Sm	9.7	10	9.9	11
Eu	3.2	3.4	3.3	3.6
Gd	9.9	10	10	11
Tb	1.4	1.4	1.4	1.4
Dy	7.7	8.0	7.8	7.4
Ho	1.3	1.4	1.4	1.2
Er	3.5	3.6	3.5	3.1
Tm	0.44	0.45	0.45	0.36
Yb	2.5	2.7	2.6	2.0
Hf	7.7	7.8	7.7	8.8
Ta	2.8	2.9	2.8	3.2
Pb	1.6	1.6	1.6	4.1
Th	2.3	2.5	2.4	2.7
U	0.91	1.1	1.0	0.37
Y/Nb	1.1	1.0	1.2	0.8
Ba/La	7.2	6.9	7.5	9.1
Th/La	0.8	0.9	0.9	0.8
Zr/Nb	8.0	7.7	7.8	7.8
Sr/Nb	13.2	13.0	13.2	13.5
Ti/Nb	596	602	601	440
Ti/Zr	85	86	86	62
Ce/Pb	38	38	38	16

steel mortar followed by wet sieving to separate 400-250 μm grain size, washed with deionized water and dried at 40 °C for 24 h. The age determinations were performed by the commercial Laboratory of Krueger Enterprises INC. (USA).

RESULTS

Petrology

The dredged basalt samples are mainly fine-grained porphyritic with a dark grey to greenish colour. Few rocks with vesicular or amygdaloidal texture are observed. Primarily the dredged basalt screes are coated with a black manganese crust. The samples PS2693-1 (1) to (3) are olivine-phyric with a fine-grained intersertal to intergranular texture. Olivine phenocrysts are euhedral to subhedral. Some mineral rims show re-absorption phenomena. Plagioclase (An 20-40; 50 vol.%) was observed primarily in lath-shaped grains with rare albite-twins. Anhedral grains with pyroxene and olivine inclusions are observed. Main constituents of the matrix are interstitial anhedral to euhedral olivine (15 vol.%), pyroxene (30 vol.%), apatite and opaque phases (10 vol.% commonly ilmenite and magnetite). Sample PS2693-1 (5) is porphyritic to glomerophytic with phenocrysts of augitic pyroxene (1-3 mm; with typical "Sanduhrstruktur"), plagioclase (0.5-1 mm) and olivine (0.5 mm). Skeletal, lath-shaped plagioclase as well as fern-shaped or blocky ilmenite and magnetite occurs in the matrix.

The matrix of all samples is relatively unaltered. In some samples, scarce interstitial submicroscopic intergrowths with strong greenish colour indicate alteration of the groundmass. Both types of olivine (phenocrysts and matrix-olivine) are strong yellow to reddish-brown without pleochroism, a result from alteration to iddingsite. In some samples, olivine is replaced by calcite along fissures of cleavage. The stable groundmass contains up to 15 % olivine as well as augite phenocrysts in sample PS2693-1 (5).

Geochemistry

The geochemical data are listed in Table 1. All samples are characterized by low mg-numbers (MgO/MgO+FeO*) between 0.37 and 0.42, high Na/K ratios (3.0-7.0) and high amounts of TiO₂ (4.0-4.8 wt.%) and P₂O₅ (1.0-1.3 wt.%). Samples (1) to (3) are similar in composition, while sample (5) has higher SiO₂ and K₂O and lower FeO*, TiO₂, and P₂O₅ concentrations. High contents of H₂O (0.7-1.2 wt.%) and Fe₂O₃ (6.7-8.9 wt.%) as well as high Fe₂O₃/FeO ratios (1.4-1.2) that indicate alteration processes (CANN 1971).

Tab. 1: Major and minor elements (wt. %) as well as trace element concentrations (ppm) of investigated samples. The mg-numbers were calculated as MgO/MgO+FeO* with FeO* as total iron. XRF = X-ray fluorescence spectrometer; ICP-MS = inductively coupled mass-spectrometer. All major elements analyzed by XRF except for ^{a)} = manganometric titration and ^{b)} = coulometric titration.

Tab. 1: Haupt- und Nebenelemente (Gew. %) sowie Spurenelementkonzentrationen (ppm) der untersuchten Proben. Die mg-Werte sind berechnet als MgO/MgO+FeO*, wobei FeO* der gesamten Eisenkonzentration als FeO entspricht. XRF = Röntgenfluoreszenz, ICP-MS = Ionisierung durch ein Argon-Plasma und Massenspektrometer als Detektor. Alle Haupt- und Nebenelemente sind mit XRF analysiert mit Ausnahme von ^{a)} = manganometrische Titration und ^{b)} = coulometrische Titration.

The CIPW-norm, calculated anhydrously with a FeO/Fe₂O₃ ratio of 0.15, yields normative olivine and hypersthene for samples 1 to 3. For sample 5, normative olivine and traces of normative nepheline were calculated. The normative mineral composition for samples (1) to (3) indicates olivine tholeiite, while traces of nepheline, which suggests that sample (5) has alkaline character.

The observed (Na₂O + K₂O)/SiO₂ ratios (0.08-0.11) and absolute abundance of incompatible trace elements (Tab. 1) are common for alkaline basalts (SHERVAIS 1982, PEARCE & CANN 1973, PEARCE & NORRY 1979, IRVINE & BARAGAR 1971). Ba/La and Th/Ta ratios close to 7.0 and 1.0, respectively (Tab. 1), this is similar to ocean island basalts (WEAVER 1990, 1991, PEARCE 1982). Following the classification by Mullen (1983) in the ternary TiO₂ – P₂O₅ – MnO discriminant diagram (Fig. 2), all basalt samples plot in the field of ocean island alkaline (OIA) basalts.

The extended normalized element pattern (Fig. 3) shows a smooth pattern with decrease to MORB compatible elements. The negative Pb “anomaly” observed for samples 1 to 3 has also been observed in some samples from the Jones Mountains and is typical for OIBs when Pb is plotted at that position in the diagram (HART et al. 1995).

In contrast to the well-defined OIB-like chemistry of the Jones Mountains and Peter I Island basalts (Fig. 3), samples 1 to 3 are strongly depleted in Cs, Rb, and K, which is unusual for OIBs. Despite these low values they have similar patterns with slightly higher La/Yb_N (7), and HFSE/Y ratios compared to alkali basalts from the Jones Mountains and Peter I Island (HART et al. 1995). Regarding typical ranges of La/Nb, K/Rb, Rb/Nb, K/Nb, K/Ba and Ba/Nb for OIB basalts of West Antarctica (e.g. HOLE & LEMASURIER 1994; Fig. 4) samples (1) to (3) have lower La/Nb (0.5-0.55), K/Ba (20), and Ba/Nb (3.5-4.9) ratios, while sample (5) is in good agreement.

The results of the K-Ar age determination are presented in Table 2. K-Ar dating of samples 1, 2 and 3 yield ages between 20.1 ± 1.0 Ma and 23.2 ± 1.2 Ma. The measured K contents are in good agreement with XRF results.

DISCUSSION

While the petrology and CIPW norm calculation indicate a tholeiitic character for samples (1) to (3), minor and trace element composition support an alkaline character for all investigated samples (e.g., Fig. 2). Although there are similarities with other West Antarctic OIBs, which are interpreted as of plume origin (PRESTVIK et al. 1990, HOLE et al. 1994, HART et al. 1995), differentiation processes may have been taking place, however, as indicated by low mg-numbers and low Ni and Cr contents of all samples. Therefore, an origin from primitive mantle, as suggested for the Jones Mountains and Peter I Island may not be the case for the DGS. The most significant differences are the low absolute and relative abundance of K, Rb, and Cs in samples (1) to (3), which is different from the OIBs of West Antarctica. The low concentration of these elements could be a result of mantle processes (fractional crystallization of a K-bearing phase, phlogopite or amphibole as residue) or secondary alteration. In the following section we

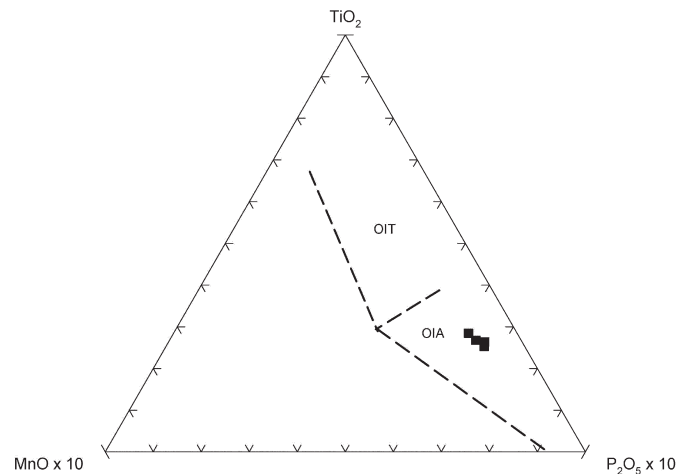


Fig. 2: MnO x 10 x TiO₂ x P₂O₅ x 10 discriminant diagram for basalts and basaltic andesites of oceanic regions after MULLEN (1983). All samples of eastern De Gerlache Seamount lay in the field for Ocean Island Alkaline basalts.

Abb. 2: MnO x 10 x TiO₂ x P₂O₅ x 10 Diskriminierungs-Diagramm für marine Basalte und Andesite nach MULLEN (1983). Alle Basaltproben vom östlichen De-Gerlache-Seamount liegen im Bereich der alkalischen Inselbasalte.

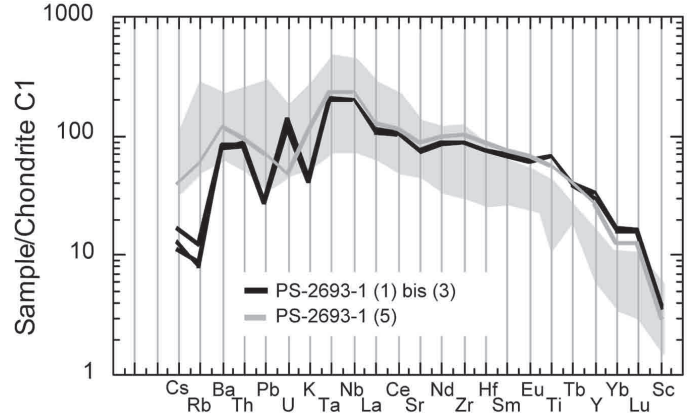


Fig. 3: Chondrite (C1) normalized extended element pattern of De Gerlache Seamount (DGS) basalts. Chondrite C1 values are from ANDERS & GREVESSE (1989). Order of elements set by increasing compatibility in MORB (HOFMANN 1988). The shaded area indicates the range of Jones Mountains and Peter I Island basalts from HART et al. (1995). The DGS basalts have similar pattern as basalts from the Jones Mountains and Peter I Island with slightly higher abundance in Sm to Lu in all samples. Sample (5) shows very good agreement to basalts of the Jones Mountains and Peter I Island while sample (1) to (3) have significantly lower abundance of Cs, Rb, and K.

Abb. 3: Chondrit (C1)-normierte Elementmuster der De-Gerlache-Seamount (DGS)-Basalte. Werte für C1-Chondrit nach ANDERS & GREVESSE (1989). Anordnung der Elemente nach zunehmender Kompatibilität in MORB (HOFMANN 1989). Das schattierte Feld markiert den Bereich der Basalte der Jones Mountains und der Peter-I-Insel (HART et al. 1995). Die DGS-Basalte haben ein ähnliches Elementmuster wie die Basalte der Jones Mountain und der Peter-I-Insel mit leicht höheren Konzentrationen von Sm bis Lu in allen Proben. Probe (5) stimmt sehr gut mit der chemischen Zusammensetzung der Basalte von Jones Mountain und Peter-I-Insel überein während die Proben (1) bis (3) wesentlich geringere Konzentrationen in Cs, Rb und K haben.

will discuss these differences with respect to mantle processes and secondary alteration and model non-modal equilibrium melting, assuming amphibole as the mantle phase.

Geochemistry

High field-strength elements (HFSE), such as Zr, Ti, P, and Nb, are immobile during weathering and low-grade metamorphism and tend to be incompatible (WOOD et al. 1976). Transi-

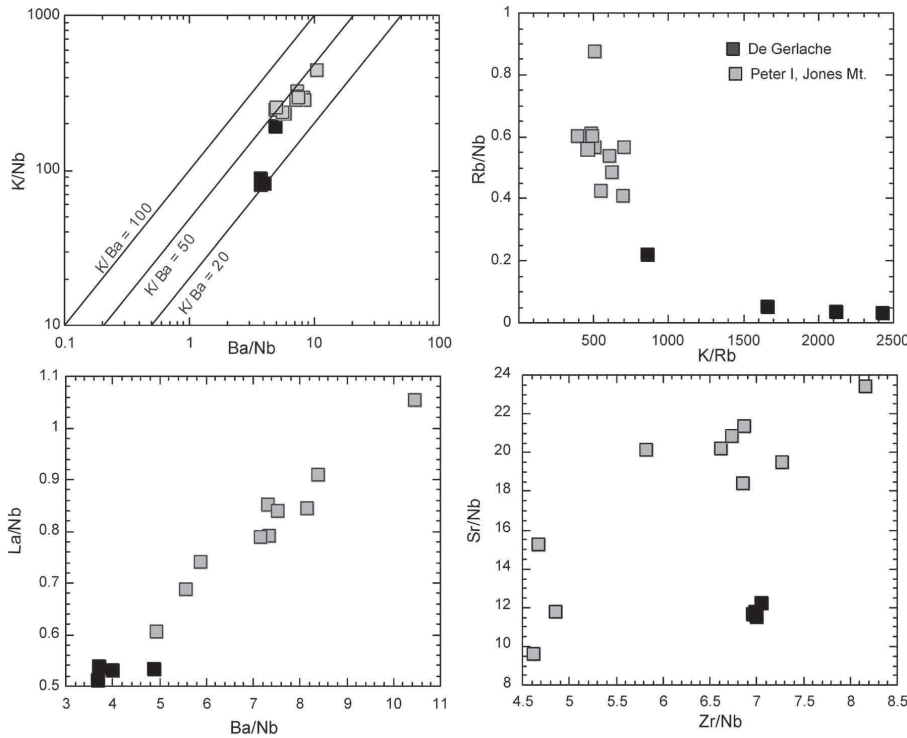


Fig. 4: Scatter plots of element ratios from De Gerlache Seamounts basalts (black squares) and basalts from Peter I Island and the Jones Mountains from HART et al. (1995) (gray squares). K/Nb, La/Nb, Ba/Nb, and Rb/Nb ratios of sample (1) to (3) are low compared to Peter I Island and Jones Mountains, while Sr/Nb and Zr/Nb ratios of all samples overlap with Jones Mountains and Peter I Island. Element ratios of sample (5) are more similar to the basalts of the Jones Mountains and Peter I Island except for Rb/Nb ratios.

Abb. 4: Elementverhältnisse der De-Gerlache Seamount-Basalte (schwarze Quadrate), von Basalten der Peter-I-Insel und den Jones Mountains (graue Quadrate). K/Nb-, La/Nb- und Rb/Nb-Verhältnisse der Proben (1) bis (3) sind geringer als für Peter-I-Insel und Jones Mountains. Alle Proben haben ähnliche Sr/Nb- und Zr/Nb-Verhältnisse wie Peter-I-Insel und Jones Mountains. Die Probe (5) ist den Basalten von Jones Mountains und Peter-I-Insel ähnlicher, mit Ausnahme des Rb/Nb-Verhältnis.

Sample	K (wt. %)	⁴⁰ Ar _{rad} (ng/l)	Age (Ma)	2 σ ±
PS-2693-1 (1)	0.470	0.659	20.1	1.0
PS-2693-1 (2)	0.406	0.656	23.2	1.2
PS-2693-1 (3)	0.425	0.670	22.6	1.1

Tab. 2: K-Ar age determination of samples PS-2693-1 (1), (2), and (3). Ages were calculated with decay constants as referred in STEIGER & JAEGER (1977).

Tab. 2: K-Ar-Altersbestimmung der Proben PS-2693-1 (1), (2) und (3). Die Alter sind mit den Zerfallskonstanten von STEIGER & JAEGER (1977) berechnet.

tion metals like Ni, Co, Sc, and Cr are also immobile but compatible in residual phases during partial melting or early liquidus mafic phases during crystallization. The low Ni and Cr contents (33-52, 60-119 ppm, respectively) and low mg-numbers (0.37-0.42) therefore, may exhibit elemental fractionation during partial melting due to residual phases. As noted by GREENOUGH (1988), fractionation in HFSE can occur during low degree of partial melting due to the low distribution coefficients of Nb compared to most HFSE in mantle clinopyroxene and garnet phases. Strong correlation among degree of partial melting, saturation index and HFSE/Nb ratios therefore is considered to be a function of the amount of clinopyroxene or garnet at low percentages of partial melting.

The Zr/Nb and Sr/Nb ratios in all DGS basalt samples (7.0 and 13.0-13.3, respectively) are similar to the ratios observed for Peter I Island and the Jones Mountains (Fig. 4), while Ti/Nb (660-680) and Ti/Zr (85-86) ratios are higher as for the Jones Mountains and Peter I Island (323-536 and 69-81, respectively, HART et al 1995). These differences may be caused by different degrees of partial melting and different amounts of residual mafic phases in the source of DGS basalts compared to Peter I Island and the Jones Mountains. However, distribution coefficients for Sr are lower as for Ti in common mantle

phases and, therefore, fractionation should cause relative enrichment of Sr compared to Ti (GREENOUGH 1988) but the DGS basalts show the opposite trend.

The large-ion lithophile elements (LILE) (e.g. K, Ba, Rb) are highly incompatible in mantle phases (with the exception of phlogopite or amphibole) and are strongly enriched in the residual liquid during partial melting (GAST 1968). In absence of a K-bearing phase, neither partial melting nor fractional crystallization has an effect on the LILE contents of alkaline basalts, which are generally formed by low percentages of partial melting. Therefore, LILE/Nb and K/LILE ratios can be applied as indicators for source heterogeneity and/or asthenosphere/lithosphere interaction (HOLE et al. 1994). Despite the low K, Rb, and Cs concentrations in samples (1) to (3), La/Nb, K/Nb, and Ba/Nb ratios (Fig. 4) are at the lower range, with sample (5) closest to the other OIBs of West Antarctica (e.g. HOLE et al. 1994, HART et al. 1995). MORB-like asthenosphere interaction is unlikely, because it would increase K/Nb and La/Nb ratios compared to OIBs. Contamination with continental crust seems unlikely for two reasons: (i) the DGS lie some 800 km away from the West Antarctic continental shelf edge, and (ii) contamination by continental crust should cause lowering in Ce/Pb ratios (continental crust: 5-7) but is about 35 for the DGS basalt and canonical value for OIB is given as 25 (HOFMANN 1988).

PRESTVIK et al. (1990) suggested a garnet-lherzolite as a possible mantle source with traces of water bound in phlogopite or amphibole (K-richterite) for the Peter I Island basalts. Both minerals are common K-bearing mantle phases, which are stable at low amounts of melting and pressures between 40 and 22 kbar (KUSHIRO 1969, OLAFSSON & EGGLEER 1983). Fractionation during partial melting of these phases could lead to low K concentration in the DGS basalt. STOREY et al. (1988) and SPÄTH et al. (1996) suggested this process as one possible reason for unusually low K concentrations in high Na/K alkaline basalts of Kerguelen Island and in lavas from the Comores

Archipelago (western Indian Ocean). Furthermore, both minerals have higher mineral-melt distribution coefficients for Ba, Rb, La, Nb, Sr, P, and Zr compared to orthopyroxene, clinopyroxene, and garnet (e.g., SPÄTH et al. 1996) and therefore, could lead to observed differences in element composition between the DGS and other West Antarctic OIBs.

To confirm this hypothesis for the DGS basalts, we modeled the composition of a basalt assuming amphibole as a residual mantle phase in primitive mantle (TAYLOR & MCLENNAN 1985) and non-modal equilibrium partial melting following GAST (1968), CONSOLMAGNO & DRAKE (1976), and HERTIGEN & GIJBELS (1976). We took a garnet-lherzolite with the ol: 0.53, opx: 0.20, cpx: 0.15, gt: 0.05 and amph: 0.07 for modal composition and assumed melting in the proportion of 10:10:30:25:25. Since K cannot be regarded as a dispersed element in this situation, K concentration was calculated by mass balance assuming 1.7 wt.% K₂O in amphibole (DEER et al. 1992). Assuming all K is bound in amphibole, K concentration in mantle is 988 ppm. Within the above constraints of source composition and proportion of melt, amphibole is exhausted after 24 % melting.

As shown in Figure 5, partial melting of 1.1 % primitive mantle with 7 % amphibole as mantle phase mimics the element composition of most of trace elements, except for Rb and Ba. Deviations in Ti and Y are about 20 % and may be explained by slightly different modal or melting proportion of the other mantle phases. Since amphibole has high amounts of Mg (~18 wt.% MgO) it may also explain low mg-numbers when present as residual phase. Distribution coefficients for Rb (0.6) and for Ba (0.5) lead to enrichment of both elements in the melt by low degree of partial melting (see also GAST 1968, GREENOUGH 1988). In order to obtain the observed concentration of Ba and Rb their concentration has to be adjusted to 0.025 ppm for Rb and to 2.0 ppm for Ba in the mantle source material. With this adjustment, partial melting of 1.1 % would lead to the observed concentration of Ba and Rb in the samples.

K-Ar age determination

For K-Ar age determination of submarine basalts with low to moderate K concentration, the following two systematic problems should be considered: i) In submarine environments, low-temperature alteration generally causes de-vitrification of volcanic glass and growth of secondary minerals (calcite, zeolites, clay minerals) which is often accompanied by an exchange of mobile elements like K and Na. These open-system processes can result in lowering of the K-Ar age due to ⁴⁰Ar loss or increase of the K content. ii) mantle-derived rocks could be enriched in argon (excess ⁴⁰Ar) with ⁴⁰Ar/³⁶Ar ratios higher than the present day atmospheric ratio (ALLÈGRE et al. 1983). This excess ⁴⁰Ar is mainly present in xenocrysts and glassy crusts. In contrast to i), excess ⁴⁰Ar would result in K-Ar ages overestimating the true geological age. Such excess ⁴⁰Ar is known from the alkaline basalts of the Jones Mountains resulting in geological unrealistic ages of 100-200 Ma (RUTFORD et al. 1972, HOLE et al. 1994).

The high oxidation state of the samples may be an indicator of low temperature alteration. On the other hand, submarine alter-

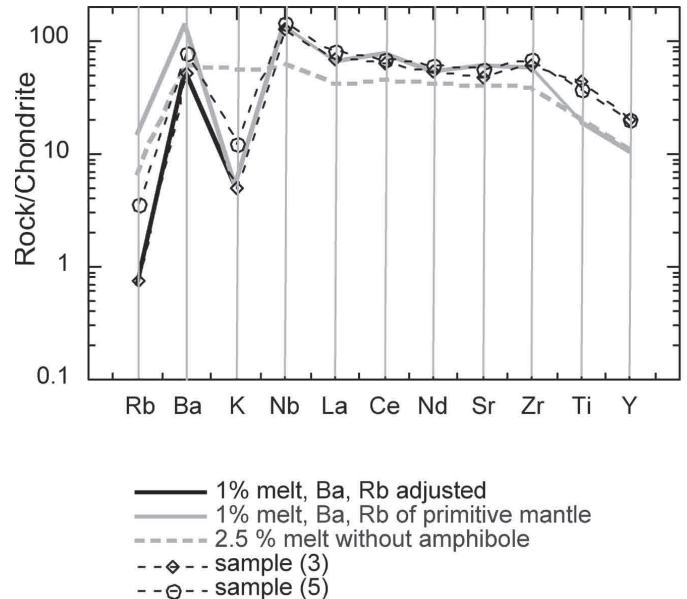


Fig. 5: Chondrite normalized element ratios of hypothetical basalt compositions calculated for different degrees of partial melting of garnet-lherzolite mantle. Sample (3) and (5) are shown for comparison. Black line: 1.1 % melt with 7 % amphibole as residual mantle phase, 5 ppm Ba and 0.55 ppm Rb. Grey line: 1.1 % melt with 7 % amphibole, 2 ppm Ba and 0.025 ppm Rb concentrations. Dashed grey line: 2.5 % melt of primitive mantle composition from TAYLOR & MCLENNAN (1985), no residual mantle phase. Best fit was achieved with 1.1 % melt with amphibole as residual phase and adjusted Rb and Ba concentration.

Abb. 5: Chondrit-normierte Elementverhältnisse von einer hypothetischen Basaltzusammensetzung, die durch teilweises Aufschmelzen von Mantelmaterial mit Granat-Lherzolitzusammensetzung berechnet wurde. Zum Vergleich sind die Proben (3) und (5) dargestellt. Die schwarze Linie gibt die Zusammensetzung für 1,1 % Aufschmelzung des Mantelmaterials mit 7 % Amphibol als zurückbleibende Mantelphase und 5 ppm Ba und 0,55 ppm Rb in der primitiven Mantelzusammensetzung an. Die graue Linie repräsentiert 1,1 % Aufschmelzung des Mantelmaterials mit 7 % Amphibol und 0,025 ppm Rb- und 2 ppm Ba-Konzentration. Die graue unterbrochene Linie zeigt 2,5 % Aufschmelzung des Mantelmaterials ohne Amphibol als Mantelphase. Die Zusammensetzung des Mantelmaterials entspricht einem primitiven Mantel (TAYLOR & MCLENNAN 1985). Die beste Übereinstimmung zwischen den gemessenen Proben und dem modellierten Basalt wurde für 1,1 % Aufschmelzung einer amphibolhaltigen Mantelquelle, die an Ba und Rb verarmt ist, erreicht.

ation should result in a K gain rather than K loss, but our geochemical results indicate that K concentrations are lower than usually expected in OIA basalts.

Magma transport

The estimated age of 20 Ma for the DGS is in concordance with the suggested age of the alkaline basalts of the Jones Mountains (10-7 Ma, HOLE et al. 1994), and the basaltic rocks of the Antarctic Peninsula (30 Ma, FUTA & LEMASURIER 1982, LEMASURIER 1990). As shown by seismic (GOHL et al. 1997, MÜLLER et al. in press) and satellite-derived gravity data (MCADOO & LAXON 1997), the DGS and Peter I Island are in alignment with a north-south striking crustal lineament which is interpreted as a crustal scar resulting from a ridge-jump event at 61 Ma (LARTER et al. 2002, EAGLES et al. 2004). Further crustal motion in a right-lateral strike-slip sense may have generated a set of basement ridges and narrow pull-apart basins along this lineament in response to the crustal motion

of the eastern West Antarctic Rift System (MÜLLER et al. in press). It is likely that this tectonic feature and the intersecting Tharp Fracture Zone results in an instability or weakening of the oceanic lithosphere, creating pathways for mantle-plume type volcanism until recent times. The measured K-Ar age of basalts of Peter I Island is 0.33-0.1 Ma (PRESTVIK et al. 1990) but the upper limit for the onset of volcanism is set at 20 Ma based on basalt volume and extrusion rate. Therefore, plume activity for the DGS and Peter I Island may have overlapped. Additionally, the occurrence of more alkaline sills in the Bellingshausen Sea DSDP Leg 35, site 323 also suggests weakening of oceanic lithosphere in the southeastern Pacific (VENNUM 1976).

CONCLUSION

Minor and trace element composition of DGS basalts suggest alkaline character, which is typical for OIBs. Compared to OIB from West Antarctica (Peter I Island, the Jones Mountains), the samples have lower mg-numbers, lower Ni and Cr concentrations, and LILE/Nb and (La/Yb)_N ratios. Three out of four samples have also very low absolute and relative abundance of K, Rb, and Cs.

Model calculation of 1.1 % partial melting of garnet-lherzolite with 7 % amphibole as residual mantle phase yields appropriate element concentrations for the most elements of these samples including K. However, this model cannot explain the low Rb and Ba concentrations of the samples. We suggest these concentrations require a Ba and Rb depleted mantle source.

The K-Ar age determinations show that the eastern DGS is of Miocene age. This time emplacement is in agreement with ages of OIB of the West Antarctic continental margin and the previously suggested early stage of Peter I Island volcanism.

The alkaline character of the DGS basalts together with geographic position and age seem to confirm the assumption of plume activity in the Bellingshausen Sea. Additionally, the occurrence of the DGS and Peter I Island volcanism along an old reactive tectonic lineation infers that it has exploited a zone of lithospheric weakness. The difference in geochemistry and petrology within this limited set of samples demands the analysis of a larger sample suite to improve these preliminary results.

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