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Sr-Nd-Pb isotopic studies of lavas of Mt. Oku volcano, North West Cameroon: A case involving HIMU, depleted and enriched mantle sources

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Sr-Nd-Pb isotopic studies have been carried out on the lavas of Mt. Oku, the central part of the continental sector of the Cameroon volcanic line (CVL). The lavas define a considerable range of Sr-Nd-Pb isotopic compositions characterized by $^{143}Nd/^{144}Nd$ = 0.512626 – 0.512937, $^{87}Sr/^{86}Sr$ = 0.699411 - 0.704279 and more radiogenic isotopic ratios $^{206}Pb/^{204}Pb$ = 18.3800 – 19.4480. $^{207}Pb/^{204}Pb$ = 15.4216 – 15.6448, $^{208}Pb/^{204}Pb$ = 37.1114 – 39.7507, with radiogenic Pb similar to the HIMU of the continent ocean boundary of the Cameroon volcanic line. These isotopic data display a linear array on the $^{143}Nd/^{144}Nd$ vs $^{87}Sr/^{86}Sr$ diagrams trending from MORB towards bulk earth. $^{143}Nd/^{144}Nd$ and $^{87}Sr/^{86}Sr$ vs. $^{206}Pb/^{204}Pb$ show a continuum of compositions that suggest differing contributions to the parental magmas from three end-members. One end-member corresponds to a mixture of high uranium high lead (HIMU) and depleted mantle (DM) source components while the other end-member corresponds to an enriched mantle source thought to be the MORB source or sub-lithospheric source. The enriched geochemical signatures (EM) of the Oku magmas are unlikely to be the result of crustal assimilation during magma ascent. Rather, they are thought to be derived from a sub-continental lithospheric mantle enriched in incompatible trace elements by ancient metasomatic processes. The HIMU component is thought to have been inherited from the fossil plume that underlay the Equatorial Atlantic during the period 130 to 100 Ma before migrating to its present site. The radiogenic initial $^{206}Pb/^{204}Pb$ ratios of the samples (~18.3800 – 19.44804) furthermore require the involvement of an ancient HIMU mantle plume in the magmatism and this may have been formed by metasomatism of fluids derived from St. Helena hot plume ca 120 Ma.

Key words: Oku, isotopes, metasomatism, HIMU, enriched geochemical signatures (EM), mantle, enrichment.

INTRODUCTION

Basaltic magmas erupted in continental intra plate setting are believed to originate from the asthenospheric mantle and their compositional diversity is attributed to fractional crystallization and interaction of melts with the heterogeneous continental lithosphere (Fitton, 1987; Fitton and Dunlop, 1985; Halliday et al., 1988, 1990; Chung et al., 1994; Peng et al., 1994; Haase et al., 2000; Gertisser and Keller, 2003). Basalts from Ngaoundere

(Miocene to Quaternary) and from the early activity (31 to 14 Ma) of the Western Highlands (Bambouto and Oku) have incompatible trace element and Sr–Nd isotopic compositions similar to those of oceanic Cameroon Volcanic Line (CVL) basalts, pointing to a similar asthenospheric mantle (Marzoli et al., 2000; Rankenburg et al., 2005; Moundi et al., 2007; Njilah et al., 2008) source. By contrast, the late (15 to 4 Ma) Western

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Highlands basanites and alkali basalts have anomalously high concentrations of Sr, Ba and P and low concentrations of Zr, which are exclusive features of continental Cameroon basalts. The genesis of these latter magmas is consistent with derivation from an incompatible element enriched, amphibole-bearing lithospheric mantle source (Marzoli et al., 2000).

Mt. Oku volcanic field lies in the continental sector of the CVL. It is a complex stratovolcanic edifice 90 km across rising to a height of 3011 m (Mt. Oku). About 2000 m of lava pile would have been erupted ranging from basalt through hawaitte, mugearite to trachyte-rhyolites, high level intrusions and intercalated pyroclastics. Njilah (1991) and Njilah et al. (2007) give K-Ar ages, major and trace element including Rare Earth Elements (REE) geochemistry as well as petrographic studies of the spectrum of lavas of this massif.

An interesting aspect of lavas of the massif is the occurrence of patchy and complex optical and chemical zoning of the pyroxenes described in Njilah et al. (2008). The silicic volcanism here occurred between 25 Ma to recent and is represented by voluminous quartz-normative trachytes and minor rhyolitic ignimbrites. These silicic volcanics are associated with slightly to moderately alkaline basalts and minor basanites. In general, onset of the silicic volcanism migrated from NE (Oku: 25 Ma) to SW (Sabga: 23 Ma; Bambouto: 18 Ma; and Mt. Manengouba: 12 Ma). The silicic volcanism of the Ngaoundere plateau (eastern branch of the CVL) is instead dominated by nepheline-normative trachytes which are associated with strongly alkaline basalts and basanitic rocks (Marzoli et al., 1999). We provide new Sr-Nd-Pb isotope compositions for the Mt. Oku volcanics in order to identify the geochemical character of the magma source region. Our data show that the parental basaltic magmas of Mt. Oku underwent a complex evolutionary history that is reflected in the mineralogy, major, trace and isotopic chemistry (Njilah, 1991, Marzoli et al., 2000). The new Sr-Nd-Pb isotope chemistry presented in this work suggests the involvement of three mantle source components, enriched, depleted and HIMU in the petrogenesis of the lavas of Mt. Oku.

Geological setting

1600 km long Y-shaped chain of tertiary to recent, generally alkaline, volcanoes called the CVL (Figure 1) represents Cenozoic volcanism in Cameroon. The CVL follows a trend of crustal weakness that stretches from the Atlantic Island of Pagalu, through the Gulf of Guinea, to the interior of the African continent (Fitton, 1987; Halliday et al., 1988; Déruelle et al., 1991). It is unique amongst intra-plate volcanic provinces in that it straddles the continental margin and includes both oceanic and continental intra-plate volcanism.

The oceanic sector constitutes a mildly alkaline volcanic series, which envoles towards phono- lite, while the con-

tinental sector evolves towards rhyolite (Lee et al., 1994.; Fitton, 1980, 1987; Fitton and Dunlop, 1985; Fitton et al., 198*3*). Isotopic studies of lavas of the CVL chain (Halliday et al., 1988, 1990, 1993) have divided it into three sectors based upon the isotopic composition and geographical location: an oceanic sector, an ocean-continent boundary zone and a continental sector.

The primitive alkali basaltic magmas of the ocean-continent boundary (Mts. Cameroon, nephilinites of Mt. Etinde and basalts of the Island of Bioko) display a distinctive Pb-isotope anomaly which diminishes away from this zone over a radius of 400 km on either side (Njilah et al., 1999). The elevated $^{206}Pb/^{204}Pb$ ratios are similar to those associated with the mantle source of the oceanic Island of St. Helena (Chaffey et al., 1989; Richard et al, 1997), commonly referred to as high uranium high lead (HIMU), whose hotspot trace can be projected back to the ocean-continent boundary at ca 120 Ma (O'Connor and Duncan, 1990).

Mt. Oku (Figure 1) occupies a central position inland of an almost continuous chain of volcanism stretching north east from Mt. Cameroon and which cuts through and sits on a basement of Pan-African granite-gneisses (approx. 600 Ma) migmatites, and biotite diorites. These rocks were uplifted during the general doming that accompanied the eruption of the CVL. Erupted rocks include basalts, trachytes, ryholites, ashflow tuff scories and volcanic ash (Njilah, 1991). The massif is a complex volcanic edifice approximately 90 E-W and 60 km N-S and rising at height of 3011 m (Mt. Oku). It is composed of four major adjacent stratovolcanoes: Mt. Oku, Mt. Babanki, Nyos and Nkambe. A 2000 m thick volcanic sequence could have existed here prior to erosion. Trachyte, rhyolite and ignimbrite constitute 85% of the volcanics We obtained a spectrum of mafic to felsic rocks from the Mt. Oku of which the mineralogy, major and trace element geochemistry and K-Ar age determinations have been discussed elsewhere (Njilah et al., 2007).

Here we discuss the Sr-Nd-Pb isotopic evidence for mantle heterogeneity under Mt. Oku volcano and show that three mantle sources are responsible for the generation of the spectrum of lavas of the Mt. Oku: HIMU, MORB (depleted) and Lithospheric (enriched) mantle sources.

METHODS

Whole rock analyses for major and trace elements were done by X-Ray Fluorescence (XRF) techniques method as described in Njilah (1991) in the geochemistry Laboratory of the University of Leeds UK. For Sr and Nd isotope analyses, (thanks to G. R. Davies at the University of Michigan, USA who did the analyses). 50 to 150 mg of sample powder was weighed accurately into Teflon bombs, (Njilah) and spiked with ^{85}Rb-^{84}Sr and ^{150}Nd-^{14}Sm spikes. These powders were digested in HF-HNO$_3$ in an oven overnight, evaporated to dryness, and converted with 15 M HNO$_3$ and 6 M HCl completely into solution. A11 reagents used were quartz distilled. Sr and REE
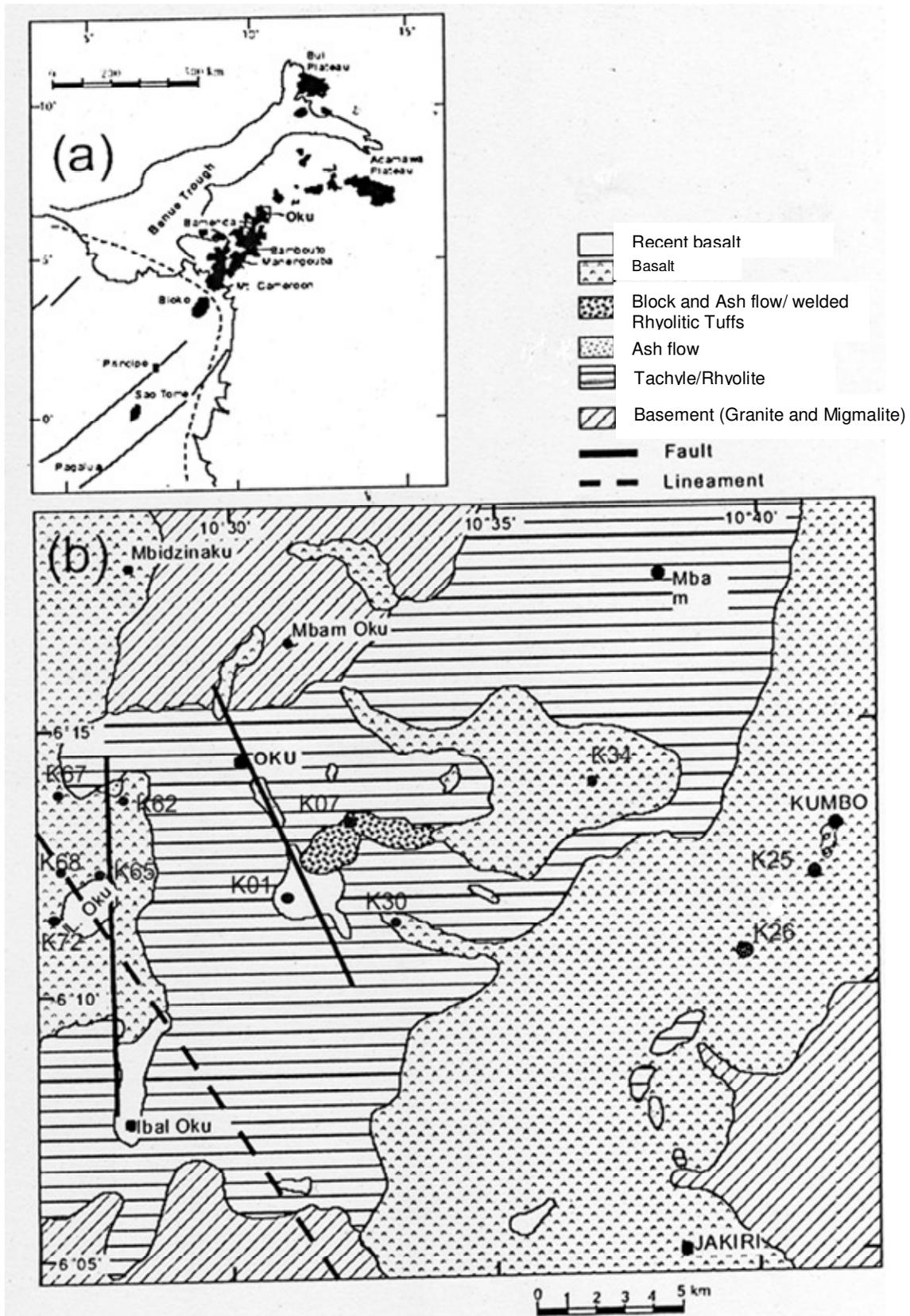
Figure 1. The Cameroon Volcanic Line (CVL) showing (a) location of Mt. Oku volcano and (b) Geological map of Mt. Oku volcano.

were separated on preconditioned cation-exchange columns with 1 N HCl and 6 N HCl as eluants. Separation of Nd from the REE fraction was achieved using 0.25 N HCl as eluant on HDEHP (Hydrogen Diethylxylphosphate) coated Bio-Rad bead resin. For Pb analyses, aliquots of 80 mg were dissolved in Savillex beakers at 15°C using a HF/HNO_3 solution. After redissolving in HCl and converting to a 0.5 N HBr solution, purification of Pb essentially followed standard HBr-HCl chemistry on columns filled with 100 µ AG-1X8, 200-400 mesh resin prior to elution with 6 N. Isotopes were measured in static mode on a Fisons-VG-Micromass-54-30 Sector multicollector mass spectrometer. Pb was loaded on single Re filaments using a H_3PO_4-silica gel mixture as reported in detail in Cameron et al. (1967). Pb was analysed at 1350°C and the data were corrected for instrumental mass fractionation of 0.7% per atomic mass unit. This value was established by two loads of NBS-981 during the course of this study calculated from $^{202}Pb/^{205}Pb$ double spiked measurements. The total Pb procedure blank during the course of this study is about 120 pg per analysis.

Sr was loaded in 1 M $NHNO_3$ on a Ta single filament and Nd was ionized on triple filament assemblies with a center Re ionization filament. For Sr and Nd isotope ratios, an exponential fraction correction was applied using $^{86}Sr/^{88}Sr$ = 0.1194 and $^{146}Nd/^{144}Nd$ = 0.7279. The accuracy was monitored by replicate measurements of NBS-987 and the Ames® Nd metal standard giving $^{87}Sr/^{86}Sr$ = 0.710257 (n=8) and $^{143}Nd/^{144}Nd$ = 0.511978 ± 12 (2s) respectively.

RESULTS

Chemical analyses for major, trace and REEs of representative samples of the spectrum of lavas of the Mt. Oku are presented in major Table 1. These data indicate that they are under-saturated or saturated alkali basalts (Ne_N > 15), and are characterized by high tenors in alkalis (Na_2O + K_2O >), Ni, Co, Nb and the relations LREE/HREE (La_N/Yb_N > 15). Furthermore, the chemical analyses of morphological and chemically zoned clinopyroxene have clearly proved the existence of more than one magma chamber beneath Mt. Oku that gave rise to these lavas (Njilah et al., 2008).

Isotope chemistry

On a plot of $^{143}Nd/^{144}Nd$, $^{87}Sr/^{86}Sr$ against MgO wt. % (Figure 2), the basic samples from Oku show trends which suggest combined fractional crystallization and crustal contamination by assimilation as the main differentiation processes that affected the magma. Nd-Sr and Pb isotope geochemistry of the CVL has been presented elsewhere (Halliday et al., 1988, 1990, 1994; Marzoli et al., 1999; Marzoli et al., 2000). The isotopic data for the Mt. Oku suite has a very wide range $^{143}Nd/^{144}Nd$ = 0.512626-0.512937, $^{87}Sr/^{86}Sr$ = 0.699411 – 0.704279, $^{206}Pb/^{204}Pb$ = 18.3800 – 19.4480, $^{207}Pb/^{204}Pb$ = 15.49706 – 15.6140 and $^{208}Pb/^{204}Pb$ = 38.3370 – 39.1800 (Table 2). On a $^{143}Nd/^{144}Nd$ vs. $^{87}Sr/^{86}Sr$ variation diagram (Njilah, 1991), the lavas plot on a linear array trending away from the field of present day MORB towards bulk earth.

Figure 3 shows $^{208}Pb/^{204}Pb$ and $^{207}Pb/^{204}Pb$ plotted against $^{206}Pb/^{204}Pb$ in relation to other volcanic centres. Some of the lavas have radiogenic Pb similar to the HIMU of the continent-ocean boundary sector of the CVL. This HIMU signature contrasts with lavas from other volcanic centres around Mt. Oku. The lavas overlap those of the continent-ocean boundary and trend towards MORB, paralleling the NHRL. The trends of Pb isotope variation for Mt. Oku are paralleled by Sr-Nd variation, that is, samples with the most radiogenic Pb have the least radiogenic Nd. $^{143}Nd/^{144}Nd$ and $^{87}Sr/^{86}Sr$, when plotted against $^{206}Pb/^{204}Pb$ (Figure 4) show a continuum of compositions that suggests differing contributions to the parental magmas from two end-members, A and B. End-member A appears to be a mixture of HIMU and depleted mantle (DM) source component while end-member B comprises of an enriched mantle source thought to be a MORB source or sub-lithospheric source.

DISCUSSION

Crustal rocks, evolving with higher Rb/Sr ratios, develop much higher present day $^{87}Sr/^{86}Sr$ ratios than the upper mantle, which has evolved with very much lower Rb/Sr ratio. MORB and OIB reach the surface having suffered little or no contamination due to the thin crust which they traverse, and the fact that they are traversing a crust of basaltic composition. In intra-continental plate domains like Mt. Oku, the magmas will have a tendency to interact with high $^{87}Sr/^{86}Sr$ and low $^{143}Nd/^{144}Nd$ Pan-African granite/gneiss crust to generate hybrid magmas. Marzoli et al. (1999) however, showed that the least differentiated silicic volcanics are isotopically similar $^{87}Sr/^{86}Sr$ < 0.70380; $^{143}Nd/^{144}Nd$ > 0.51278 to the associated alkaline basalts suggesting differentiation processes without appreciable interaction with crustal materials in Mt. Oku and neighboring Bambouto. Since the mobility of Rb and Sr in the melt (in situ silicate) (H_2O + CO_2 and chlorite medium) interaction is considerably higher than Sm and Nd Light Rare Earth Elements (LREE), the fluid induced melt in the upper mantle becomes isotopically more homogeneous with respect to Rb-Sr compared to Sm-Nd causing variable ε_{Nd} (~Nd +5.3 to -3.24). Such heterogeneity can be interpreted by the participation of two mantle reservoirs: a depleted MORB and a HIMU OIB-type source. The isotopic systematics of the Oku cannot be accounted for by simple two-component mixing between an unmetasomatized mantle and a HIMU component. Rather, they are most reasonably explained by contamination by some enriched subcontinental lithosphere magmatic plume juice component characterized by high $^{206}Pb/^{204}Pb$. Nd-Sr isotopic data for primitive basalts from the CVL suggest that the mantle source is heterogeneous and that this heterogeneity could have evolved in the last 125 to 100 Ma since the initiation and the opening of the Gulf of Guinea

Table 1. Major, trace and REEs of representative samples from the Mt. Oku.

Rock	K01	K03	K07	K14	K16	K19	K25	K26	K27	K28	K29	K30	K34	K35
SiO_2	46.96	46.70	46.41	65.29	44.29	48.41	50.35	42.98	45.30	42.22	41.73	44.59	42.86	43.98
TiO_2	3.00	2.95	3.57	0.75	3.59	2.25	2.13	4.46	3.79	5.78	4.80	3.47	3.61	3.64
Al_2O_3	15.59	15.53	15.28	11.82	13.64	16.36	16.26	13.84	15.94	13.96	13.89	14.45	13.28	14.37
Fe_2O_3	12.17	11.90	12.88	8.52	13.67	11.03	11.29	14.90	13.11	14.69	13.48	12.48	13.15	12.57
MnO	0.19	0.19	0.18	0.36	0.21	0.18	0.20	0.23	0.19	0.17	0.18	0.19	0.18	0.19
MgO	6.26	6.03	7.33	0.35	9.19	4.85	3.44	6.29	6.83	9.05	9.75	8.79	10.98	8.30
CaO	9.32	9.00	8.49	0.94	9.90	7.01	5.82	10.05	8.89	9.86	10.41	10.08	9.79	10.92
Na_2O	3.98	3.67	4.29	5.61	4.44	3.99	4.87	3.21	3.11	2.90	2.62	3.55	2.83	3.83
K_2O	1.66	1.71	1.00	4.12	1.51	2.63	2.29	1.10	1.26	1.02	1.28	1.60	1.24	1.68
P_2O_5	0.89	0.88	0.98	0.09	0.86	0.50	1.13	2.20	0.68	0.71	1.05	0.86	1.02	0.84
L.o.l.	0.57	1.41	1.38	2.12	-0.25	2.83	2.11	0.75	0.90	0.40	1.11	0.33	0.82	-0.18
Total	100.61	99.99	101.80	99.99	101.07	100.04	99.91	00.01	100.01	100.78	100.30	100.40	99.77	100.15
Cr	136	138	186	<3	331	73	<3	46	84	170	216	360	353	247
Co	39	38	47	17	50	43	33	46	49	54	46	44	55	45
Ni	58	58	99	5	156	46	4	26	51	158	135	133	250	102
Cu	46	44	37	7	65	38	12	36	34	64	45	42	50	53
Zn	94	99	109	262	104	96	128	115	98	90	93	95	100	91
Rb	30	33	21	78	27	47	33	15	21	11	22	31	24	29
Sr	1136	1094	1275	14	928	464	873	864	867	1602	1667	1355	1352	1191
Y	26	25	24	80	23	33	41	36	26	19	23	24	23	25
Zr	237	249	232	936	204	364	475	203	234	140	182	215	169	205
Nb	54	55	48	194	51	34	82	46	48	33	51	58	50	59
Pb	<5	<5	<5	13	<5	6	<5	<5	<5	<5	<5	<5	<5	<5
Ba	681	693	666	100	554	298	697	1414	454	513	609	711	690	690
La	33.30	48.00	49.30	147.80	41.20	39.10	66.00	52.30	20.60	44.90	42.80		41.70	45.20
Ce	81.60	102.10	110.20	306.80	86.80	86.30	155.20	130.60		55.30	102.30	95.60	92.70	99.20
Pr	10.63	12.06	14.05	33.89	10.39	10.09	18.79	17.47		7.94	13.02	11.89	11.75	12.21
Nd	46.20	49.40	55.60	126.10	44.40	40.00	77.90	81.60		37.60	56.40	50.00	50.90	51.10
Sm	9.44	9.45	10.31	23.64	8.89	8.27	15.70	16.85		8.32	11.43	9.91	10.22	10.23
Eu	3.24	3.26	3.42	5.95	3.11	2.30	4.61	8.50		3.25	4.10	3.51	3.68	3.52
Gd	8.43	8.88	9.47	20.34	8.31	8.14	13.33	15.63		7.77	10.03	8.85	9.12	9.18
Dy	6.45	6.52	6.82	19.14	6.29	7.58	10.17	10.41		5.41	6.98	6.46	6.52	6.87
Ho	1.07	1.08	1.14	3.31	1.02	1.35	1.70	1.63		0.86	1.12	1.04	1.04	1.11

Table 1. Contd.

Rock	K41	K42	K44	K52	K54	K62	K63	K64	K65	K67	K68	K69	K70	K71
Er	2.93	2.93	3.08	9.19	2.67	3.95	4.70	4.13		2.27	2.89	2.79	2.78	2.97
Yb	2.18	2.18	2.25	7.90	1.93	3.34	3.54	2.60		1.49	1.98	1.98	1.89	2.10
Lu	0.31	0.32	0.25	1.14	0.27	0.50	0.51	0.36		0.21	0.29	0.28	0.27	0.30
Y	27.00	26.80	0.33	84.50	25.40	35.6	42.60	40.00		22.10	27.20	26.00	25.60	27.50

Rock	K41	K42	K44	K52	K54	K62	K63	K64	K65	K67	K68	K69	K70	K71
SiO_2	44.33	42.02	44.29	42.05	43.50	44.25	45.41	40.58	43.02	42.56	43.48	38.94	43.02	42.87
TiO_2	3.65	3.30	3.67	5.30	3.50	3.14	3.54	4.87	3.20	3.98	4.96	4.39	4.97	4.67
Al_2O_3	13.89	12.84	14.03	12.81	13.77	13.00	14.45	12.97	13.03	13.44	14.08	12.39	13.83	13.82
Fe_2O_3	13.68	12.09	13.98	14.66	13.36	13.13	13.32	13.97	13.24	12.97	14.26	12.51	14.05	13.81
MnO	0.19	0.17	0.19	0.18	0.21	0.19	0.18	0.18	0.19	0.17	0.18	0.16	0.18	0.19
MgO	9.39	10.62	9.04	10.40	9.30	10.92	8.11	7.59	11.90	8.71	8.15	7.39	8.31	7.93
CaO	9.95	10.09	9.75	10.12	10.75	10.50	10.11	9.18	10.54	9.64	9.34	8.41	9.44	9.34
Na_2O	3.43	4.04	3.22	2.82	3.77	3.33	3.78	3.68	2.52	3.43	4.00	3.48	3.25	3.24
K_2O	1.44	1.08	1.43	1.10	1.43	1.36	0.83	1.40	1.6	1.40	1.36	1.35	1.37	1.51
P_2O_5	0.84	0.71	0.88	0.86	0.83	0.69	0.58	0.84	0.68	0.85	0.93	0.86	0.97	0.99
L.o.l.	-0.62	0.45	-0.18	---	-0.45	-0.45	0.13	-0.34	0.43	-0.30	-0.56	-0.79	-0.47	-0.37
Total	100.2	97.44	100.29	100.29	99.96	100.08	100.45	99.92	99.82	96.87	100.19	89.08	98.92	98.00
Cr	286	496	257	430	266	490	248	240	553	268	227	230	---	228
Co	52	56	56	52	52	54	51	51	56	47	53	51	---	49
Ni	150	218	143	190	93	325	109	87	376	155	103	114	---	113
Cu	63	50	53	38	42	114	39	45	114	51	48	41	---	45
Zn	102	89	109	100	97	100	97	98	92	102	98	103	---	102
Rb	28	31	36	29	33	30	49	24	20	21	25	23	---	26
Sr	937	998	913	1130	887	755	776	1386	746	1264	1353	1370	---	1367
Y	23	22	22	18	26	24	23	22	24	23	21	21	---	22
Zr	197	173	203	124	220	182	214	198	176	158	191	186	---	201
Nb	48	45	50	36	62	51	47	46	51	39	44	45	---	45
Pb	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	---	<5
Ba	547	459	665	485	555	509	341	561	546	533	572	593	---	622
La		49.60	37.10	31.00	47.80	40.70	36.30	36.80	40.6	38.20	43.20	42.40	43.50	41.70
Ce		91.30	82.90	65.50	99.70	83.20	82.90	84.50	82.50	85.00	91.40	94.70	95.20	93.60
Pr		11.11	10.21	8.84	11.79	9.78	10.11	10.64	9.94	10.97	11.19	12.69	11.90	11.76
Nd		46.70	43.80	40.30	48.66	41.40	42.50	45.30	41.30	45.80	48.40	50.70	51.00	49.40

Table 1. Contd.

Sm	9.37	8.98	8.31	9.60	8.20	8.58	9.21	8.16	9.08	9.54	9.83	10.22	9.75
Eu	3.19	3.07	3.18	3.16	2.79	2.85	3.39	2.78	3.30	3.54	3.65	3.74	3.56
Gd	8.50	8.22	7.81	8.86	7.76	7.94	8.30	7.69	8.41	8.47	8.87	9.16	8.60
Dy	6.42	6.23	5.51	6.96	6.20	6.15	5.81	6.11	6.06	6.04	6.13	6.37	6.02
Ho	1.04	1.03	0.89	1.16	1.03	1.02	0.94	1.01	0.98	0.97	1.01	1.02	0.96
Er	2.71	2.69	2.33	3.20	2.74	2.86	2.68	2.79	2.58	2.50	2.65	2.71	2.54
Yb	1.94	1.96	1.53	2.37	2.06	2.04	1.77	2.04	1.76	1.80	1.80	1.88	1.80
Lu	0.27	0.28	0.21	0.34	0.30	0.30	0.25	0.30	0.25	0.26	0.26	0.27	0.26
Y	25.70	25.60	21.80	29.00	25.60	25.40	23.20	25.20	23.70	23.70	23.80	24.90	23.60

(Halliday et al., 1990). Homogeneity of trace element characteristics of the mantle source, on the scale of 1000 km or more is implied by the geochemical similarity between the alkali basalts erupted in the oceanic and continental sectors of the CVL, though small-scale heterogeneity may persist (Fitton and Dunlop, 1985). The enriched geochemical signatures are thought to be derived from a subcontinental lithospheric mantle enriched in incompatible trace elements by ancient metasomatic processes. The radiogenic initial $^{206}Pb/^{204}Pb$ ratios of the samples (~17.3165 – 20.2503) furthermore require the involvement of an ancient high μ mantle reservoir in the magmatism and this may have been formed by metasomatism involving fluids derived from St. Helena hot plume ca 120 Ma.

Origin of the three mantle sources

Isotopic variations cannot be related to a simple temporal evolution of a single component but rather imply a mixture in variable proportions between the two end-members (Dieter et al., 1991; Zendler et al., 1982; Karmalkar and Rege 2002; Escrige et al., 2003) or more end members (Njilah et al. 1999). Temdjim et al. (2004) have, from the study of ultramafic xenoliths, shown upper-mantle heterogeneity in Nyos (northern flanks of the Oku massif). Moundi et al. (2007) have put in evidence the data which indicate a source in an enriched lithospheric mantle (EM) that produced the transitional basalts of the Bamoun plateau 75 km to the south, in contrast to a source closer to HIMU, which could have produced alkali basalts. Our studies show that the melts produced in Mt. Oku and the rest of the CVL have signatures from three sources: plume components (HIMU), asthenospheric components (Depleted) and lithospheric components (Enriched). On the basis of Sr-Nd-Pb isotopic studies, it is clear that the parental magmas were derived from a source region which is largely insensitive to the gross differences that one might expect in the lithosphere between oceanic and continental regions. The old lithospheric mantle beneath Africa should be chemically and isotopically very different from the young Atlantic Ocean lithosphere and, therefore, if it had been involved extensively in the petrogenesis of the continental sector magmas, they should bear a distinctive geochemical fingerprint, which they do not. Sr-Nd-Pb isotopic studies have revealed that the basic magmas from Mt. Oku, and the CVL, as a whole, could be derived from mixing of partial melts derived from a three source components: HIMU, depleted and enriched mantle. The question now is, what is the origin of these three mantle sources?

The sub continental lithospheres in most areas studied have been found to be enriched in incompatible elements at various times throughout geological time. To explain the origin of these three mantle sources of the Oku volcano, we think that, at ca 120 Ma the low density St. Helena plume up welled, undergoing adiabatic decompression resulting in partial melting. Normally, a deep mantle plume originates from a depth within the lower mantle and the core mantle boundary (Roy et al., 2004). The melts segregated from their source and ascended towards the surface, but because they were low degree partial melts, they became trapped in the mechanical boundary where they caused
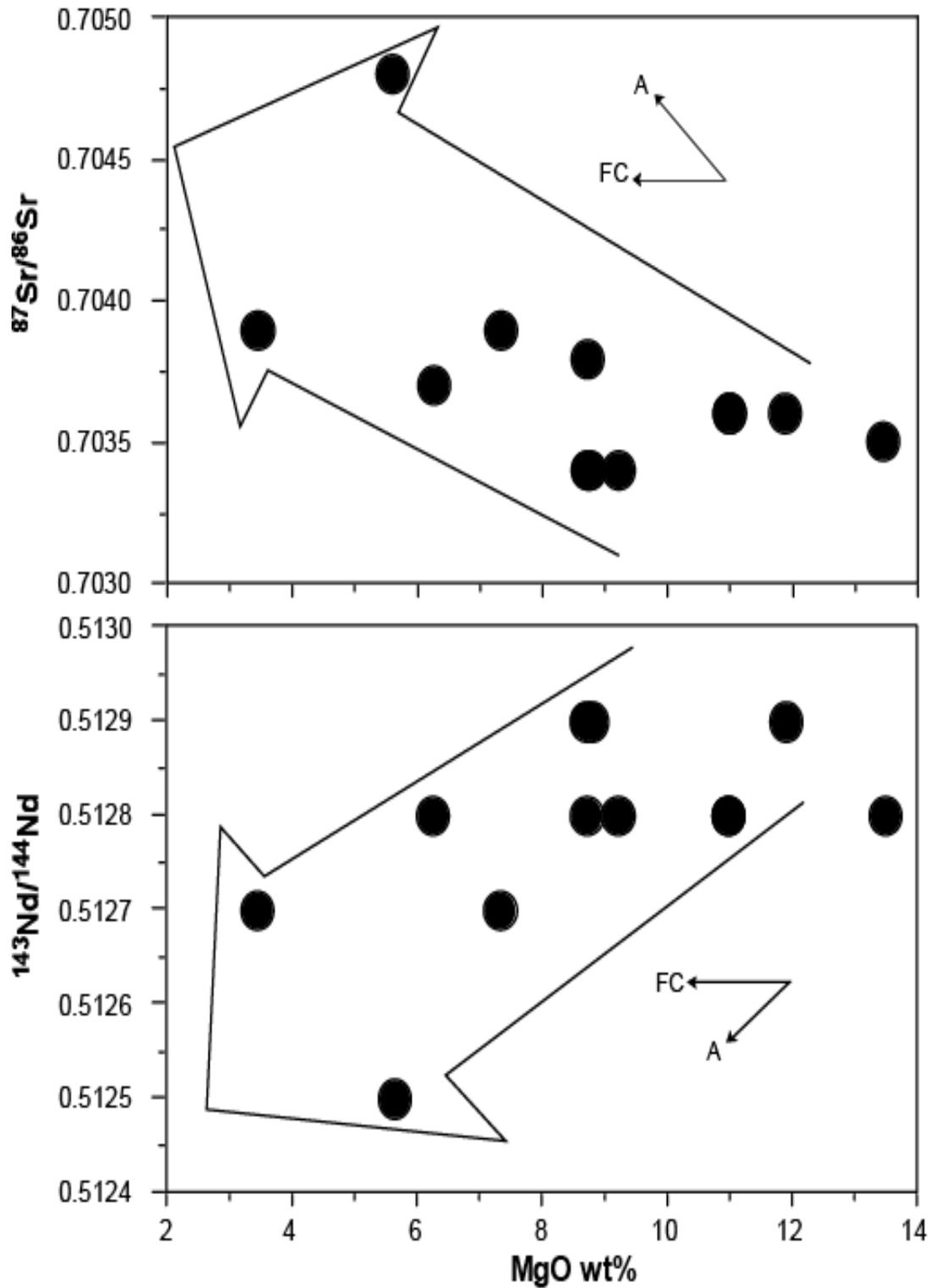
Figure 2. Variation of $^{143}Nd/^{144}Nd$ and $^{87}Sr/^{86}Sr$ plotted against MgO. Vectors show the effects of fractional crystallization (FC) and assimilation (A).

metasomatic enrichment of the upper mantle (Mckenzie,   1989).   Sea   floor   spreading,   starting   at   120   Ma

Table 2. Radiogenic Sr-Nd-Pb[2]isotopic data for selected basic volcanic rocks from the Oku-Ndu area. Also included are data for MgO, Ni and Cr. 87Sr/86Sr, indicates age corrected data.

Ident	87Sr/86Sr	*87Sr/86Sr	143Nd/144Nd	Age Ma	206Pb/204Pb	207Pb/204Pb	208Pb/204Pb	Ni(ppm)	Cr (ppm)	wt.% MgO	Rock type
K01	0.7037	0.7037	0.5128	1.0000				58.0000	136.0000	6.2600	Hawaiite
K07	0.7039	0.7039	0.5127	17.0000				99.0000	186.0000	7.3300	Basalt
K25	0.7039	0.7039	0.5127	17.0000	18.3800	15.5180	38.5530	4.0000	2.0000	3.4400	Hawaiite
K34	0.7036	0.7036	0.5128	17.0000				250.0000	353.0000	10.9900	Basalt
K34R	0.7036	0.7036	0.5128	17.0000				250.0000	353.0000	10.9900	Basalt
K65	0.7036	0.7035	0.5129	20.0000				376.0000	553.0000	11.9000	Basalt
K67	0.7038	0.7038		17.0000	18.6070	15.5290	38.3370	140.0000	201.0000	8.7100	Basalt
K72	0.7038	0.7038	0.5128	16.0000	18.5120	15.4970	38.3370	106.0000	223.0000	7.9300	Basalt
K73	0.7034	0.7034	0.5129	1.0000	19.4480	15.5890	39.1420	115.0000	183.0000	8.7700	Basalt
K74	0.7034	0.7034	0.5129	1.0000	19.4160	15.6140	39.1800	46.0000	76.0000	8.7120	Basalt
K77	0.7034	0.7034		0.0890				124.0000	192.0000	9.2200	Basalt
K83			0.5129	25.0000				453.0000	686.0000	13.4600	Basalt
K84					19.2630	15.5340	38.6960			8.7300	Basalt
K86	0.7048	0.7048	0.5125	15.0000				7.0000	2.0000	5.6100	Hawaiite

caused the African lithosphere to migrate with respect to the underlying hot zone (Fitton, 1987; Halliday et al., 1988). This, in effect, caused migration of the presently active St. Helena hotspot to its present-day position as described by O'Connor and Duncan (1990), leaving the metasomatised enriched mantle coupled to the lithosphere.

At 65 Ma, magmatic activity was initiated along the CVL with the emplacement of sub-volcanic intrusions (ring complexes). Melts were probably generated from the metasomatised domains (Vollmer, 1983; Karmalkar and Rege, 2002) or enriched mantle.

From 35 Ma to present, the partial melts of the metasomatised mantle (composed of HIMU, depleted and enriched components) have erupted through channel ways to the surface forming the extrusive series of the CVL. The HIMU characteristics of the lava of Mt. Oku are, therefore, fingerprints of the involvement of the Cretaceous St. Helena hotspot in the petrogenesis of the magmas of the CVL as a whole. More detailed geochemical and geochronological studies are required to fully understand the part played by the St. Helena hot plume in time and space in the generation of magmas of the Mt. Oku and the CVL as a whole.

Conclusion

Radiogenic isotope compositions (Sr, Nd, Pb) of mafic rocks of Mt. Oku show continuous variations connecting three distinct mantle reservoirs: HIMU, enriched and depleted mantle reservoirs. The trends of radiogenic isotopes have been interpreted as metasomatism induced in the mechanical boundary (lithospheric upper mantle) layer by fluids from the St. Helena mantle uprising plume ca 120 Ma before migration to its present site.

The melts became trapped in the mechanical boundary where metasomatic enrichment of the upper mantle occurred. The strong regionality of major and trace elements together with structural geology and geophysical evidence, support shallow present day mantle processes in the generation of lavas of the Mt. Oku and the CVL as a whole. Present day magmatism is therefore suggested to be derived partial melting of this mechanical boundary layer by adiabatic decompression.
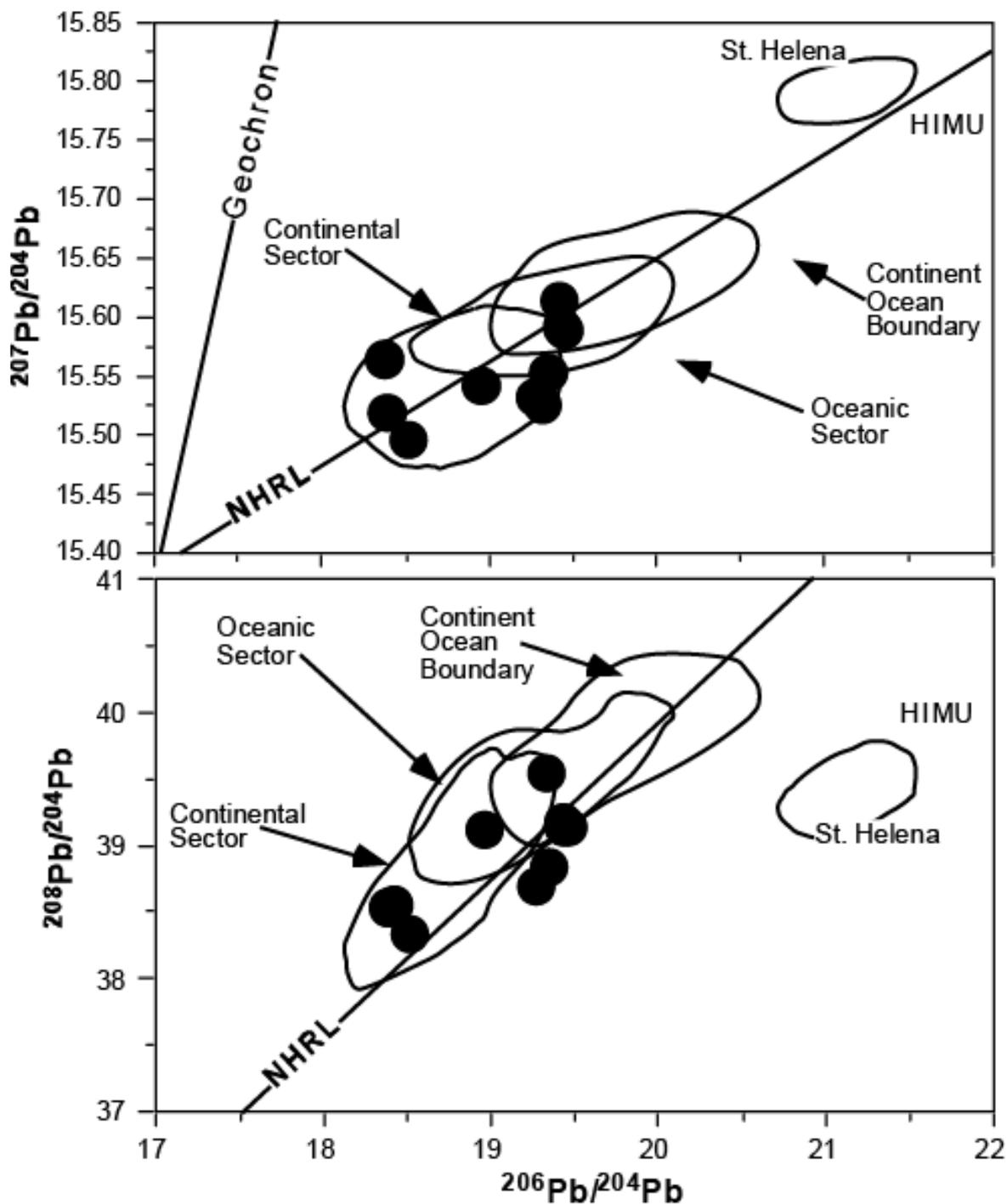
Figure 3. Variation of $^{208}Pb/^{204}Pb$ and $^{207}Pb/^{204}Pb$ plotted against $^{206}Pb/^{204}Pb$ for mafic rocks from Oku compared with data from other CVL lavas. NHRL is the northern hemisphere reference line.
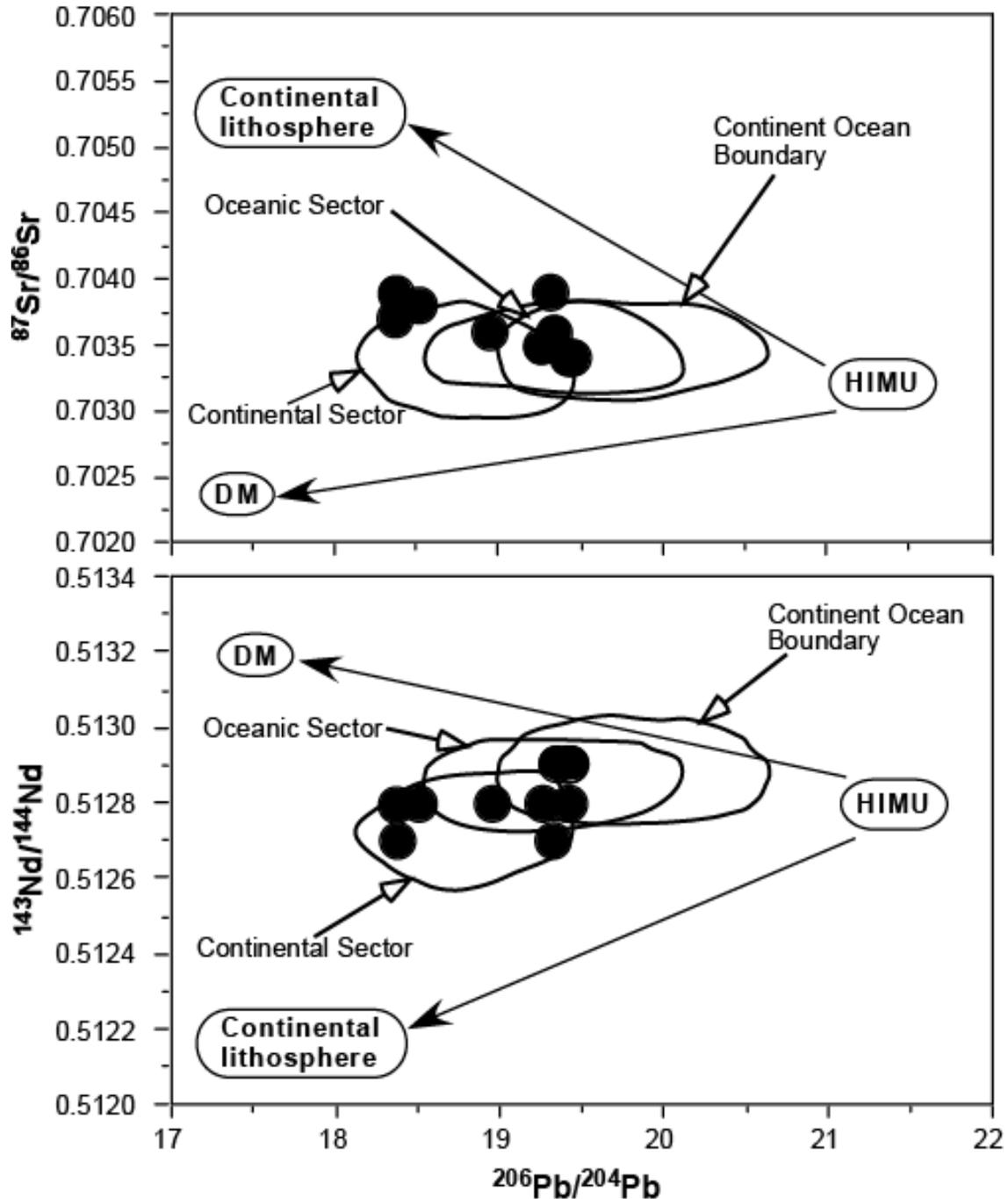
Figure 4. Variation of $^{143}Nd/^{144}Nd$ and $^{87}Sr/^{86}Sr$, plotted against $^{206}Pb/^{204}Pb$ for the lavas of Oku compared with oceanic, ocean-continent boundary and continental sector volcanics (from literature cited in the text). The data may be described in terms of three mantle components described in the text i.e. depleted mantle (DM), enriched mantle or continental lithospheric mantle and HIMU sources.

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