Geochemistry of tertiary-quaternary lavas of Mt. Oku Northwest Cameroon

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Abstract

The Oku massif occupies the central position amongst the continental sector volcanoes of the Cameroon Volcanic Line (CVL). Field observations, petrographic major, trace and REE geochemistry show that lavas are basanite/alkali basalt-trachyte/rhyolite suited with a distinct compositional gap within the benmoreite field. This gap, which cannot be explained by sampling bias, may therefore reflect density filtration within the magmatic plumbing system. However, accumulation and fractionation of major mineral phases: pyroxenes, olivines and plagioclases appear to have controlled magma evolution. Fractional crystallization has been shown to be the major differentiation process that gave rise to the spectrum of magmas of this stratovolcano though crustal contamination in high level magma chambers cannot be precluded in this intraplate continental setting. K-Ar age determinations show that the volcanic activity in Mt. Oku occurred in three distinctive episodes 25-22 Ma, 18-14 Ma and < 1 Ma. There is no evidence for volcanic activity between 14 and 1Ma. Less than 1 Ma BP, activity resumed creating abundant cones and craters.

---------- *Keywords*: Oku, stratovolcano, geochemistry, K-Ar ages, compositional gap.

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Geoquímica de las lavas terciarias-cuaternarias del Monte Oku al nordeste de Camerún

Resumen

El Monte Oku ocupa la posición central en el sector continental de los volcanes de la Línea Volcánica de Camerún (CVL). Las observaciones del terreno, petrográfica mayor, huella y REE geoquímica, indican que esas lavas son basanita/basalto alcalino trachita/reolita junto al boquete composicional dentro del terreno benmoreita. Este boquete, que no se puede explicar por diagonal de muestreo, puede por lo tanto reflejar la densidad de filtración dentro del sistema magmático. Sin embargo, la acumulación y la fragmentación de las mayores fases minerales: piroxenas, olivinos y plagioclasa, parecen haber controlado la evolución del magma. La cristalización ha mostrado ser el mayor proceso de diferenciación que da a lugar al espectro de los magmas de este estrato-volcán, aunque la contaminación cortical en el nivel superior de las cámaras del magma no puede ser impedida en este medio continental intra-plato. Las determinaciones *K-Ar age* indican que la actividad volcánica del Monte Oku ocurrió en tres episodios precisos, 25-22 Ma, 18-14 Ma y < 1 Ma. No hay evidencia de actividad volcánica entre 14 y 1 Ma. Para edades < 1 Ma BP, la actividad volcánica fue reasumida creando conos y cráteres abundantes.

---------- *Palabras clave*: Oku, estratovolcán, geoquímica, *K-Ar age*, boquete composicional.

Introduction

The Cameroon volcanic line (CVL) is a continuous 1600-km long Y-shaped chain of Tertiary to Recent, generally alkaline volcanoes that follow a trend of crustal weakness which stretches from the Atlantic island of Pagalu, through the armpit of Africa into the interior of the African continent (figure 1). Associated with the volcanic line is a series of over 60 syenite and granite ring complexes, which range in age from 66 to 33 Ma [1, 2, 3, 4]. Volcanism started ca 35 Ma ago and continued to the present without any apparent migration of the focus of activity with time.

The continental sector of the CVL is represented by the volcanic massifs of Mount Cameroon, Manengouba, Bambouto, Oku, the Adamawa plateau and Biu plateau (in Nigeria) which cut through and emplaced on a basement of Pan African granite-gneisses (approximately 600 Ma). The Oku massif, which occupies a central position along the continental sector of the trend, is a complex stratovolcanic edifice ~ 90 km in diameter and reaching a height of 3011 m (Mt. Oku). The eruptive products range from basanite and alkali basalt through hawaiite, mugearite to trachyte-rhyolite flows, high level intrusions and intercalated pyroclastics. The basement rocks upon which the lavas were erupted include granites, migmatites, and biotite diorites of Pan-African age. Detailed field observation and K-Ar ages have allowed reconstruction of the volcanic history. This study focuses on the major, trace including REE geochemistry and K-Ar ages obtained. These data have enabled the history of the eruptions and petrogenesis of the Mt. Oku volcanic suites to be evaluated.

Field relations

The basement upon which the Oku lavas were erupted includes granites, migmatites and biotite diorites which were uplifted during the general doming that accompanied the eruption of the CVL. They could have been a pile of over 2000 m of volcanic material on Mt. Oku prior to widespread erosion. 80% of the 5-7% natural exposures occur in the more felsic alkaline members of the volcanic suite, particularly flows of trachyte, rhyolite and welded rhyolitic tuffs. These form steep erosion escarpments and plugs, some of which have very little or no vegetation cover. Mafic lava flows (basanite, and basalt) are normally almost completely obscured by lateritic weathering products and thick mountain forest with deep soil profiles. Table 1 and figure 2, summarize the general litho logical characteristics of the Mt. Oku volcano. Three distinct volcanic series have been identified:

Oku Lower Series made up of basic lava flows some of which lodge fragments of basement granite partially digested. The trachyte and rhyolite of this series occur in the form of flows and plugs. They are fractured by hydrothermal fluids which precipitated micro veins of galena and chalcedony. This gives the diagnostic field difference between evolved rocks of the Oku Lower Series and those of the Oku Upper Series.

Oku Middle Series comprising basaltic flows overlain by trachyte and rhyolite intercalated with pyroclastic flows. Most of the peaks of the Mt. Oku volcano are trachyte plugs. Block and ash flows and ash flow tuffs are common.

Oku Upper Series constitutes the most recent phase and is characterized by phreatic and phreatomagmatic volcanic products. It is composed of a series of recent cinder cones and craters. One of these craters forms a circular maar now occupied by Lake Oku, one of the largest maars of the Cameroon Line. Of the numerous cinder cones and craters, only the ejector of Lake Oku contains mantle xenoliths [5]

Analytical Techniques

Prior to electron microprobe analysis, polished thin sections were studied under the Scanning Electron Microscope (SEM). Back scattered electron (BSE) images taken using the SEM were particularly useful for understanding mineral textures. Following this preliminary SEM

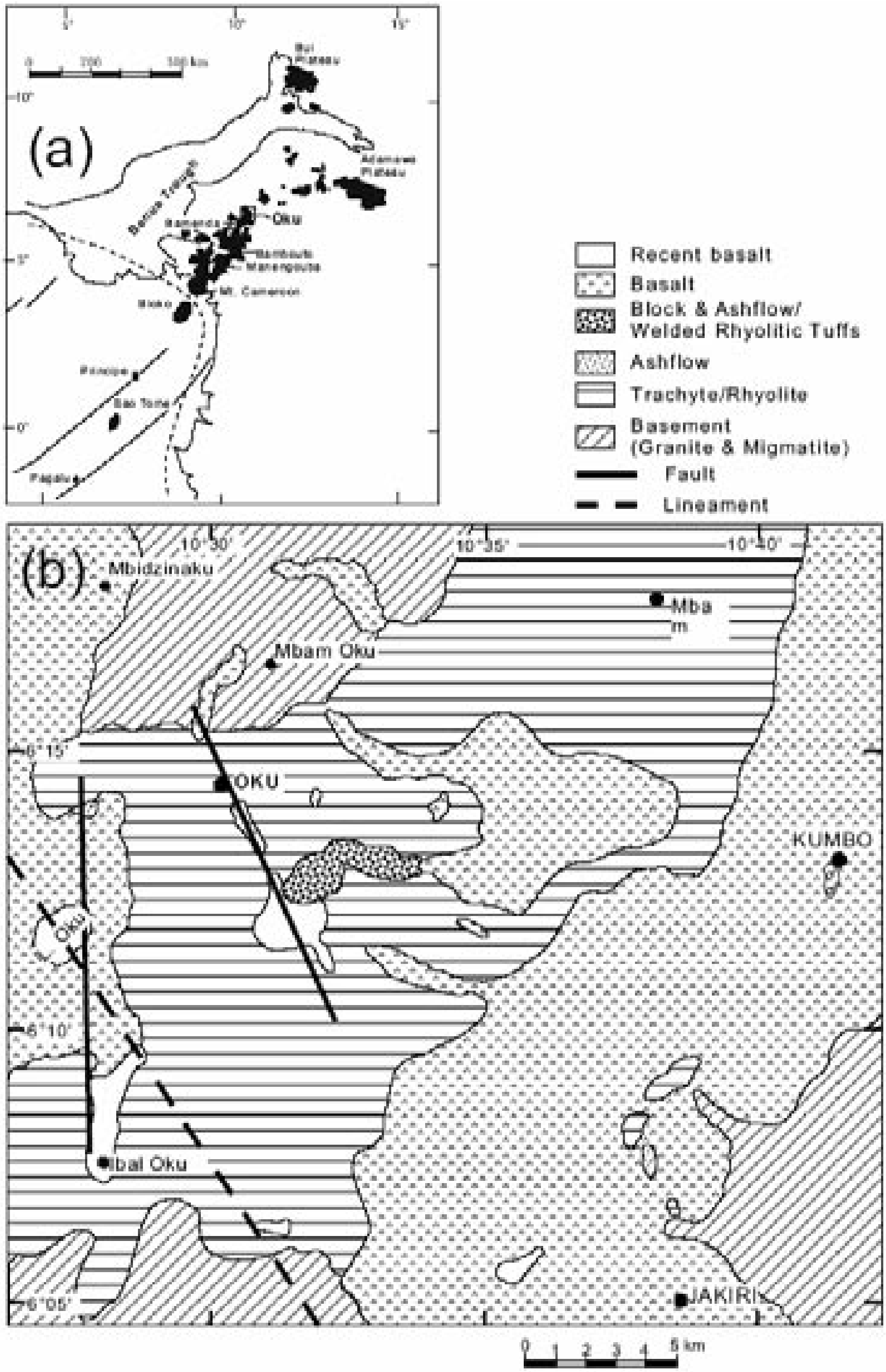

Figure 1 Geological map of the Mt. Oku volcano.

Table 1 Stratigraphic description of the Mt. Oku volcano

Series	*Rock Type*	*Field observation*	*Comment*
Oku Upper Series	Airfall material	Inversely graded siliceous pumice lappilli, vesicular to dense lapilli	
	Scoria cones and Craters	Scoria and ash rimming cones and craters contain spinel lherzolite mantle xenoliths.	Constitute the youngest flows < 1 Ma years old.
Oku Middle Series	Mafic Rocks	Steeply dipping jointed mafic flows, occupying small paleo-valleys. Pillow lavas	Constitute inhospitable cliffs
	Felsic Rocks	Trachyte intrusives extrusive trachytes and rhyolites	
	Pyroclastic Rocks	Block and ash flows	Contain fragments of trachytes. Rhyolite and basalt in greyish ash
		Ashflow tuffs	Carry volcanic bombs
Oku Lower	Felsic Rocks	Intrusive trachytes Extrusive trachytes or rhyolites	The extrusives are criss crossed with microveins of galena and chalcedony

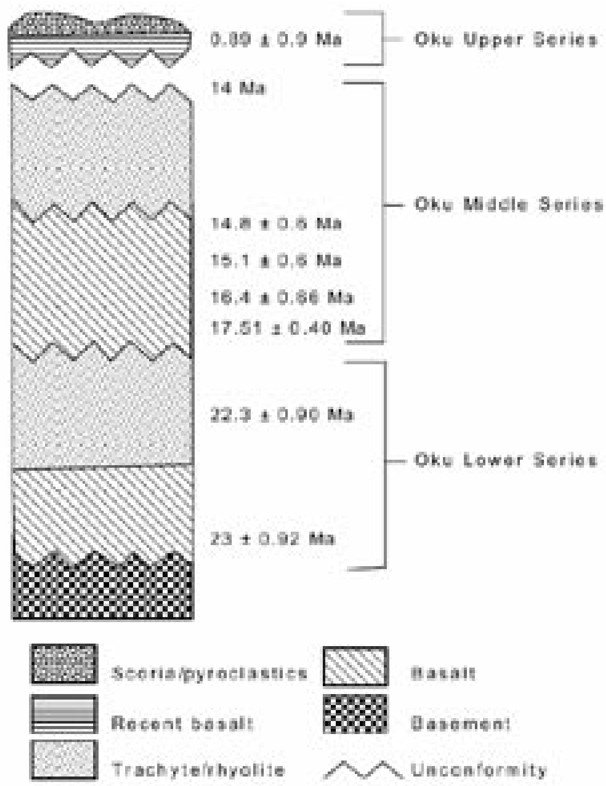

Figure 2 Schematic stratigraphic section of the Mt. Oku volcano and the K-Ar ages of representative samples

analysis the electron microprobe was then used for detailed chemical analysis of both phenocryst and groundmass phases.

Major and trace element analyses were obtained from over 100 samples as part of this study using the X-ray fluorescence technique. Major elements were analysed on fused discs prepared from a 1:10 mixture of rock powder with lithium borate *Spectroflux* cast into glass discs. Trace elements were measured on pressed powder pellets prepared from 15 g of rock powder mixed with 2 ml moviol solution binder (agglutinate) and compressed between steel discs. REE analyses were carried out by Inductively Coupled Plasma (ICP) in Leeds University UK.

K-Ar ages were determined on whole rocks in Leeds University. Argon was determined in a glass vacuum system using ^{38}Ar tracer from an aliquot system. A two-stage clean up procedure was used: stage one, incorporating a Ti-sponge furnace and liquid nitrogen trap. The purified gases were then drawn into a second clean-up section, on activated charcoal containing a Ti/Zr sponge furnace. Argon isotopes were measured on a modified AEI MS10 mass spectrometer fitted with an automatic peak switching and digital output [6]. Errors were estimated by taking the percentage difference between replicate argon determinations, on samples less than 20 Ma, plotted as a function of radiogenic ^{40}Ar, and the best fit estimate of the two errors in individual analyses. This method was developed by analysis of over 100 duplicate Ar measurements on volcanic rocks between 0.1 and 20 Ma, with varying amounts of atmospheric Ar contamination, and found to give the most realistic error estimates for samples in this age range. International standards were analyzed and atmospheric argon ratios were determined on a regular basis. For further details, see reference [6] for analytical procedures.

Mineralogy

Figure 3 summarizes the petrographic characteristics of the compositional spectrum of volcanic rocks from the Mt. Oku volcano. The mafic rock types basanite and alkali basalt include both aphyric and strongly porphyritic end members. Phenocrysts of clinopyroxene and olivine are ubiquitous, accompanied by plagioclase and titanomagnetite. They range from euhedral to anhedral, some of which are resorbed. Microphenocrysts of olivine, clinopyroxene, titanomagnetite and plagioclase are common. The groundmass is dominated by orientation of feldspar laths.

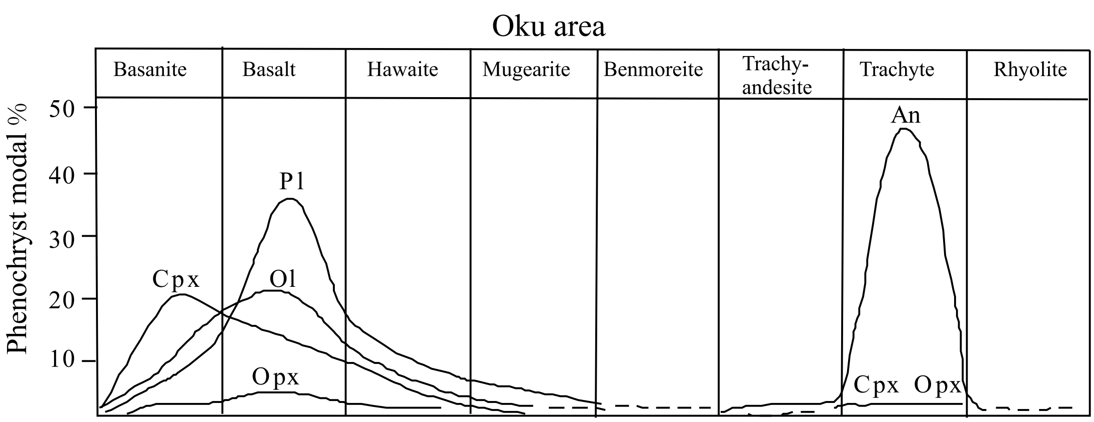

Figure 3 Approximate variation of phenocryst modal proportion with rock type. The curves show the maximum modal proportion of each mineral. Note the following abbreviations used: Pl. = plagioclase; Ol. = olivine, Op = opaque; Opx = Orthopyroxene Cpx. = clinopyroxene; An. = anorthoclase. Dashed lines indicate that the mineral may or may not be present

Olivine

Olivine ranges from subhedral to euhedral and almost all the phenocrysts are compositionally zoned with forsterite rich cores and more fayalite rich outermost rims. It occurs as both phenocryst and as groundmass phases in the primitive (high Mg, Ni and Cr) to intermediate rock types. Olivines show a considerable compositional range that varies between Fo_{86}- Fo_{62}.

Amphibole

These are soda amphiboles of riebeckite-arfvedsonite compositions similar to those described by [7]. On the basis of 24(O, OH, F) the average composition of these amphiboles was calculated to be: $[K_{0.23}Na_{2.39}Ca_{0.12}][Fe_{4.6}Mg_{0.1}Mn_{0.1}\ Ti_{0.2}A1_{0.11}]\ \Sigma_5[Si_{7\cdot 9}Al_{0.1}]\Sigma_8O_{22}\ (OHF)_2$

Clinopyroxene

Most of the clinopyroxene fall in the salite and diopside fields on the wollastonite-enstatite-ferrosilite triangular plot (figure 4). They, like the olivines, range from subhedral to euhedral types where they occur as phenocrysts. The Mg# = (Mg/Mg+Fe_T+Mn) of the clinopyroxene range form 88 in the cores of the phenocrysts of some primitive basalts to 65 in some groundmass outermost rims.

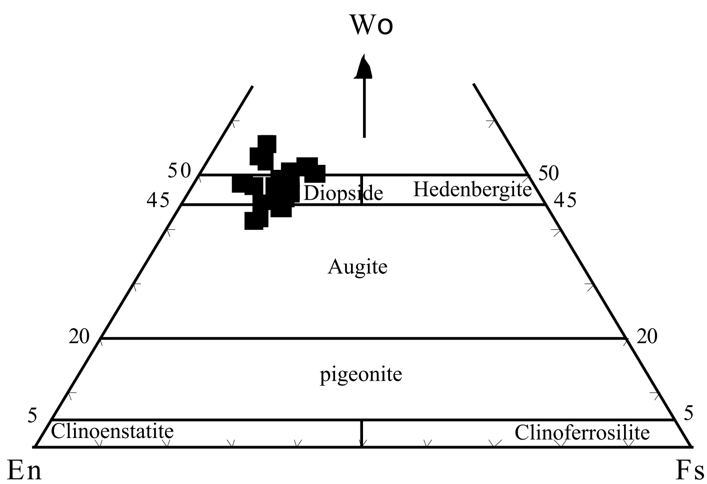

Figure 4 Compositional variation of the pyroxene phases in volcanic rocks from the Mt. Oku volcano in the wollastonite-enstatite-ferrosilite triangle (classification after [8]

Plagioclase

The plagioclases range in composition from An_{71-30}. Interstitial plagioclase representing late stage phases range from An_{18} to almost pure albite $An_{1.5}$ Plagioclase occurs as phenocrysts, microphenocrysts and groundmass. The resorbed phenocrysts exhibit both normal and reversed zoning.

Alkali feldspar

They range in composition from Ab_{68-57} in case of the phenocrysts and Ab_{65-33} in the groundmass phases. Corona structures of anorthoclase around first formed feldspar are common with compositions ranging between $An_{37(core)}$ to $An_{64(outermost\ rim)}$.

Potassium feldspars are predominant in the evolved members of the volcanic suite. In the benmoreites, they occur as groundmass phases only whilst in the trachytes, megacrysts with resorbed edges and phenocrysts are abundant.

Fe-Ti oxides

The proportion of Fe-Ti oxides increase with magma evolution and are very abundant in the trachytes. The Fe-Ti oxide minerals comprise titanomagnetite, spinel, and ilmenite. In some cases, they occur as inclusions in olivines, clinopyroxenes and plagioclase where occasionally, they are found clustered together.

Geochemistry

Major and trace element compositions of selected representative samples of Mt. Oku lava series are presented in Table 2. On a total alkali (Na_2O+K_2O wt.%) versus SiO_2 wt.% (TAS) plot after [9] the lavas define a bimodal suite with a marked "Daly gap" between 52 and 58 wt.% SiO_2 (Figure 5). The spectrum of volcanic rocks clearly grade into each other and the field boundaries shown are simply used to provide a working nomenclature for the individual rock types. The volcanic rocks follow an under-saturated evolutionary trend with rhyolite as the most extreme differentiate. Similar differentiation sequences have been noted for other intra-continental plate alkali volcanic suites in Africa e.g. Jebel Mara in Sudan [10, 11] and the continental sector of the CVL [1].

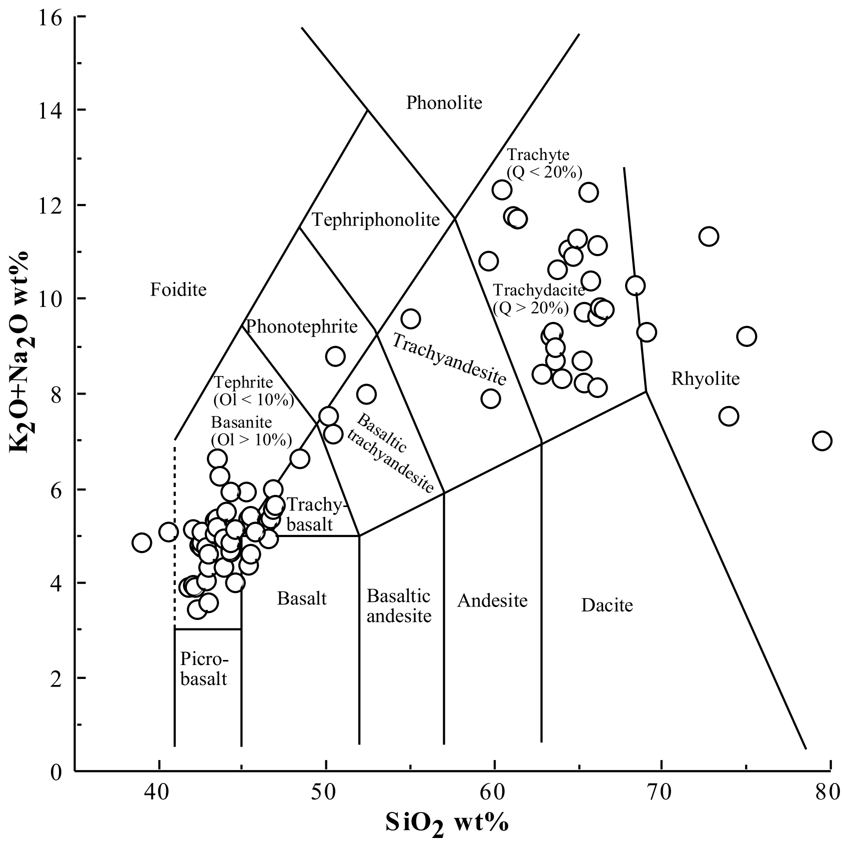

Figure 5 Plots of the investigated samples in the Na_2O+K_2O – SiO_2 diagram (Harker variation diagram). The different fields are after [9]

Table 2 Chemical composition of representative Mt. Oku volcano lava

	K01	*K03*	*K07*	*K14*	*K16*	*K19*	*K25*	*K26*	*K90*	*K91*	*K92*	*K18*	*K20*	*K33*	*K36*	*K40*	*K45*
SiO_2	46.96	46.7	46.41	65.29	44.29	48.41	50.35	42.98	50.5	46.86	42.58	60.41	63.33	61.12	66.3	63.58	68.99
TiO_2	3	2.95	3.57	0.75	3.59	2.25	2.13	4.46	2.15	5.41	3.01	0.53	0.67	0.26	0.78	0.76	0.45
Al_2O_3	15.59	15.53	15.28	11.83	13.64	16.36	16.26	13.84	16.48	15.53	13.69	15.17	16.28	17.29	13.24	10.56	12.8
Fe_2O_3	12.17	11.9	12.88	8.52	13.67	11.03	11.29	14.9	12.97	15.33	12.36	5.63	4.15	6.59	6.16	10.66	4.96
MnO	0.19	0.19	0.18	0.36	0.21	0.18	0.2	0.23	0.21	0.2	0.18	0.38	0.09	0.2	0.28	0.06	0.25
MgO	6.26	6.03	7.33	0.35	9.19	4.85	3.44	6.29	2.77	9.72	8.32	0.22	1.67	0.19	0.04	0.1	0
CaO	9.32	9	8.49	0.94	9.9	7.01	5.82	10.05	5.7	10.86	9.6	0.88	2.94	1.26	0.13	0.21	0.16
Na_2O	3.98	3.67	4.29	5.61	4.44	3.99	4.87	3.21	6.08	4.52	3.64	7.22	4.01	5.9	5.17	4.4	4.92
K_2O	1.66	1.71	1	4.12	1.51	2.63	2.29	1.1	2.73	1.47	1.44	5.13	5.19	5.84	4.68	4.29	4.41
P_2O_5	0.89	0.88	0.98	0.09	0.86	0.5	1.13	2.2	1.24	1.15	0.72	0.14	0.32	0.1	0.09	0.08	0.07
L.O.I.	0.57	1.41	1.38	2.12	-0.25	2.83	2.11	0.75				2.63	0.86	1.18	3.63	4.77	2.83
Total	100.61	99.99	101.8	99.99	101.07	100.04	99.91	100.01	100.75	101.05	95.37	98.38	99.53	99.94	100.52	100.03	99.82
Cr	136	138	186	0	311	73	0	46	24	199	207	0	19	0	0	0	0
Co	39	38	47	17	50	43	33	46	37	50	52	12	17	15	10	21	11
Ni	58	58	99	5	156	46	4	26	26	101	140	0	13	0	5	6	4
Zn	94	99	109	262	104	96	128	115	92	100	104	186	72	130	192	351	92
Rb	30	33	21	78	104	96	128	115	33	15	33	100	186	122	61	110	83
Sr	1136	1094	1275	14	928	464	873	864	1032	1841	805	148	597	110	16	7	3
Y	26	25	24	80	23	33	41	36	24	20	26	58	30	50	56	107	70
Zr	237	249	232	936	204	364	475	203	250	156	238	806	229	1174	577	1293	1140
Nb	54	55	48	194	51	34	82	46	60	43	63	143	15	146	123	261	226
Pb	0	0	0	13	0	6	0	0	0	0	0	8	27	15	7	18	12
Ba	681	693	666	100	554	298	697	1414	567	684	509	731	1482	883	50	39	0

Table 2 (continuation)

	K01	K03	K07	K14	K16	K19	K25	K26	K90	K91	K92	K18	K20	K33	K36	K40	K45
La	33.3	48	49.3	147.8	41.2	39.1	66	52.3	49.2	39.7	43.7	115.6	149.1			188.3	138.9
Ce	81.6	102.1	110.2	309.8	86.8	86.3	155.2	130.6	107.4	90.9	90.2	239	177			387.8	282.7
Pr	10.63	12.06	14.05	33.89	10.39	10.09	18.78	17.47	12.78	11.63	11.14	26.23	26.68			42.7	30.41
Nd	46.2	49.4	55.6	126.1	44.4	40	77.9	81.6	51.7	51.5	45.7	94.6	94.2			157.3	109
Sm	9.44	9.45	10.31	23.64	8.89	8.27	15.7	16.85	10.19	10.38	9.02	17.4	14.98			29.48	19.69
Eu	3.24	3.26	3.42	5.95	3.11	2.3	4.61	8.5	3.38	3.9	3.14	3.6	2.38			6.49	2.01
Gd	8.43	8.88	9.47	20.34	8.31	8.14	13.33	15.63	9.13	9.24	8.5	14.45	10.5			25.73	16.36
Dy	6.45	6.52	6.82	19.14	6.29	7.58	10.17	10.41	6.93	6.3	6.39	13.72	7.28			24.7	15.5
Ho	1.07	1.08	1.14	3.31	1.02	1.35	1.7	1.63	1.15	1.01	1.04	2.41	1.24			4.33	2.72
Er	2.93	2.93	3.08	9.19	2.67	3.95	4.7	4.13	3.15	2.61	2.75	6.83	2.89			12.16	7.72
Yb	2.18	2.18	2.25	7.9	1.93	3.34	3.54	2.6	2.32	1.72	1.97	6.12	2.44			10.48	7.04
Lu	0.31	0.31	0.27	1.14	0.27	0.05	0.51	0.36	0.34	0.25	0.27	0.91	0.34			1.52	1.04
Y	27	26.8	0.33	84.5	25.4	35.6	42.6	40	28.7	24	25.6	61.6	32.1			112.6	69.9

Figure 6 shows the variation of a range of major element oxides TiO_2, Al_2O_3, Fe_2O_3, MnO, CaO, Na_2O, K_2O and P_2O_5 as a function of SiO_2 content for the volcanic suite. These diagrams demonstrate that the mineral phases most likely to exert strong control on the major element variations are olivine, clinopyroxene and plagioclase ± magnetite. The marked kinks in the trends indicate the onset of crystallisation of a particular phase. The liquid lines of descent do not represent the evolution of a single batch of magma but that of a series of broadly similar batches, evolving by similar processes in a high-level magma chamber system [12, 13].

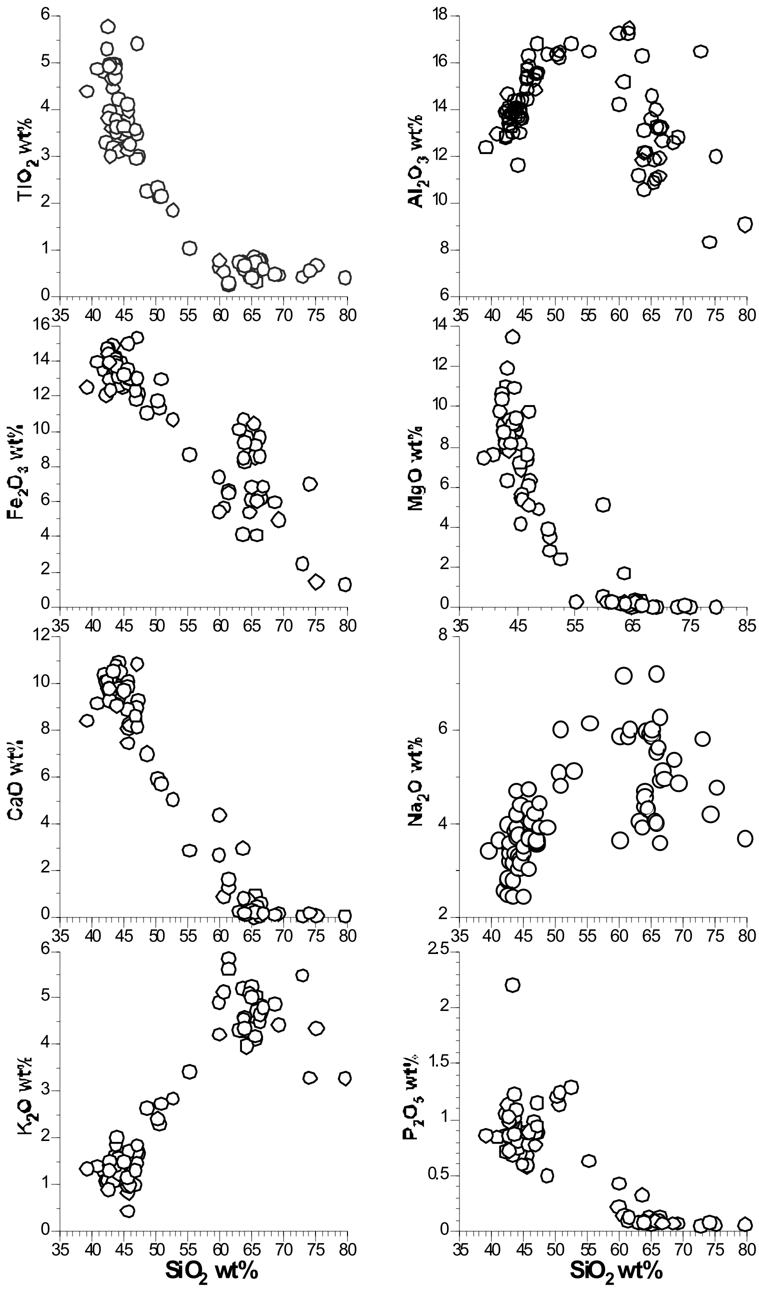

Figure 6 Harker variation diagram of wt. % major element oxides plotted against wt. SiO_2. Fe_2O_3=total iron

Abundances of the trace elements are plotted against SiO_2 as an index of differentiation in figure 7. These elements show similar characteristics with a general increase in abundance with increasing wt. % SiO_2. However, the abundances in the more siliceous rocks (> 65% wt. SiO_2) scatter widely. Compatible trace elements Ni and Cr are both enriched in basic end members (Ni > 450 ppm Cr > 700 p. p. m.) and become progressively depleted in the magma with fractionation. The most primitive samples have been normalized to primitive mantle (figure 8).

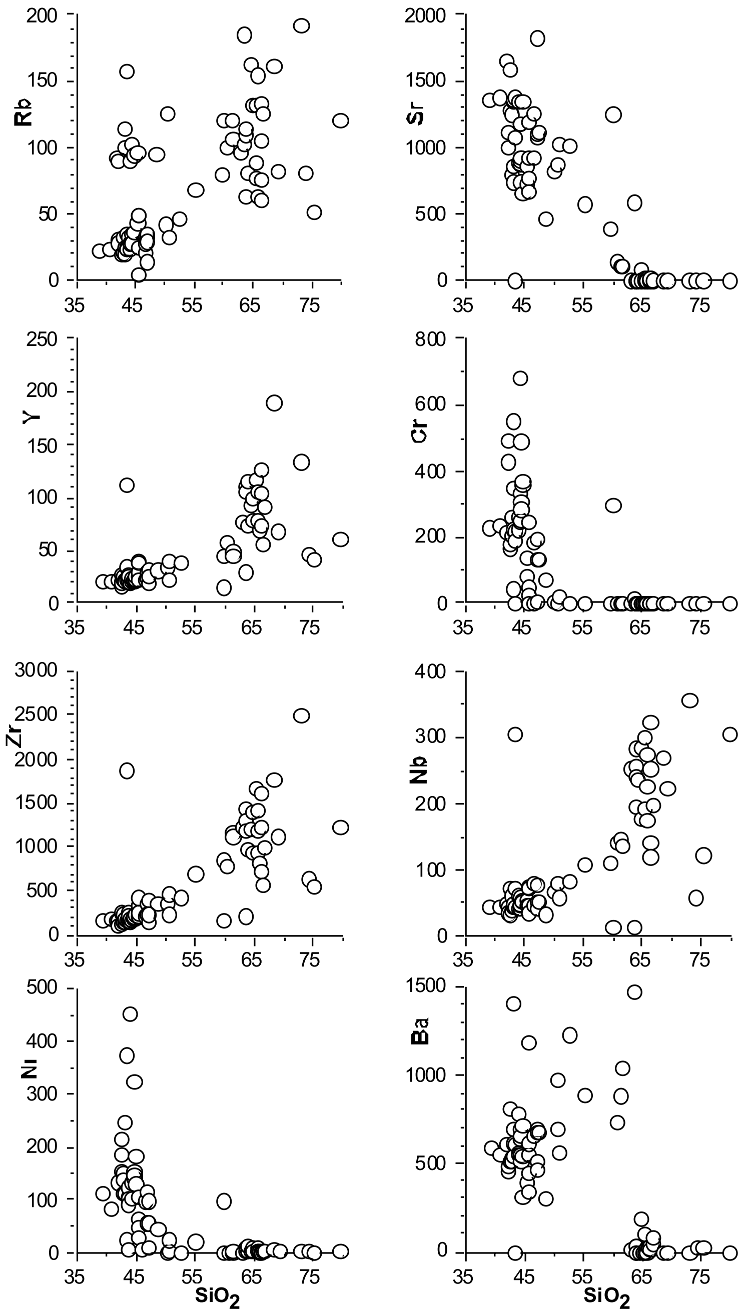

Figure 7 Harker variation diagrams for compatible and incompatible elements plotted against SiO_2

Troughs occur at Rb, K, and Zr whereas Ba, Nb show peaks. This observation suggests that the magmas from Mt. Oku could have been produced from the same source and undergone the same differentiation history. The negative anomalies in K and Sr and the relatively low normalised Ba and Rb concentrations suggest the presence of a residual potassic amphibole phase at the source.

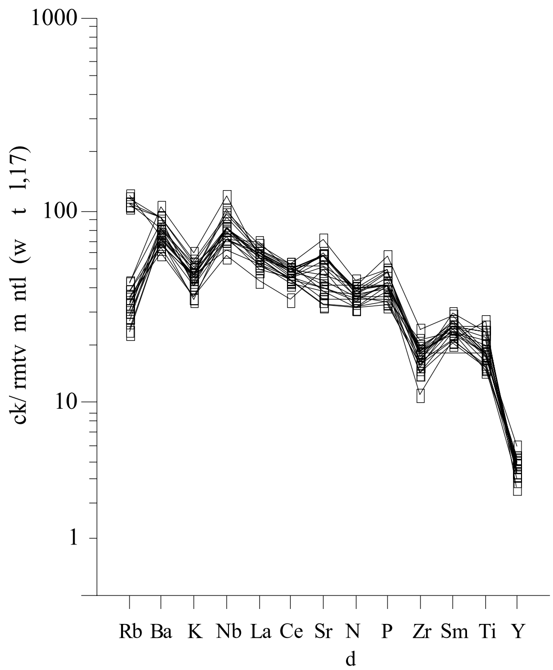

Figure 8 Primitive mantle normalized incompatible element concentrations of representative primitive (MgO > 6 wt. %) basalts of Mt. Oku (normalizing values from [14])

Note the large positive and negative Eu anomalies depicting accumulation and then fractionation of plagioclase

Chondrite normalised REE patterns for both basic and felsic end members of the suite are presented in figure 9. The general pattern is that of LREE enrichment relative to HREE. The felsic rocks are more enriched than the basic rocks.

K-Ar data are presented in table 3. These data combined with one K-Ar age from the same locality show that the Mt. Oku volcano experienced three periods of volcanic activity: 23-22 Ma, 18-14 Ma; and < 1 Ma. Volcanism was episodic rather than continuous. There is long gap of inactivity between 14 and 1 Ma and the present data indicates no evidence of volcanic activity within this interval.

Discussion

Volcanic History of the Mt. Oku volcano

Marzolli et al. [15] used K-Ar age determination carried out on selected rock samples and field observations showed that volcanic activity was initiated ca 31 Ma ago in the north eastern part of the massif around Ndu with the eruption of basic lava flows of the Ndu Lower Series (NLS), probably along a NNW-SSE trending fracture system that stretched from Ndu north westward to Mt. Rtufu and beyond. Volcanism did not start

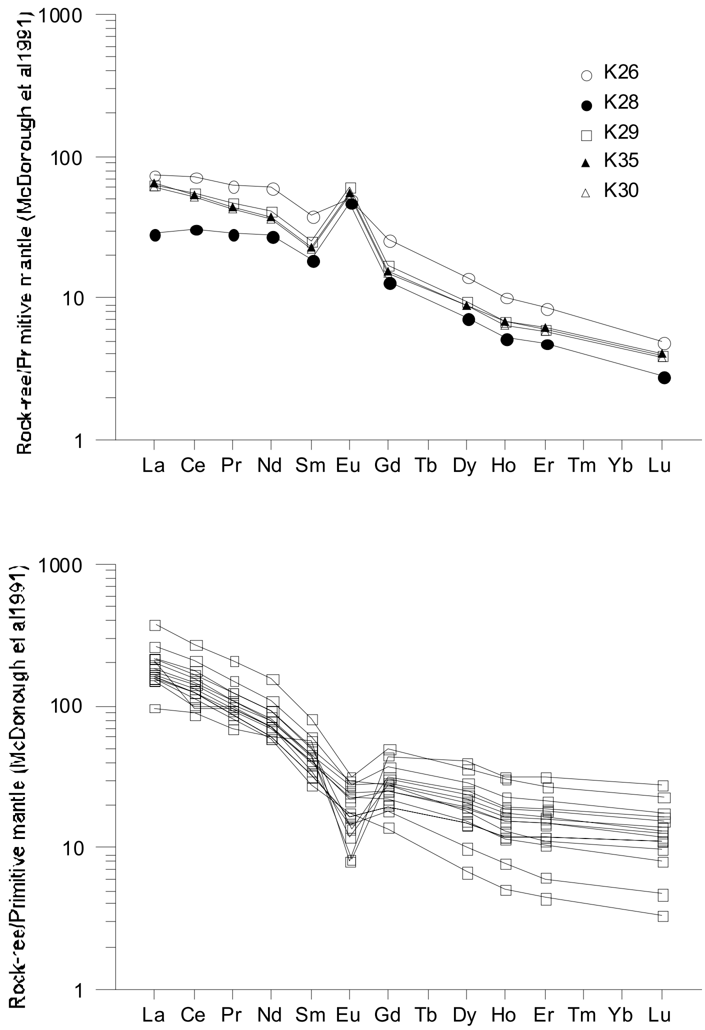

Figure 9 Chondrite normalized rare earth element patterns. Normalizing values from [14]

Table 3 K-Ar data from the rocks of the Oku area

Sample number	*Rock type*	*Locality*	*%K*	*Vol. 40 Ar RAD. CCSTP/g x10^{-5}*	*%40AR rad.*	*Age Ma*	
K77	Basalt	Ibal Oku	1.595	0.0055	4.9	0.89 ±. 1	3
K29	Basalt	Faikwi	1.061	0.0615	51.5	14.80 ±. 6	
K35	Basalt	Tadu	1.623	0.0899	67.3	15.10 ±. 6	2
K70	Basalt	Ndong Mawess	1.139	0.0728	48.8	16.4 ±. 7	
K09	Trachyte	Vinjini	3.400	0.2978	18.7	22.33 ±. 9	
K84	Basalt	Verkovi	0.820	0.0733	18.2	22.90 ± 1	1

Analyses by D. C. Rex, Dept. of Earth Sciences, Leeds University.

in Oku until 25 Ma. Daly [16] has demonstrated using ^{40}Ar-^{39}Ar age determinations that silicic magmas of Mt. Oku have ages of 25-24 Ma. Two samples from this work K84 (basalt) and K09 (trachyte) both gave K-Ar ages of 22.90 ± 1Ma and 22.33 ± 0.9Ma (table 3) respectively, suggesting that this phase of volcanism lasted for 3 Ma.

The basic lava flows in the Mt. Oku volcano are overlain by more felsic flows of trachyte and rhyolite which were later affected by hydrothermal activity, depositing micro veins of galena in a stockwork-mineralisation. East of Oku village, the veins are composed of chalcedony. The trachyte sample K09 is from this area.

After a hiatus of ca 4 Ma, volcanic activity commenced approximately 18 Ma ago and continued to ca 14 Ma with the eruption of basic lava flows. A hawaiite from Kumbo (K25) comes from the same locality as (C91) of Fitton and Dunlop (1985), which gave a K-Ar age of 17.21 ± 0.40 Ma. One basalt sample (K70) from a basalt overlooking (NW) Lake Oku gave an age of 14.0 ± 0.7 Ma. Basic lavas (K35 and K29) have given ages of 15.1 ± 0.6 and 14.8 ± 0.6 Ma respectively. These flows are columnar jointed with complex joint orientations suggesting emplacement in small valleys. The highest of these basic flows is overlain by trachyte and rhyolite intercalated with block and ash flows, and welded rhyolitic tuffs.

There is little evidence for volcanic activity between 14 Ma and 1 Ma. Erosion dominated during this period and gave rise to the numerous gullies and erosion escarpments.

After this long quiescent phase, volcanic activity resumed in the Mt. Oku volcano < 1 Ma BP. This phase was characterized by phreatic and phreatomagmatic eruptions. The numerous cinder cones and craters that dot the volcano testify for the explosive nature of this phase. One of these craters forms a circular maar now occupied by Lake Oku. Some recent basic flows can be traced back to their vents. A basic sample, K77, from a 4-km long flow south of Lake Oku gave an age of 0.89 ± 0.10 Ma (BP).

Volcanism was in general, episodic rather than continuous, with younger flows tending to cover the older flows. Throughout the volcanic activity of Mt. Oku volcano, there seem to have been an increase in volume of silicic products in each series and a decrease in the abundance of basaltic rocks.

Geochemical implications

On the basis of the petrography, major element trends outlined above, fractional crystallization in high level magma chambers appears to be the main process that modified the primitive magmas as they passed through the thick silicon continental crust below the Mt. Oku volcano. However, the data do not preclude the possibility of significant contamination by crustal assimilation to produce hybrid felsic magmas (trachytes and rhyolites). It is clear from figures 5 and 6 that in the Mt. Oku volcano, basic and felsic magmas have been erupted in much larger quantities than associated intermediate magmas. This has created a hiatus within the composition spectrum from 52 to 58% SiO_2, giving rise to an apparent Daly Gap. The origin of the Daly Gap has been a point of debate for a number of researchers [7, 17, 18, 19, 20, 21]. Many link the Daly gap to sampling bias but in the course of this work, sampling bias was minimized such that it is not a likely explanation for the hiatus.

Njilah [5] showed that geochemical data for the Ntumbaw anorogenic ring complex [5, 22] completely fill the Daly gap of the volcanic suite of the Mt. Oku volcano. The meager representation of magmas of intermediate composition in the volcanic suite may therefore be explained in the fact that as basic magmas ascend through the crust, they loose heat and begin to differentiate. This may result in an increase in viscosity and density, due to increasing iron content e.g. [21] prior to the onset of magnetite crystallization. This increased density is likely to cause magmas of intermediate composition to stagnate within the upper crust where they fractionate and differentiate to trachyte and then to rhyolite. In such magma chambers, the magmas may be zoned as suggested by [19, 20, 23], with the lighter trachytic magma at the top and readily available for extrusion. It is possible that within the Mt. Oku volcano, these lighter magmas acted as a further filter in a density stratified magma chamber system, preventing the dense mafic-intermediate magmas from erupting. Other factors such as the position of the magma chamber in the crust and therefore the density contrast between the magma and the wall-rock and viscosity of the magma might also have contributed to the development of the Daly gap.

Because of the intimate links Ni and Cr have with particular fractionating phases, element plots show distinct kinks (figure 7) that depict participation of these phases in crystal fractionation processes. On the plot of Ni (ppm) versus SiO_2 wt%, two kinks can be observed; the first represents olivine fractionation and the second olivine fractionation accompanied by clinopyroxene and magnetite. The differentiation from trachyte to rhyolite is associated with anorthoclase fractionation as a significant reduction in total alkali content occurs after trachytic lavas. Basalt show strong positive Eu anomaly on a chondrite normalized spider diagram while trachyte and rhyolite show positive anomaly indicating plagioclase accumulation and fractionation respectively in accordance with petrographic observation.

Several reports [24, 25, 26] have suggested that many felsic magmas may be generated by volatile-induced partial melting of the crust, including both crystalline basement rocks and their cover of earlier volcanic material. The presence of partially digested granulite xenoliths in basalt samples, partially melted and metamorphosed granite xenoliths in basic rocks and the intergrowth of orthopyroxene, clinopyroxene and olivine in basalt sample K83 [5] are all evidences that the magmas of the Mt. Oku volcano may have experienced crustal contamination. In most of the variation diagrams, some specific samples tend to fall off the trends. The most likely explanation for this is that they could have suffered from crustal contamination.

Conclusion

The major element geochemistry of the Oku volcano shows that they form a basanite/alkali basalt-trachyte/rhyolite suited with a Daly gap within the benmoreite field. Sampling bias does not explain the origin of the Daly Gap and we conclude that it must reflect density filtration within the magma tic plumbing system. Evidences from petrographic, major element, trace element, and REE, show that fractional crystallization played a fundamental role in the evolution of magmas.

We have used field observations, geochemical data and K-Ar age determinations to reveal three episodes of volcanic activity on the Mt. Oku. A fissure type eruption started 31 Ma ago in the Ndu area, and with time, activity migrated to the SW and became focused, resulting in the construction of the Mt. Oku volcano. In accordance with these data the Mt. Oku volcano, is characterized by three volcanic series: 24 - 22 Ma, 18 Ma and 14 Ma. A break in volcanic activity seems to have occurred between 14 and 1 Ma, as no evidence for volcanic activity of this age has been found in the course of this work. Less than 1 Ma years ago, activity resumed with the creation of abundant volcanic cones and craters.

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