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# Geochemistry of lavas from maar-bearing volcanoes in the Oku Volcanic Group of the Cameroon Volcanic Line

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ABSTRACT

Lake Nyos is located at the summit of a stratovolcano in the Oku Volcanic Group (OVG) along the Cameroon Volcanic Line. The sudden release of magmatic $CO_2$ trapped at the bottom of Lake Nyos in August 1986 caused historical casualties of 1750 people and over 3000 cattle. New geochemical data of volcanic rocks from the Nyos volcano and the first available data for volcanic rocks from other maar-bearing volcanoes (Lakes Elum, Wum and Oku) in the OVG are presented and compared. Lavas from the Nyos, Elum and Wum volcanoes show similarities in major and trace elements and Sr–Nd–Pb isotopes, suggestive of a similar mantle source. However, this source is slightly different from that of the Oku volcano. The samples from Lake Oku have lower alkali, higher $TiO_2$ and more depletion and enrichment in most incompatible trace elements than those from the Nyos, Elum and Wum volcanoes. These differences and those observed in the Sr–Nd–Pb results are consistent with a heterogeneous source for lavas in the OVG. Trace element compositions suggested the presence of garnet in the source (<6% garnet) and modelled melting results indicate <2% partial melting of the source material. Isotope data plot within the focal zone, extending towards enriched mantle 1 (EM1; e.g. Lakes Oku and Nyos samples). This indicates the involvement of at least three mantle components: depleted mid-ocean ridge basalt mantle, high-μ and EM1 components in the magmatism of the lavas studied. The contributions of these components in different proportions, originating from asthenospheric and subcontinental lithospheric mantle sources, can account for the observed variations in geochemical characteristics. The geochemical characteristics of the studied lavas indicate that the magma source need not necessarily have an abnormal $CO_2$ concentration to pose a potential threat. Degassing of an ordinary magma chamber and the migration of gas to the bottom of the lakes through cracks and faults can lead to the accumulation of $CO_2$ in lake bottoms. This is controlled by tectonic parameters (fractures and faults) that enhance degassing from the magma chamber to the lake bottom and physical parameters of the lake (e.g. size, depth, temperature and solubility) that control $CO_2$ stability.
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## 1. Introduction

The Cameroon Volcanic Line (CVL) has witnessed the eruption of pyroclastic materials and lava flows from Mt. Cameroon (Deruelle et al., 1983, 1987, 1991; Suh et al., 2003, 2008) and a catastrophic eruption of $CO_2$ gas from two volcanic lakes (Freeth and Kay, 1987; Kling et al., 1987) during the last four decades. The CVL is a continuous ~1600 km long, Y-shaped chain of Tertiary to recent volcanoes that developed simultaneously on the ocean floor and continental crust (Fitton and Dunlop, 1985; Fitton, 1987; Deruelle et al., 2007). It has been suggested that the chain of volcanoes is geochemically similar (Fitton and Dunlop, 1985). The chain extends from the island of Annobon in the Gulf of Guinea (Atlantic Ocean) into the African plate. The central volcanoes in the continental sector of the CVL include Mt. Cameroon, Mt. Manengouba, Mt. Bambouto and Mt. Oku, as well as two plateaus, Ngaoundere and Biu (Fig. 1a: Fitton, 1987; Halliday et al., 1990; Marzoli et al., 1999, 2000; Ngounouno et al., 2000; Rankenburg et al., 2005).

There are more than 37 volcanic lakes in the continental sector of the CVL. Of this total, 20 are known to be more than 40 m deep. Moreover,

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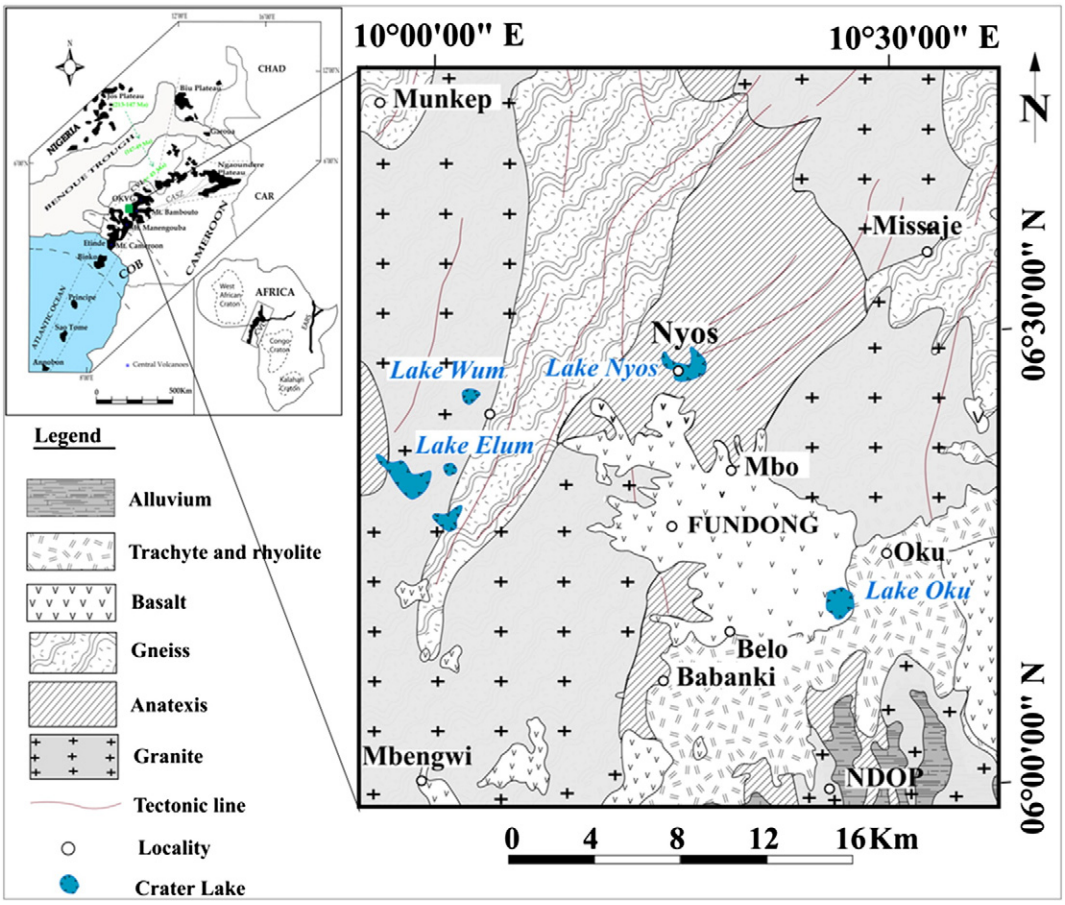


**Fig. 1.** Geological map of the study area. The inset on the left shows the position of the Oku volcanic group along the Cameroon Volcanic Line. The volcanic rocks cut through basement rocks of Precambrian age.
Adapted from Asaah et al. (2014a).

15 out of the 20 deep lakes have volumes greater than 5 million cubic metres (Freeth et al., 1992). Of the large, deep lakes along the CVL, Lakes Monoun (disaster in 1984) and Nyos (disaster in 1986) are the only two lakes known to have exploded lethal $CO_2$ that recorded historic casualties: Lake Monoun (37 people) and Lake Nyos (1787 people and over 3000 cattle) (Freeth and Kay, 1987; Kling et al., 1987; Sigurdsson et al., 1987; Kusakabe et al., 1989; Lockwood and Rubin, 1989; Freeth et al., 1990). This great loss alerted the international scientific community to the initially unrecognized potential natural hazards posed by volcanic lakes that trap and accumulate gas in their bottoms (Kling et al., 1987; Sigurdsson et al., 1987; Freeth et al., 1990). Numerous studies have suggested that the $CO_2$ gas that exsolved from these lakes was of magmatic origin (Sano et al., 1987, 1990; Sigurdsson et al., 1987; Kusakabe et al., 1989; Kusakabe and Sano, 1992; Nagao et al., 2010), even though little information is available on the geochemistry of the volcanic rocks around these maar lakes.

An important step in the investigation of magmatic $CO_2$ gas from these lakes is to understand the geochemistry of the erupted lavas before and during maar formation. The aim of this study is to examine the petrogenesis of volcanic rocks from the Nyos volcano and compare it with those of rocks from Lakes Wum, Elum and Oku. All these lakes are located in the Oku Volcanic Group (OVG). As the $CO_2$ gas exsolving and accumulating below Lake Nyos is of magmatic origin, comparing the geochemical characteristics of lavas from the Nyos volcano with those of other maar-bearing volcanoes in the OVG might give an insight into the nature of the magma source and the potential risk. Asaah et al. (2014a) reviewed the petrogenetic processes beneath the CVL and suggested that the magmatism beneath the CVL is largely controlled by melting and mixing of the asthenospheric and subcontinental lithospheric mantle (SCLM) source materials in different proportions. Major elements, trace elements and radiogenic Sr–Nd–Pb isotope data generated in this study will be used to interpret the mantle and petrogenetic processes that gave rise to the studied lavas.

## 2. Geological setting

The OVG (longitudes 9°54′ to 10°50′ E, latitudes 6°00′ to 6°40′ N, Fig. 1) is one of the four major volcanic centres in the continental sector of the CVL. It is a large volcanic area, consisting of four stratovolcanoes: Mts. Oku, Babanki, Nyos and Nkambe. These volcanoes make up the Bamenda–Wum–Nkambe range that culminates at Mt. Oku (3011 m a.s.l.). The OVG forms part of the Western Cameroon Highlands and is located about mid-way on the continental CVL. The area is bordered to the north-east by the Ngaoundere Plateau and to the south-east by Mt. Bambouto. For the purpose of this study, the OVG has been subdivided into three main districts based on their geographic location: the Wum, Bamenda and Oku–Nkambe districts.

The characteristic volcanic suite of the OVG ranges from primitive-basanite-dominant in the Wum district to dominantly more evolved trachytes and rhyolites in the Bamenda and Oku–Nkambe districts (Marzoli et al., 1999, 2000; Njilah et al., 2007; Kamgang et al., 2010, 2013; Aka, 2014; Asaah, 2015). These rocks cut through highly faulted meta-granitic and granitic basement rocks of Precambrian age (Lasserre, 1978; Dunlop, 1983, Fig. 1). Available K–Ar and Ar–Ar ages for the lava range are 31–12.5 Ma (Fitton and Dunlop, 1985; Marzoli et al., 1999, 2000). However, evidence of recent volcanic activity is manifested by the presence of morphologically recent cinder cones (Fitton

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