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Geochemistry and origin of ultramafic enclaves and their basanitic host rock from Kula Volcano, Turkey

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ABSTRACT

The Quaternary Kula Volcanic Province is located in western Anatolia, Turkey. This Na-alkaline anorogenic volcanism includes exposures of around 80 cinder cones, lava flows, and tuffs, representing one of the youngest volcanic activities in this region (1.9–0.026 Ma). The magmatism is related to an extensional regime and is interpreted as being derived predominantly from the asthenospheric mantle.

The lava flows are mostly of a basanitic composition and host rare comagmatic enclaves. The enclaves are composed of two dominant lithologies: amphibolites and clinopyroxenites with and without olivine. Amphibole is usually resorbed and replaced by a rhoenite-rich breakdown corona. The mineral composition of the breakdown corona suggests an eruption temperature slightly below 1100 °C. Pressure and temperature calculations show that clinopyroxene crystallization began in the magma at 12–15 kbar and 1150–1200 °C. Together with amphibole and later crystallized olivine, clinopyroxene was probably stored as cumulates at the walls of feeder dykes or small chambers.

The compositional variation of clinopyroxene from cumulates and lavas indicates two compositionally different clinopyroxene types. Mg-rich clinopyroxene is present in both lavas and cumulates, while the green-core Mg-poor clinopyroxene is observed exclusively in host lavas. Trace element analyses of clinopyroxene indicate that the clinopyroxenes from cumulates and lavas are comagmatic and crystallized in equilibrium with liquids whose compositions were the same as those of the lavas. On the other hand, the green-core clinopyroxenes were derived from a different melt source from the lavas. They crystallized in the lithospheric mantle and were incorporated into the basanitic melt.

In contrast to the primitive composition of lava olivines, the more evolved composition of enclave olivines is a result of fractional crystallization processes, whose cumulate products (clinopyroxenites and amphibolites) are directly observable. For example, a lower Fo component and Sc and V depletion in olivine from enclaves are mirrored by Sc and V enrichment in olivine from lavas.

In the initial phases of Kula volcanism, mantle-derived primary melts underwent deep-pressure fractionation of pyroxenites and amphibolites at the base of the crust. Calculations of the ascent rate suggest that the ascent of the magma from the Moho to the surface took only 4–11 days. After a period of time, a second batch of melt rose and incorporated the cumulates as enclaves. This new melt most probably originated from a slightly different mantle source, indicated by the presence of the green-core clinopyroxenes.

1. Introduction

It is well known that mantle-derived melts which intrude into continental lithosphere very often stagnate on their way to the surface. The crystallizing assemblages may be stored as high-pressure cumulitic material. The fractional crystallization of these early crystal phases will affect the composition of the evolving lavas, both in terms of major and trace element contents. Ne-normative silica-undersaturated alkaline basic magmas like basanites, tephrites, and phonotephrites have been the subject of numerous studies, which focused on melt production by partial melting of peridotite (e.g. Falloon et al., 2001; Hirose, 1997; Hirose and Kushiro, 1993; Jaques and Green, 1980), or phase equilibria in fractionating basaltic magmas at low pressure (e.g., Baker and Eggler, 1987; Bowen, 1928; Grove and Bryan, 1983; Jakobsson and Holloway, 1986; Longhi, 1991; Nielsen and Dungan, 1983; Shaw, 1999; Shaw et al., 1998). A few studies which investigated high pressure phase equilibria of Ne-normative silica-undersaturated alkaline basic magmas (Pilet et al., 2010; Sack et al., 1987) demonstrated that

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clinopyroxene is more stable at higher pressure, while olivine is restricted to lower pressures.

The Kula Volcanic Region in western Anatolia, Turkey represents one of the best preserved Quaternary volcanic provinces in the Aegean Region. In contrast to older surrounding volcanic regions in western Anatolia (Fig. 1) that are dominated by K-enriched volcanism and typically have an orogenic geochemical signature (e.g. Innocenti et al., 2005; Lustrino and Wilson, 2007; Prelević et al., 2012; Wilson and Biancini, 1999), the Kula volcanics exhibit a primitive Na-alkaline character which is interpreted as being derived dominantly from the asthenospheric mantle (Alıcı et al., 2002; Sölpüker, 2007; Tokçaer et al., 2005).

Ultramafic enclaves are common in the Kula lavas (Richardson-Bunbury, 1996). Richardson-Bunbury (1996) described these enclaves as comparable with lherzolitic mantle material. Gülen (1990) called these igneous enclaves “mantle enclaves”, but without presenting any data. Holness and Bunbury (2006) presented geochemical data and interpreted them as igneous-related, cumulitic glassy enclaves. They assumed that such comagmatic enclaves cannot be transported to the surface by monogenetic feeder systems. This was in contrast with the widely accepted opinion that the approximately 80 cinder cones within the Kula Volcanic Province each represent a single eruption event (e.g. Richardson-Bunbury, 1996). According to Holness and Bunbury (2006), the feeder dykes that transported enclave-bearing magmas to the surface had to be used at least twice: the first batch of magma stored the enclaves in the feeder system, whereas the second batch consumed them during its ascension.

Here, we aim to study the potential genetic relationship between enclaves, lavas, and their mantle source from the Kula Volcanic Province. In order to tackle this issue, we studied the major and trace element compositions of minerals from enclaves and lavas. We confine pressure and temperature limitations for several mineral assemblages. Our ultimate goal was to assemble a comprehensive model for the evolution of the enclave-bearing magma from Kula Volcanic Province.

2. Geological setting

The geological history of western Anatolia is dominated by collisional tectonics that caused major lithospheric thickening south of the Izmir–Ankara suture zone during Late Cretaceous to Early Tertiary times (Fig. 1). After Oligocene time, this changed into a dominantly extensional regime, and there are different models explaining the cause of extension: the most widely accepted model is based on subduction that places the Aegean region and southwestern Anatolia in a back-arc setting (Fytikas et al., 1984; Le Pichon and Angelier, 1979), with backward migration (rollback) of the North Tethyan subducting slab representing a cause of the widespread extension. Alternatively, the orogenic collapse is proposed to be a major driving force of the extensional regime developed after the late Oligocene time (Seyitoğlu and Scott, 1996). This post-Oligocene NE–SW extension within western Anatolia initiated the formation of prominent NW–SE trending grabens (Fig. 1).

Widespread volcanism is contemporaneous with the post-Oligocene extensional tectonics within southwest Anatolia. The volcanism is dominantly high-K calc-alkaline and ultrapotassic, with a strong “orogenic” signature (sensu Lustrino and Wilson, 2007), similar to other Mediterranean volcanic provinces (Conticelli et al., 2002, 2009; Lustrino and Wilson, 2007; Lustrino et al., 2011; Prelević et al., 2005, 2012). On the other hand, the Na-alkaline volcanism with an “anorogenic” geochemical signature occurs in this region and typically postdates the orogenic one. This transition from orogenic to anorogenic volcanism is interpreted as being due to substantial changes in the composition of the (lithospheric) mantle source. This was probably affected by delamination during the last 20 My: Upwelling of asthenospheric mantle through a slab tear or window (Prelević et al., 2012), which causes the interaction, is recognized by several geophysical models (Biryol et al., 2011; Faccenna et al., 2004; Özacar et al., 2010; Spakman et al., 1988, 1993).

The Kula Volcanic Province represents the youngest volcanic activity in southwestern Anatolia. Around 80 volcanic edifices are located on the north flank of the Alaşehir Graben. Their field covers an area of 300–400 km^2 (Richardson-Bunbury, 1996; Tokçaer et al., 2005) in a rectangular shape. The erupted material has a volume of about 2.3 km^3, which is small compared to other volcanic provinces in the Aegean region (Richardson-Bunbury, 1996). It erupted in three different stages, which are mainly distinguished by their morphology (e.g. Ercan, 1993; Hamilton and Strickland, 1841; Richardson-Bunbury, 1996; Westaway et al., 2004): The Burgaz stage (stage 1) is the oldest

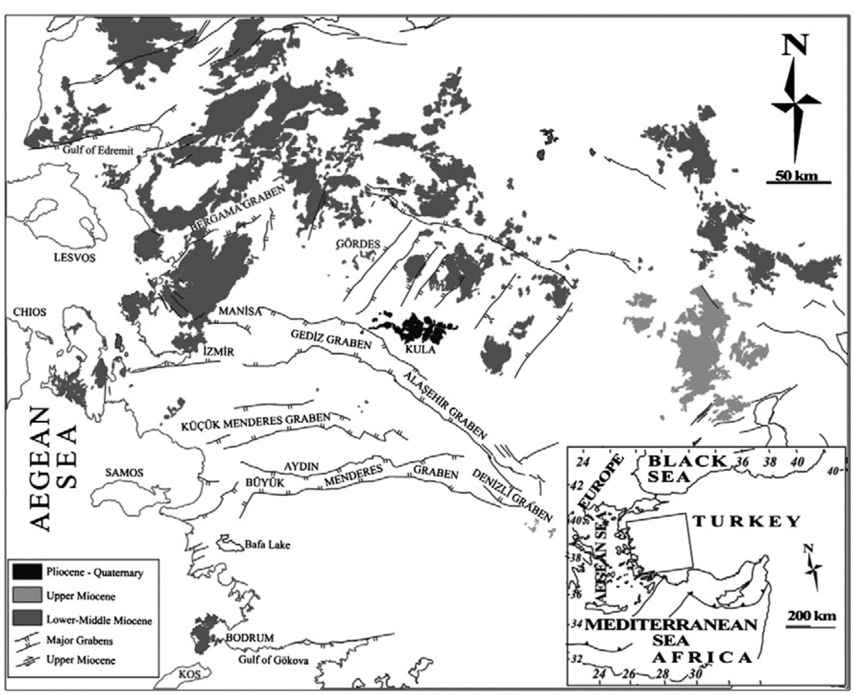

Fig. 1. Volcanic rocks and tectonic structures in Western Anatolia, Turkey. The map displays the NW–SE migration of volcanism and the E–W extension of the major grabens. Light gray rocks from Lower to Middle Miocene represent trachitoids and ultrapotassic rocks, whereas older rocks (dark gray) are mainly andesites and dacites.