Post-caldera dacites from the Santorini volcanic complex, Aegean Sea, Greece: an example of the eruption of lavas of near-constant composition over a 2,200 year period

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Abstract. The post-caldera Kameni islands of the Santorini volcanic complex, Aegean Sea, Greece are entirely volcanic and were formed by eleven eruptions between 197 B.C. and 1950. Petrographic, mineral chemical and whole-rock major and trace element data are presented for samples of lava collected from the products of seven eruptive cycles which span the entire period of activity. The main phenocryst phases are plagioclase, clinopyroxene, orthopyroxene and titaniferous magnetite, which are weakly zoned (e.g. plagioclase – An55 to An42). The lavas are typical calc-alkaline dacites and show a restricted range of composition (from 64.1 to 68.4 wt. % SiO2). The phenocrysts were in equilibrium with the melts at temperatures of 960–1012 °C, pressures of 800–1500 bars and oxygen fugacities of 10^{-9.6} to 10^{-9.9} bars. The pre-eruptive water content of the magmas was 3–4 wt. % but since the lavas contain only 0.1–0.4 wt. % H2O, a considerable amount (about 0.01–0.015 km3) of water was lost prior to or during eruption. This indicates that the magmas rose to the surface gradually allowing the (largely) non-explosive loss of volatiles. The lavas were probably extruded initially from more or less cylindrical conduits which developed into fissures as the eruptions proceeded. The post-caldera lavas evolved from more mafic parental magmas (basalt-andesite) via fractional crystallization. The small range of compositional variation shown by these lavas can be explained in terms of near-equilibrium crystallization. Analyses of samples of lavas belonging to single eruption cycles and to individual flows indicate that the underlying magma chamber is compositionally zoned. The average composition of erupted magma has remained approximately constant since 1570 A.D. but that fact that the 197 B.C. magma was slightly richer in SiO2 provides additional evidence that the magma chamber is compositionally zoned. Crystal settling has not affected the composition of the magma over a 2,200 year period of time which indicates that the melts do not behave as Newtonian fluids. Zonation was thus probably established prior to the 197 B.C. eruption though it is possible that it is developed and maintained by crystal-liquids differentiation processes other than crystal settling (e.g. boundary layer crystallization). The data indicate that there has been no significant cooling during 2,200 years; the maximum amount of cooling is ≤50 °C and is probably less than ~30 °C. Two hypotheses are considered to explain the thermal and chemical buffering of the post-caldera magma chamber: (i) The magma chamber is large and heat losses due to conduction are largely compensated by latent heat supplied by thick, partially crystalline cumulate sequences. (ii) Periodic influx of hot mafic magma, which does not mix with the dacitic magma, inhibits cooling. The second alternative is favored because the post-caldera lavas differ geochemically from the pre-caldera lavas which signifies that a new batch of magma was formed and/or emplaced after the catastrophic eruption of 1390 B.C., and hence that mafic magmas may still be reaching upper crustal levels.

Introduction

The volcanic complex of Santorini is located in the south-central Aegean sea, Greece, about 140 km north of Crete (Fig. 1). This island belongs to the Hellenic volcanic arc which also includes Crommyonia, Methana, Aegina, Poros, Milos, Yali and Nisyros. Volcanism along this arc, which began about 3 m.y. B.P. (Barberi et al. 1977; Fytikas et al. 1976; Ferrara et al. 1980), is thought to be related to subduction of the African plate beneath the Aegean microplate (Ninkovitch and Hayes 1972; Papazachos and Comninakis 1978a, b). A submarine trench, or series of trenches, has been located to the south of Crete (Le Pichon et al. 1979) and presumably marks the site of subduction. It is believed that subduction along this trench system (there may well have been earlier ones) began about 12 m.y. B.P. (Fytikas et al. 1976) and has now virtually ceased. To the best of our knowledge, no true oceanic crust has been found to the south of Crete, so it appears that the type of plate interaction is continental-continental rather than the more common oceanic-oceanic type (Makris 1978).

The volcanic products on all islands of the Hellenic arc belong to the calc-alkaline series or suite. The petrology and geochemistry of the lavas on most of these islands are currently being studied in detail, initially with a view to establishing the nature of the processes which occur in the sub-volcanic (intra-crustal) magma chambers – a necessary precursor to more detailed studies aimed at evaluating sub-crustal (i.e. upper mantle) processes. Our approach to this problem has been to study the temporal variations in erupted lava composition. A number of such studies have been made at calc-alkaline volcanic centers in various parts of
Fig. 1. Geologic map of the Aegean showing the location of the Hellenic trench system, the Hellenic arc, and Santorini. Abbreviations: KE - Kefallinia; PE - Peloponnesos; RH - Rhodes

the world and the results have, to a large extent, been summarized by Gill (1981). It is commonly found that erupted lavas become more differentiated with time (Katsui et al. 1975; Rose et al. 1977; Rose et al. 1978; Fairbrothers et al. 1978; Stern 1979; White and Mc Birney 1979; Luhr and Carmichael 1980; Martin and Rose 1981; Walker and Carr 1983) although periodic reversals of this general trend can occur. These variations are generally interpreted as indicating progressive crystal-liquid differentiation with or without the superimposed effects of magma mixing.

To date, most of our data have been obtained for the lavas of Santorini, and cyclic variations in the eruptive sequences of two of the shield volcanoes in this volcanic field have likewise been interpreted in terms of recurrent fractional crystallization and magma mixing (Huijsmans and Barton 1983a; also, manuscript in preparation). In addition, there is evidence that the magma chambers underlying these volcanoes were compositionally stratified. Evidence for this has previously been reported mostly from studies of zoned ash flows (Lipman et al. 1966; Hildreth 1979, 1981; Ritchey 1980) and it is noteworthy that Vitaliano et al. (1978) demonstrated that compositional variations in ash flows erupted during the last caldera-forming event on Santorini are consistent with withdrawal of magma from progressively deeper levels in a stratified magma body.

In the present paper we report the results of a petrological and geochemical study of the post-caldera lavas which are unusual in that they show a remarkably restricted range of composition. Furthermore, the average composition of these lavas has remained approximately constant over a time period of 2,200 years. On the basis of the results we place constraints upon the physical conditions under which