Factors controlling sulfur concentrations in volcanic apatite

GENYONG PENG,1 JAMES F. LUHR,1 AND JAMES J. McGEE2

1Department of Mineral Sciences, NHB-119, Smithsonian Institution, Washington, DC 20560, U.S.A.
2U.S. Geological Survey, Reston, Virginia 22092, U.S.A.

ABSTRACT

Apatite crystals from two types of samples were analyzed by electron microprobe for 15 major and trace elements: (1) apatite in H2O- and S-saturated experimental charges of the 1982 El Chichon trachyandesite and (2) apatite in volcanic rocks erupted from 20 volcanoes. The SO3 contents of the experimental apatite increase with increasing oxygen fugacity (fO2), from ≈0.04 wt% in reduced charges buffered by fayalite-magnetite-quartz (FMQ), to 1.0–2.6 wt% in oxidized charges buffered by manganosite-hausmanite (MNH) or magnetite-hematite (MTH). The SO3 contents of MNH- and MTH-buffered apatite also generally increase with increasing pressure from 2 to 4 kbar and decreasing temperature from 950 to 800 °C. The partition coefficient for SO3 between apatite and oxidized melt increases with decreasing temperature but appears to be independent of pressure.

Apatites in volcanic rocks show a wide range of SO3 contents (<0.04 to 0.63 wt%). Our sample set includes one group known to contain primary anhydrite and a second group inferred to have been free of primary anhydrite. No systematic differences in apatite S contents are observed between these two groups. Our study was initiated to define the factors controlling S contents in apatite and to evaluate the hypothesis that high S contents in apatite could be characteristic of S-rich anhydrite-bearing magmas such as those erupted from El Chichon in 1982 and Pinatubo in 1991. This hypothesis is shown to be invalid, probably chiefly a consequence of the slow intra-crystalline diffusion that limits re-equilibration between early formed apatite and the evolving silicate melt. Contributing factors include early crystallization of most apatite over a relatively small temperature interval, common late-stage magmatic enrichment of S, progressive oxidation during magmatic evolution, and strong controls on S contents in apatite exerted by fO2, temperature, and pressure.

INTRODUCTION

Recent eruptions of anhydrite-bearing tephra at El Chichon (1982) and Pinatubo (1991) volcanoes were accompanied by large injections of S gases into the atmosphere: 7 and 20 megatons of SO2, respectively (Bluth et al. 1992). These observations stimulated research into the possible relationship between S-rich volcanic eruptions and short-term global climatic changes (Luhr 1991; Bluth et al. 1992, 1993; Hansen et al. 1992). Anhydrite-saturated magmas of the type erupted at El Chichon and Pinatubo appear to have the following common features: highly-oxidized, crystal-rich, fluid-saturated, rich in amphibole or biotite, and erupted in subduction-zones (Luhr et al. 1984; Luhr 1991; Imai et al. 1993; Pallister et al. 1995, 1996; Luhr and Melson 1996). Primary volcanic anhydrite is readily erased from the geological record because it is highly soluble in water. Thus, S-rich anhydrite-bearing magmas may be much more common than presently realized (Luhr et al. 1984). One approach to the estimation of volatiles released to the atmosphere during volcanic eruptions is the “petrologic method” of Devine et al. (1984), which bases the estimate on the mass of erupted material and the difference in S contents between glass inclusions and matrix glass. This method,