Chemie der Erde xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Chemie der Erde

journal homepage: www.elsevier.com/locate/chemer

Sugarloaf Mountain, central Arizona, USA: A small-scale example of Miocene basalt-rhyolite magma mixing to yield andesitic magmas

Ellen J. Craig, R.V. Fodor*

Department of Marine, Earth, and Atmospheric Sciences, North Carolina State University, Raleigh, NC, 27695 USA

ARTICLE INFO

Keywords:
Hybrid andesite
Spongy plagioclase
Resorbed quartz
Miocene volcanism
Arizona
USA

ABSTRACT

Sugarloaf Mountain is a 200-m high volcanic landform in central Arizona, USA, within the transition from the southern Basin and Range to the Colorado Plateau. It is composed of Miocene alkalic basalt (47.2–49.1 wt.% SiO_2; 6.7–7.7 wt.% MgO) and overlying andesite and dacite lavas (61.4–63.9 wt.% SiO_2; 3.5–4.7 wt.% MgO). Sugarloaf Mountain therefore offers an opportunity to evaluate the origin of andesite magmas with respect to coexisting basalt. Important for evaluating Sugarloaf basalt and andesite (plus dacite) is that the andesites contain basaltic minerals olivine (cores Fo_{76-86}) and clinopyroxene (~$Fs_{9-18}Wo_{35-44}$) coexisting with Na-plagioclase ($An_{48-28}Or_{1.4-7}$), quartz, amphibole, and minor orthopyroxene, biotite, and sanidine. Noteworthy is that andesite mineral textures include reaction and spongy zones and embayments in and on Na-plagioclase and quartz phenocrysts, where some reacted Na-plagioclases have higher-An mantles, plus some similarly reacted and embayed olivine, clinopyroxene, and amphibole phenocrysts.

Fractional crystallization of Sugarloaf basaltic magmas cannot alone yield the andesites because their ~61 to 64 wt.% SiO_2 is attended by incompatible REE and HFSE abundances lower than in the basalts (e.g., Ce 77–105 in andesites vs 114–166 ppm in basalts; Zr 149–173 vs 183–237; Nb 21–25 vs 34–42). On the other hand, andesite mineral assemblages, textures, and compositions are consistent with basaltic magmas having mixed with rhyolitic magmas, provided the rhyolite(s) had relatively low REE and HFSE abundances. Linear binary mixing calculations yield good first approximation results for producing andesitic compositions from Sugarloaf basalt compositions and a central Arizona low-REE, low-HFSE rhyolite. For example, mixing proportions 52:48 of Sugarloaf basalt and low incompatible-element rhyolite yields a hybrid composition that matches Sugarloaf andesite well − although we do not claim to have exact endmembers, but rather, viable proxies. Additionally, the observed mineral textures are all consistent with hot basalt magma mixing into rhyolite magma. Compositional differences among the phenocrysts of Na-plagioclase, clinopyroxene, and amphibole in the andesites suggest several mixing events, and amphibole thermobarometry calculates depths corresponding to 8–16 km and 850° to 980 °C. The amphibole P-T observed for a rather tight compositional range of andesite compositions is consistent with the gathering of several different basalt-rhyolite hybrids into a homogenizing 'collection' zone prior to eruptions. We interpret Sugarloaf Mountain to represent basalt-rhyolite mixings on a relatively small scale as part of the large scale Miocene (~20 to 15 Ma) magmatism of central Arizona. A particular qualification for this example of hybridization, however, is that the rhyolite endmember have relatively low REE and HFSE abundances.

1. Introduction

Processes identified for the origins of intermediate-composition magmas include direct melting of upper-mantle lherzolite or lower-crustal amphibolite, basaltic magma differentiation, and mixing of basaltic and silicic magmas (e.g., Anderson, 1976; Eichelberger, 1978, 2010; Beard and Lofgren, 1991; Brophy and Dreher, 2000; Annen et al., 2006; Hosono et al., 2008; Macdonald et al., 2008; Reubi and Blundy, 2009; Kent et al., 2010; Perugini and Poli, 2012). Because intermediate-magma origins are varied and can represent multiple processes, it is important to examine occurrences of andesitic and dacitic lavas not yet studied in geochemical and mineralogical detail. Sugarloaf Mountain, a small, ~4 km^2 Miocene volcanic field in central Arizona (Figs. 1 and 2), is a candidate for providing information about the processes that create intermediate-composition magmas, particularly because it is formed by coexisting andesitic and basaltic lavas (e.g., Skotnicki, 1992; Skotnicki

* Corresponding author.
E-mail address: rfodor@ncsu.edu (R.V. Fodor).

https://doi.org/10.1016/j.chemer.2017.11.001
Received 28 March 2017; Received in revised form 1 November 2017; Accepted 2 November 2017
0009-2819/ © 2017 Elsevier GmbH. All rights reserved.

Fig. 1. Sketch map of Arizona showing the locations of Sugarloaf Mountain and the Goldfield-Superstition volcanic province (G-SVP), both at the northern portion of the southern Basin and Range. Inset map shows location of Arizona within the United States.

and Leighty, 1997) where the basalt may in some way be 'parental' to the andesites.

In order to explore the relationship between the Sugarloaf basaltic lavas and the coeval hornblende- and quartz-bearing andesitic lavas (Skotnicki, 1992; Skotnicki and Leighty, 1997), we collected 16 lava samples that represent Sugarloaf Mountain from its base to its peak, about 200 vertical meters (Fig. 2). Our objectives were to determine whether the intermediate lavas formed by (i) differentiation of basaltic magma; (ii) dehydration melting of lower crustal rock; (iii) hybridization due to basaltic magmas mixing with silicic magmas; (iv) a combination of these processes; or (v) by a process independent of any relationship with coexisting basaltic lavas.

We addressed our objectives by determining petrographic details for the 16 lava samples, their major and trace element whole-rock compositions, and mineral compositions for representative samples. We additionally studied the petrography and mineral compositions of an isolated clinopyroxene-rich lithic fragment from one of the lavas. Our collective data enabled exploring relationships between intermediate-composition and basaltic lavas by fractional crystallization, dehydration melting, and by calculations that represent linear mixing between Sugarloaf Mountain basaltic magma and a rhyolite representative of central Arizona Miocene magmatism.

2. Geologic setting and sampling

Sugarloaf Mountain is located ~50 km northeast of Phoenix, Arizona, USA, at the northern boundary of the southern Basin and Range physiographic province where it transitions to the Colorado Plateau (Fig. 1). It is on the northern fringe of one of southwestern North America's largest Cenozoic volcanic provinces, the ~8000 km^2 Goldfield-Superstition volcanic province (G-SVP) in central Arizona (Fig. 1; Fodor and Vetter, 2011). Regionally, magmatism in this geologic time is associated with the collapse of the Farallon subduction system beneath western North America and the onset of Basin-Range extension (e.g., Lipman et al., 1972; Coney and Reynolds, 1977; Ferrari et al., 2002; Bryan and Ferrari, 2013). Sugarloaf Mountain represents only one small portion of the voluminous G-SVP, but by itself provides insights to some complex igneous processes that occurred during the G-SVP eruption history. Detailed geologic mapping of Sugarloaf Mountain was first conducted by Skotnicki (1992) as part of an M.S. thesis project and later by the Arizona Geological Survey (Skotnicki and Leighty, 1997).

The nearest basalt fields for which compositions are known are the Stewart Mountain field (Singer and Fodor, 2013), ~10 km south-southwest of Sugarloaf Mountain, and the western portion of the G-SVP located from 15 to 25 km south of Sugarloaf (Fig. 1; Fodor and Vetter, 2011). To estimate the ages of Sugarloaf Mountain lavas, it is necessary to evaluate radiometric ages available for basalt and rhyolite in surrounding volcanic fields, as no ages exist for Sugarloaf lavas. The most reliable relevant age is ~20.5 Ma ($^{40}Ar/^{39}Ar$ sanidine age) for the earliest magmatism in the G-SVP south of Sugarloaf that is expressed as a small-scale rhyolite dome (McIntosh and Ferguson, 1998). Other ages were determined by K-Ar for lavas closer to Sugarloaf. One example is ~15.53 Ma for a basalt at nearby Stewart Mountain, and a second example is ~14.78 Ma for andesitic lava from the area of Bartlett Dam, ~15 km northwest of Sugarloaf (Shafiqullah et al., 1980; Singer and Fodor, 2013). Based on these ages for nearby volcanic fields, Sugarloaf Mountain lavas are inferred to represent Miocene volcanism ~20–15 Ma.

Sugarloaf Mountain is layered owing mainly to its stratigraphic succession of individual intermediate lavas that overlie basalt lavas. It is ~200 m above surrounding landscape, which is largely Precambrian granitoid rock (Fig. 2). The original extents of Sugarloaf lavas and their vent source(s) are unknown, and only ~0.75 km^3 remain after erosion and Basin and Range faulting. Because of a long erosional period, contacts between lavas are obscured by rubble.

The Sugarloaf profile shows a plateau, or mesa, marking its top and another mesa about midway down the eastern side (Fig. 2), the head of which is inferred to mark the trace of a normal fault (Skotnicki, 1992) (Fig. 3A). This suspected normal fault (Fig. 3A) could account for a stratigraphic offset. The reason is that Sugarloaf intermediate lavas were emplaced above basaltic lavas, and our study showed that above the midlevel mesa, at least one basaltic lava lies above intermediate lavas at the inferred fault. Therefore, intermediate lavas in the lower portion of Sugarloaf Mountain may correlate with those near or at its peak. Sample locations are labeled on the topographic map in Fig. 3B, and latitude-longitude coordinates are listed in the Appendix A.

3. Petrography

One thin section of each lava sample was studied by petrographic microscope to determine modal mineral percentages and rock textures. About 1500–2000 points on each thin section were counted, and the modal results are in Table 1.

Four Sugarloaf lava samples are basalt. Three basalt samples have phenocrysts of subhedral olivine that are strongly iddingsitized to where only the cores remain fresh (Fig. 4A) or grains are entirely iddingsitized. Sizes of these largely subhedral olivine grains, including their iddingsitized rims, range from ~0.5 to 2 mm, and they occupy from ~5 to 7 vol.%. These samples have clinopyroxene that occurs mainly as ~1 to 2 mm glomerocrysts of small, subhedral grains (Fig. 4A), and less as individual grains that are subhedral and ~1 to 1.5 mm. The total clinopyroxene volume observed in three samples is from ~11 to 15%. The groundmasses are intergranular plagioclase, clinopyroxene, olivine as iddingsite, Fe-Ti oxides, and interstitial alkali feldspar (this latter was determined by electron microprobe) (Fig. 4A). In one sample, P-4, the groundmass oxide grains reach 0.5 mm in size.

The fourth basalt sample, SL-6, has subhedral to euhedral clinopyroxene and olivine phenocrysts, each from ~0.3 to 1 mm, in a hyaloophitic groundmass containing plagioclase and Fe-Ti oxide

Download English Version:

https://daneshyari.com/en/article/8850189

Download Persian Version:

https://daneshyari.com/article/8850189

Daneshyari.com