THE WASHINGTON PASS VOLCANIC CENTER: EVOLUTION AND ERUPTION OF MINETTE MAGMAS OF THE NAVAJO VOLCANIC FIELD

S.N. Ehrenberg (Department of Earth and Space Sciences, University of California, Los Angeles, California 90024)

Minettes of the Navajo Volcanic Field are of interest because they formed at depths of at least 150 km and appear to be genetically related to kimberlite diatremes. Minettes and their extrusive equivalents (trachybasalts) at the 2 km diameter subsidence crater at Washington Pass were chosen for detailed study because of the relatively well-developed eruptive history displayed in the crater stratigraphy and the presence of contrasting mafic and trachytic lavas. Eruption began with ejection of voluminous pyroclastic deposits, including both tuff-breccias, composed predominantly of comminuted sediments with subordinate minette and crystalline basement fragments, and agglomerates, composed mainly of minette clasts. These deposits are thickest (>100 m) on the east and west sides of the crater, where they are exposed in cliffs produced by landsliding. On the west, tuff-breccias predominate and exhibit a remarkable alternation of coarse- and fine-grained beds 0.1 - 1 m thick, suggestive of rhythmic variation in the physical properties in the eruptive medium. On the east, the pyroclastic materials are mostly agglomerates. Low-angle cross-bedding is common in all the pyroclastic beds, but in the eastern agglomerates this feature is accompanied by dune structures. Some of these formed by accretion on the lee side, while others display accretion on the side facing the crater. Asymmetrical bomb sags are also abundant in this area.

After the pyroclastic activity waned, thick trachybasalt flows covered the crater floor, and plugs of glassy to aphanitic minette were intruded in the crater center. These rocks consist of phenocrysts of phlogopite, diopside, and olivine (~Fo80) in a matrix of biotite, cpx, and Ti-magnetite microphenocrysts and interstitial sanidine, analcime, and chlorite. Xenoliths are uncommon in the mafic lavas. The eruption terminated with extrusion of a small volume of trachyte from vents cutting the plugs in the crater center. The trachyte is much lighter in color than the earlier flows and consists of biotite and diopside phenocrysts in a trachytic groundmass of sanidine laths and interstitial brown clay-like material. Intensely metasomatized xenoliths 1-5 cm in diameter of spinel lherzolite and websterite comprise ~5% of the volume of this flow. The trachyte is richer in Si, Al, Na, and K and lower in Fe, Ca, Ti, and P than the mafic rocks, but contains similar Mg and Ni (Table 1). A similar sequence of flows also occurs capping East Sonsela Butte, 15 km west of Washington Pass. The East Sonsela Butte trachybasalts and trachyte are very similar in both petrography and composition to their Washington Pass counterparts (Table 1).

Discussion. The basal pyroclastic beds at Washington Pass and other Chuska Mountains craters are the surface expression of diatreme formation; similar maar-like deposits probably capped the more deeply eroded Navajo minette diatremes, such as Shiprock, Bennett Peak, and Agathla Peak. At all of the minette centers, eruption appears to have proceeded in a single cycle of (1) diatreme formation and (2) intrusion or effusion of minette magma, although the relative development of these two stages varies at different centers. The presence of common fragments of lower crustal and uppermost mantle rock types (garnet granulite, spinel lherzolite, and websterite) in the pyroclastic rocks and the substantial fraction (10-40%) of pumice in the agglomerate at Washington Pass indicate that the pyroclastic activity was not the result of near-surface groundwater/magma interaction, but probably reflects release of juvenile mantle volatiles. The characteristic cross-bedding, dunes, and accretion structures at Washington Pass, together with the asymmetrical bomb sags, suggest that the pyroclastic material was deposited by both base-surge and ballistic modes of transport.

The most intriguing problem at Washington Pass is the relationship between the contrasting mafic and trachytic lavas. This contrast is also observed at East Sonsela Butte, Buell Park, and just north of the Chuska Mountains where the felsic Mitten Rock neck stands equidistant between the mafic volcanic centers of Shiprock, the Thumb, and Beautiful Mountain. One way that mafic magmas may become more felsic is by removal of early-crystallizing minerals, and, indeed, phlogopite- and diopside-rich nodules which appear to be phenocryst segregations are common in the minettes. However, in contrast to other felsic minettes, the Washington Pass and East Sonsela Buttes trachytes have Mg and Ni contents similar to the associated mafic rocks. This pattern and the presence of altered lherzolite fragments throughout virtually every hand sample of the rock suggests that assimilation of peridotite contributed to the trachyte composition. Using a least-squares-fitting FORTRAN routine, an approximate fit to the composition of the trachytes may be obtained by removing 36% phenocrysts from the mafic composition and adding 9% peridotite (Table 1). The bimodal character of the Washington Pass and East Sonsela Butte magmas may thus be the result - at least in part - of fractional crystallization and assimilation of wall rock in an uppermost mantle magma chamber. Residuals for Al and especially K are large, however, indicating that this may not be the entire explanation. One problem may be that the trachyte contains relatively iron-rich biotite phenocrysts, whereas magnesian phlogopites typical of mafic minettes were used in the model.

The least-squares-fitting technique meets with variable success in relating divers minette compositions from other localities in the volcanic field. The felsic Mitten Rock minette may be approximated by subtracting 25% phenocrysts from Shiprock minette. However, removal of assumed phenocryst compositions cannot have produced the Shiprock or Mitten Rock minettes from the more mafic Thumb composition, suggesting that the Thumb may represent a completely seperate batch of primary magma. The inverse correlation of SiO_2 and REE in these three necks may be the result of either apatite fractionation or smaller percentages of melting for the more mafic liquids.

It seems probable that the compositional diversity of the Navajo minettes reflects the interplay of several different processes. Fractional crystallization and reaction with wall rocks are both likely to have influenced the compositions of these liquids during their ascent through very long and narrow conduits. In addition, the effects of these processes may have been superimposed upon primary compositional differences, relating to local variations in conditions of melting and bulk composition during the formation and extraction of a small percentage of melt from a large volume of possibly inhomogeneous and complex upper mantle. More significant than the compositional diversity, however, is the overall coherence of bulk compositions, mineral chemistry, and petrography exhibited by the Navajo volcanic centers. Compare, for example, columns 1, 4, and 8 in Table 1. The minette magmas represent the response of a single, K- and Rb-enriched region of the upper mantle to a relatively minor thermal or tectonic disturbance from a previous state of equilibrium. Evidence for the nature of this disturbance may be contained in the mantle xenoliths incorporated by the minette, as described in an accompanying abstract.

Table 1. Compositions of minettes and extrusive rocks from Navajo volcanic centers and computed best fits to higher silica compositions using combinations of phenocrysts, peridotite, and more mafic compositions.

	Ave. Washington Pass mafic (8)*	Ave. Washington Pass felsic (3)	Best least-squares fit to felsic composition	Ave. East Sonsela Butte mafic (5)	Ave. East Sonsela Butte felsic (3)	Best fit to felsic composition	Minette from the Thumb (A103THM)	Shiprock south dike (74-A07-SRM-WSB) **	Best fit to Shiprock using Thumb + phenocrysts	Mitten Rock (a072MTR)	Best fit to Mitten Rock using Shiprock + phenocrysts	Best fit to Mitten Rock using Thumb + phenocrysts
SiO_2	52.4	57.3	56.7	51.4	59.2	57.6	47.3	52.2	52.5	57.8	56.6	57.5
TiO_2	1.9	0.9	1.1	2.1	0.9	1.1	2.4	1.9	2.6	0.8	1.4	2.0
Al_2O_3	11.0	11.8	12.3	10.8	12.0	12.6	9.2	11.2	11.4	12.4	12.6	12.7
FeO	6.6	4.1	4.0	6.6	4.0	3.8	7.6	6.5	6.4	4.5	4.3	4.3
MnO	0.09	0.06	0.09	0.10	0.06	0.13	0.14	0.11	0.18	0.07	0.12	0.24
MgO	9.0	9.0	8.9	9.5	8.4	8.1	13.3	8.0	8.0	5.5	5.2	5.3
CaO	7.1	4.4	4.4	7.6	3.8	3.6	8.8	7.4	7.3	6.3	6.4	5.8
Na_2O	2.0	2.3	2.6	1.5	2.1	2.1	1.2	2.0	1.8	2.6	2.5	2.4
K_2O	5.9	6.6	6.0	6.0	7.5	5.9	4.7	6.4	5.0	7.3	6.8	4.5
P_2O_5	0.9	0.6	0.5	0.8	0.5	0.3	2.3	1.0	1.2	0.8	0.4	1.3
ig. loss	2.5	3.0	3.0	2.8	2.5	3.5	3.2	2.3	4.6	1.7	2.7	4.8
Ni	304	309		320	281		481	288		160		
Cr	407	324		478	341		631	296		123		
Sc	14	9		16	9		17	14		10		
Sr	1304	1541		1204	1192		1504	1295		1376		
Rb	155	183		189	239		132	159		159		
La	115	136		109	104		185	140		117		
Sm	15	17		15	14		28	20		15		
Yb	1.2	0.7		1.4	0.9		2.2	1.9		1.2		

Major elements (wt. %) and Sr by x-ray flourescence. Trace elements (ppm) by I.N.A.A. (Prof. J.T. Wasson's Lab).
*Number of sample localities averaged for major element data. Trace element data are from fewer samples.
**Shiprock major element data are average of U.C.L.A. analysis and J.S.C. analysis courtesy of Dr. A.J. Irving.