GEOPHYSICAL RESEARCH LETTERS, VOL. 31, L18605, doi:10.1029/2004GL020489, 2004

Microlite textures and volatile contents of obsidian from the Inyo volcanic chain, California

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Received 10 May 2004; revised 12 July 2004; accepted 26 August 2004; published 21 September 2004.

[1] We test the hypothesis that microlite textures record progressive degassing during magma ascent. We compare microlite number density (N_V) and H_2O concentrations in pyroclastic and effusive obsidian (OBS) from the Inyo Volcanic Chain, CA. Comparisons reveal a weak correlation between microlite N_V and H_2O; however, most obsidians (OBSs) of a given volatile content exhibit a wide range of N_V. Factors other than degassing must also influence final groundmass texture. We postulate that OBS textures record different ascent rates and residence histories prior to eruption from the conduit. We conclude that microlites do not sensitively indicate the extent of magmatic degassing, rather, they provide qualitative indications of magma ascent and residence time. INDEX TERMS: 8414 Volcanology: Eruption mechanisms; 8434 Volcanology: Magma migration; 8439 Volcanology: Physics and chemistry of magma bodies. Citation: Castro, J. M., and C. Mercer (2004), Microlite textures and volatile contents of obsidian from the Inyo volcanic chain, California, Geophys. Res. Lett., 31, L18605, doi:10.1029/2004GL020489.

1. Introduction

[2] Groundmass textures in volcanic rocks preserve information about the dynamics of magma ascent and eruption. For example, vesicle shapes record the flow regime and ascent rates of magma in volcanic conduits [e.g., Rust et al., 2003]. Crystal size distributions reflect magma cooling histories and residence times [e.g., Cashman and Marsh, 1988]. And, crystal preferred orientations provide insight into the dynamics of effusive eruptions [e.g., Castro et al., 2002].

[3] Comparatively less is known about the extent to which microlites (crystals <30 mm), reflect degassing history and the extent of degassing. Swanson et al. [1989] proposed that because microlites form in response to magmatic degassing, their appearance in eruptive products will signal early volatile loss from the system. Moreover, experimental evidence [e.g., Geschwind and Rutherford, 1995] suggests that microlites form on eruptive timescales in response to degassing-induced undercooling. It seems likely then, that "the extent of degassing may be reflected in the microlite crystallinity of quenched magma" [Hammer et al., 2000]. To date, direct comparisons between magmatic volatile contents and microlite textures in natural volcanic rocks have not been reported. Such comparisons would help to evaluate the sensitivity of microlite crystallization to degassing. Correlations between volatile and microlite contents, should they exist, would provide a basis for inferring the extent of degassing from textural observations alone.

[4] In this paper, we compare clinopyroxene (cpx) and plagioclase (plag) microlite textures to corresponding H_2O contents measured on OBS produced during the 550–650 yr. b.p. eruptions of the Inyo volcanic chain, CA [Miller, 1985] (Figure 1). Our goal is to determine the extent to which microlites record the extent of volatile-loss and in doing so, evaluate the use of microlite textures as an indicator of progressive magma degassing.

2. Methods

[5] Pyroclastic OBSs were collected from airfall tephra deposits emanating from the Obsidian Dome (OD) and South Deadman (SD) vents (Figure 1). Isopach maps were used to determine the sampling locations [Miller, 1985]. Once a location was chosen, a pit 1–1.5 m deep was dug in the tephra deposit. Glassy pyroclasts, 1–4 cm in diameter, were the primary material collected and analyzed. The stratigaphic positions of samples were documented in each pit. OBSs were also collected from the Inyo Domes, and from the glassy margin of the Inyo dike (RDO-3A), cored from depth of approximately 650 m [Eichelberger et al., 1986].

[6] All OBSs correspond to the "finely porphyritic" (FP) rhyolites defined by Bailey et al. [1976]. Due to chemical heterogeneities within the FP rhyolites [e.g., Vogel et al., 1989], major and trace element compositions were determined on OBS selected for textural and volatile analysis. These analyses allow us to compare microlite textures in compositionally equivalent rhyolites. Major and trace element analyses were determined by X-ray fluorescence and laser ablation inductively coupled plasma mass spectrometry at Michigan State University.

[7] H_2O concentrations were determined with Fourier Transform Infrared Spetroscopy (FTIR). FTIR measurements utilized a Thermo Nicolet Nexus 670 FTIR spectrometer interfaced with a Continuum IR microscope at the University of Oregon, and a Nicolet 20SXB FTIR spectrometer attached to a Spectra Tech IR Plan microscope at the American Museum of Natural History. Each sample was analyzed 1–10 times, with spots positioned in microlite-poor regions. For crystal-rich clasts, corrections to the effective sample thickness were made based on measurements of microlite volume fractions.

[8] Textural measurements consisted of: 1) clinopyroxene (cpx) number density (N_V), or the number of cpx microlites per volume, 2) the volume percent of cpx (F_V), 3) plagioclase (plag) area number density (N_A), and 4) the area

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fraction of plag (F_A). Volume-based plag N_V was calculated from N_A and F_A using the stereological conversion expression: $N_V = N_A/(F_A/N_A)^{1/2}$ [Cheng and Lemlich, 1983]. Transmitted light, petrographic images (1000X) served as the basis for cpx N_V and F_V measurements [Castro et al., 2003]. Measurements of N_A and F_A were made on back-scattered electron images (2000X) of OBS acquired with a JEOL JSM-5610 scanning electron microscope operating at 10 keV and 14 mm working distance.

3. Results

[9] Pyroclastic OBSs vary considerably in terms of their abundance of cpx and plag. Two end-member textures are defined based on the relative proportions of cpx and plag (Figure 2). One category is termed "cpx-dominant" (CD), as cpx is the primary microlite phase. CD OBSs are characterized by high and variable cpx N_V (10^7 to 10^9 cm ^{3}), and uniformly low F_V (<4 vol.%). Plag occurs in CD OBS as rare lath-shaped crystals. The second textural class is termed "plag-dominant" (PD; Figure 2b), as these OBSs contain abundant, lath-shaped, plag microlites of moderate N_V (10^8 cm ^{3}) and variable F_A (2–30%). Cpx N_V is also high in PD OBS (10^8 cm ^{3}), and overlaps with values in CD OBS. Of 110 pyroclastic OBSs examined, approximately 25% are PD, 60% are CD, and 15% are of intermediate texture.

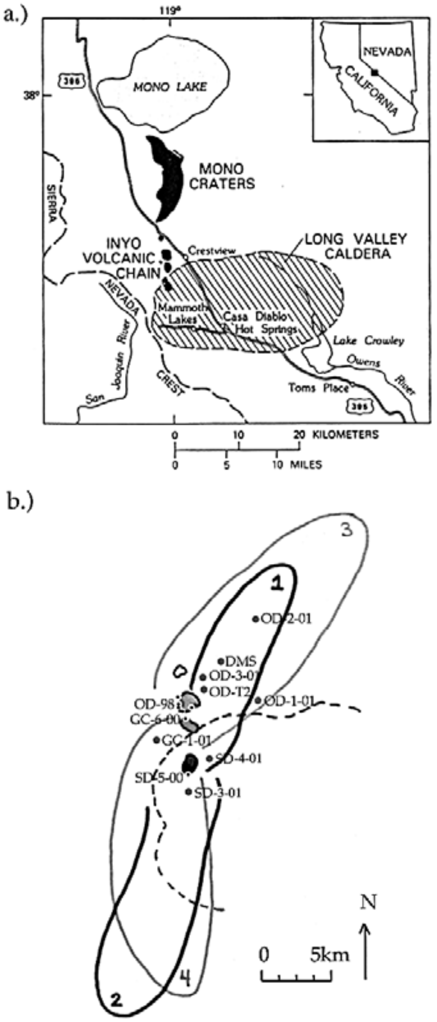

Figure 1. a.) Location of the Inyo volcanic chain [Miller, 1985]. b.) Map of the Inyo domes (center) and pyroclastic units (elliptical curves). The numbers refer to the eruption sequence. Sample locations are shown as grey (pyroclasts) and black (dome lavas) dots.

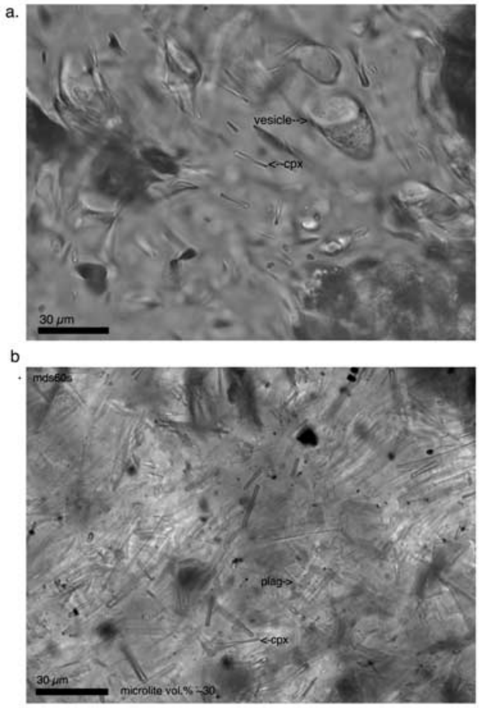

Figure 2. Photomicrographs (1000X) of pyroclastic OBS. Scale bar is 30 mm. a.) "Cpx-dominant" OBS. b.) "Plag-dominant" OBS.

[10] We recognized no spatial relations between CD and PD OBSs and the specific tephra deposit or stratigraphic position within deposits. In fact, samples collected from the same stratigraphic horizon often contain both CD and PD OBS. Therefore, OBS textures do not appear to be a function of the vent sampled or order within the eruptive sequence.

[11] Major and trace element compositions of OBSs match those determined in earlier studies [e.g., Vogel et al., 1989] (Table A1)[1]. Furthermore, there is no systematic relation between OBS texture and bulk composition. These observations suggest that OBSs are indeed juvenile and that textural variability is not a function of magma composition.

[12] Average cpx and plag N_V, F_V, and F_A are plotted versus H_2O content in Figure 3 (see Table A2)[1]. Vertical bars show the range of N_V, F_V, and F_A measured on different spots within single thin sections. Data points without error bars represent single spot analyses. The analytical uncertainty in H_2O is generally smaller than symbols, however, for samples containing a range in H_2O, error bars indicate two standard deviations about the mean. We expect some

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[1] Auxiliary material is available at ftp://ftp.agu.org/apend/gl/2004GL020489.

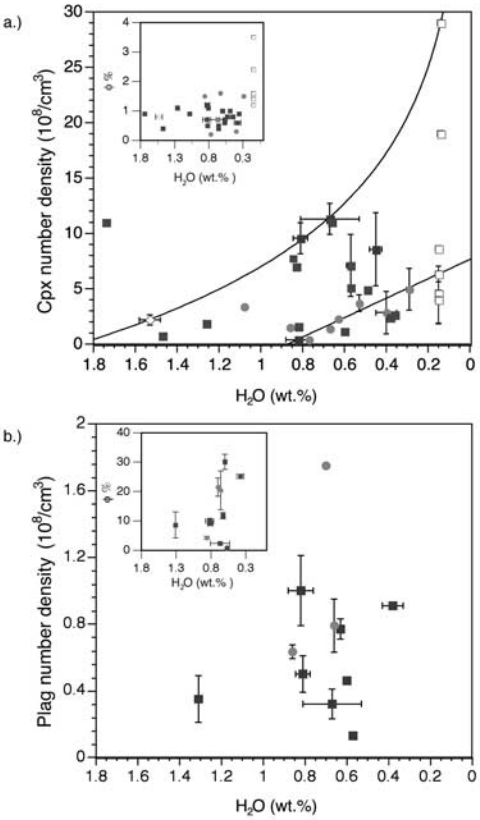

Figure 3. a.) Cpx N_V versus wt.% H_2O in pyroclastic OBS (solid squares = OD; solid circles = SD), domes (open squares), and the dike (open diamond) [Westrich et al., 1988]. b.) Plag N_V versus wt.% H_2O. Symbols are the same as in a. Insets show variation of cpx F_V and plag F_A.

uncertainty in H_2O contents due to the effect of crystallization raising the H_2O of the residual melt. This effect may be important in a few PD OBSs with moderate F_A (20–30 vol.%), provided that second boiling did not re-equilibrate melt H_2O to the final pressure. OBSs span a range in H_2O content (0.11–1.8 wt.%) and H_2O species concentrations indicate that the measured H_2O is entirely magmatic (see Figure A1 and Table A3).

[13] Cpx N_V varies considerably in the analyzed OBSs (Figure 3a). N_V varies by factor of about 30, and its range tends to increase with decreasing H_2O. The greatest scatter in N_V (factor of 25) occurs at the lowest H_2O contents. Among pyroclastic OBSs collected from the OD vent, N_V varies by nearly 1 order of magnitude between 0.4 and 0.8 wt.% H_2O. Thus, no correlation exists between this parameter and H_2O. There is however an exponential increase in the maximum N_V with decreasing H_2O if the total range of H_2O is considered.

[14] Average cpx N_V and H_2O measured on SD pyroclastic OBSs form a tighter, positively sloping linear trend (Figure 3a). N_V increases by a factor of about five from the relatively H_2O-rich glasses to the more degassed samples.

[15] Plagioclase N_V is plotted against H_2O in Figure 3b. In OD vent OBSs, plag N_V is highest at 0.82 wt.% H_2O. The maximum observed N_V occurs in a SD vent OBS with about 0.7 wt.% H_2O. As was observed for cpx N_V, plag N_V varies considerably over a narrow range of H_2O. Thus, no correlation is found between plag N_V and H_2O content. Similarly, cpx N_V in these PD OBSs does not show a systematic change with H_2O content (Table A2).

[16] Like cpx and plag N_V, F_V and F_A also span a range of values at specific H_2O contents (Figure 3). The maximum F_V and F_A both increase with declining H_2O. Other than these patterns, the data are quite scattered and no correlation with H_2O is found.

4. Discussion

[17] Inyo OBS textures are diverse, and in most cases, they appear to vary independently of the H_2O concentration. Differences in the degree of volatile loss, may however, account for some of the observed textural variations. For example, the inverse correlations between cpx N_V and H_2O (Figure 3a), while crude, show that some extensively degassed OBSs contain higher microlite contents than less-degassed OBSs. These patterns may indeed reflect an increase in the degree of undercooling with eruption progress.

[18] The correlations between cpx N_V and H_2O are accompanied by considerable scatter, showing, for example, that similarly degassed OBSs may develop very different textures. How do such striking textural differences arise in OBSs that have undergone the same amount of degassing? In addition to degassing-induced undercooling, the amount of time a melt resides in an undercooled state prior to quenching will control the extent of crystallization. Indeed, experimental studies [e.g., Hammer and Rutherford, 2002] highlight the importance of crystallization delays resulting from kinetic limitations to microlite nucleation and growth. These studies show that minerals expected to crystallize according to phase equilibria may in fact fail to do so under conditions of rapid decompression, as the time scales of volatile exsolution and melt stiffening (seconds to minutes), are much shorter than crystallization time scales (hours to days) [Geschwind and Rutherford, 1995]. Thus, extensively degassed, microlite-poor glasses, sometimes inferred to have experienced relatively minor volatile loss compared to their microlite-rich counterparts [e.g., Swanson et al., 1989], may be the products of rapid decompression, and therefore, rapid ascent.

[19] In light of experimental findings, we interpret extensively degassed, microlite-poor OBS as magma that experienced relatively rapid ascent and consequently, short residence times. By comparison, OBS with equal H_2O but greater N_V and F may have ascended more slowly and thus, experienced more time in the conduit prior to quenching. By this reasoning, CD OBSs having both low N_V and H_2O may be the remnants of melt that underwent rapid, unhindered ascent. Their characteristically low N_V and F_V, and lack of plag, which is expected to crystallize at low pressures [e.g., Cashman and Blundy, 2000], is evidence that the crystallization interval was short compared to that of CD OBSs with higher N_V. PD OBS may have experienced the longest residence times, involving either slow ascent or stalling at shallow levels to allow sufficient time for extensive plag crystallization.

[20] The observation that a variety of OBS textures erupt during discrete events, along with an abundance of micro-

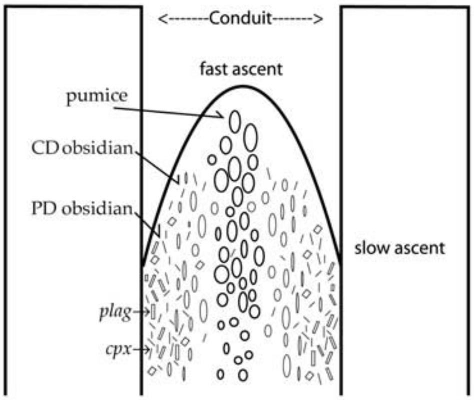

Figure 4. Schematic view of magmatic flow in a conduit. Regions of high (PD OBS) and low (CD OBS) crystallinity may develop according to the flow velocity profile (bold curve), as this controls residence time.

lite-free pumice [Eichelberger and Westrich, 1981], suggests that textural heterogeneities exist in close proximity of one another in the conduit. If textural heterogeneities reflect variations in ascent rate and residence time, then the geometry of flow in the conduit may control the spatial distribution of textures; i.e., regions of different crystallinity may develop according to the flow velocity profile (Figure 4). For example, flow will be slowest or even stalled near the conduit margins due to viscous drag. In this region, magma will have the requisite time to crystallize extensively in response to degassing. PD OBS may form in this marginal region. Cooling at the margins may further enhance crystallization of PD OBS. Flow velocities will increase inboard of the conduit margins, and will be highest in the center of the conduit. CD OBS with high N_V may originate just inboard of the conduit margins, where higher ascent rates preclude the formation of abundant plag. Low-N_V CD OBS and microlite-free pumice may originate from the relatively fast moving central part of the conduit. Explosive venting of conduit magma will sample these lateral textural heterogeneities thereby producing a mixture of variably crystallized material in tephra deposits.

5. Conclusion

[21] In summary, the large range in N_V, F_V, and F_A with H_2O suggests that microlites in rhyolitic OBS, and perhaps in the rhyolitic groundmasses of many intermediate volcanic rocks, are not reliable indicators of the extent of degassing. Textural variations instead reflect a range of crystallization environments in the conduit, controlled in part by ascent rate, residence time, devolatilization, and possibly conductive cooling. However, where the effects of cooling can be deemed negligible on the time scales of magma ascent, as may be the case for some explosive eruptions, shifts in microlite mode and texture within a pyroclastic deposit, coupled with measurements of H_2O, may provide a qualitative indication of magma ascent rate or residence time.

[22] Acknowledgments. We thank two anonymous reviewers and M. Manga for comments. We also thank P. Wallace and C. Mandeville for help with FTIR and T. Vogel for XRF analyses. J.M.C. is grateful for support from the Alexander von Humboldt Foundation and NSF grant CCLI-0087895.

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