An improved clinopyroxene-based hygrometer for Etnean magmas and implications for eruption triggering mechanisms

CRISTINA PERINELLI1, SILVIO MOLLO1,2,*, MARIO GAETA1, SERENA PIA DE CRISTOFARO3, DANILE M. PALLADINO1, PIETRO ARMIENTI1, PIERGIORGIO SCARLATO2, AND KEITH D. PUTIRKA5

1 Dipartimento di Scienze della Terra, Sapienza-Università di Roma, Ple Aldo Moro 5, 00185 Roma, Italy
2 Dipartimento Nazionale di Geofisica e Vulcanologia, Via di Vigna Murata 605, 00143 Roma, Italy
3 Dipartimento di Scienze della Terra, Università degli Studi di Torino, Via Valperga Caluso 35, 10125 Torino, Italy
4 Dipartimento di Scienze della Terra, Università degli Studi di Pisa, Via S. Maria 53, 56126 Pisa, Italy
5 Department of Earth and Environmental Sciences, California State University, Fresno, 2576 E. San Ramon Avenue, MS/ST25, Fresno, California 93740-8039, U.S.A.

ABSTRACT

We have refined the clinopyroxene-based hygrometer published by Armienti et al. (2013) for a better quantitative understanding of the role of H2O in the differentiation of Etnean magmas. The original calibration data set has been significantly improved by including several experimental clinopyroxene compositions that closely reproduce those found in natural Etnean products. To verify the accuracy of the model, some randomly selected experimental clinopyroxene compositions external to the calibration data set have been used as test data. Through a statistic algorithm based on the Mallows’ C_r criterion, we also check that all model parameters do not cause data overfitting, or systematic error.

The application of the refined hygrometer to the Mt. Etna 2011–2013 lava fountains indicates that most of the decreases in H2O content occur at P < 100 MPa, in agreement with melt inclusion data suggesting abundant H2O degassing at shallow crustal levels during magma ascent in the conduit and eruption to the surface.

Keywords: Mt. Etna, clinopyroxene, hygrometer, H2O content

INTRODUCTION

The plumbing system of Mt. Etna volcano (Sicily, Italy) has a multifaceted geometry (Bozzano et al. 2013), variable in space and time and consisting of storage zones at different depths, where primitive magmas, containing different H2O contents, undergo fractional crystallization, degassing, and mixing processes (e.g., Armienti et al. 2004). For example, the explosive activity of the volcano is ascribed to gas-rich magmas and/or fluxes of abundant volatiles from the deeper portions of Mt. Etna plumbing system, i.e., ~20 km depth (Ferlito and Lanzafame 2010). In this scenario, volcanic eruptions are fed by the upward migration of hot, fluid-saturated, poorly dense, and highly buoyant magmas from depth, with implications for mineral and melt compositions, degree of crystallization, magma ascent velocity and type of eruption (Armienti et al. 2007; Ferlito et al. 2014; Collins et al. 2015; Vetere et al. 2015). For the deeper portions of the plumbing system, Armienti et al. (2013) modeled the P-T-H2O-CO2 path of fluid-undersaturated magmas feeding some important eruptions, finding that the clinopyroxene liquidus is constrained to fall between 500–900 MPa, 1100–1180 °C, 3–4 wt% H2O, 0.23–0.31 wt% CO2. To estimate the melt-H2O content of Etnean magmas, Armienti et al. (2013) calibrated an empirical clinopyroxene-based hygrometer:

\[ \text{wt\% H}_2\text{O} = (a\text{DiHd} + b\text{EnFs} + c\text{CaTs} + d\text{Jd} + e\text{CaTi} + fP + gT)K \]  (1)

where DiHd = diopside + hedenbergite, EnFs = enstatite + ferrosilite, CaTs = Ca-Tschermak, Jd = jadeite, CaTi = CaTi-Tschermak (see Putirka 1999), and below, \( a = 19.45, b = -0.62, c = 8.39, d = 49.33, e = -86.02, f = -0.37, g = -0.37, K = 3.92, \) P is in GPa, and T is in °C. The calibration data set is comprised of experiments on Etnean magmas (e.g., Dolfi and Trigila 1983) or magmas similar in composition and selected from the LEPR database (http://lepr.ofmresearch.org); see Supplementary1 Data Table 1S for further details. Notably, as stated in Armienti et al. (2013), the application of Equation 1 is restricted only to clinopyroxenes in equilibrium with trachybasaltic and hawaiitic melts, for which the regression model has a relatively low standard error of estimate (SEE = ±0.5).

1Deposit item AM-16-125916, Supplemental Material. Deposit items are free to all readers and found on the MSA web site, via the specific issue’s Table of Contents (go to http://www.minsocam.org/msa/ammin/toc/2016/Dec2016_data/Dec2016_data.html).