Estimating SiO$_2$ content of lava deposits in the humid tropics using remotely sensed imagery

Cielo F. Bastero *, Alfredo Mahar F.A. Lagmay

National Institute of Geological Sciences, College of Science, University of the Philippines, Diliman, Quezon City 1101, Philippines

Abstract

Remote sensing methods used to determine the rheology and SiO$_2$ composition of lava flows on Mars were utilized to estimate the composition of lava deposits in the Philippines. Test cases were conducted on two lava domes and two lava flow deposits to determine whether remote sensing methods can be applied as a rapid and economical means to assess hazards associated with volcanoes in the humid tropics. Our study shows that dimensional parameters derived from digital elevation models (DEMs) generated from airborne sensors are effective in determining the SiO$_2$ content of lava deposits. The SiO$_2$ values computed from the rheological properties of lava are found to be comparable to geochemically analyzed field samples. These results suggest that remote sensing methods to estimate the composition of lava deposits is viable and can serve as a potentially useful tool for rapid and economic hazards assessment of volcanoes in tropical regions. With the growing number of high-resolution satellite sensors that routinely image the Earth's surface, such a technique can be widely utilized.
© 2005 Elsevier B.V. All rights reserved.

1. Introduction

Digital elevation models (DEMs) generated from remotely sensed imagery can be used to estimate the rheology and SiO$_2$ content of lava deposits (Lanz, 1999; Bulmer and Campbell, 1999; Thomson and Head, 2000; Warner and Gregg, 2002). This method has been used extensively to study the composition of lava deposits on Mars where access to samples for geochemical analysis was not possible until recently. In previous papers, the estimation of SiO$_2$ content of lava deposits on Mars entailed the description of its physical parameters to determine its rheology. These parameters were in turn used to compute the yield

strength, which is directly related to the viscosity and SiO$_2$ content of the lava deposit.

Studies estimating yield strength and SiO$_2$ content have also been conducted on lava deposits on Earth (Moore et al., 1978). Similar remote sensing techniques were applied on the Sabancaya lava flows in Peru (Bulmer and Campbell, 1999) where rheological parameters and SiO$_2$ content were estimated. In this paper, the composition of lava deposits in the Philippines was determined using DEMs generated from airborne (AIRSAR and Aerial photographs) imagery. The lava deposits that were studied are eruptive products of Mayon and Malinao volcanoes in Bicol and two lava domes formed on the southeast flank of Makiling Volcano in Laguna, Philippines (Fig. 1). This is the first instance where remote sensing methods to determine lava composition is applied to a humid tropical environment.

---

* Corresponding author.
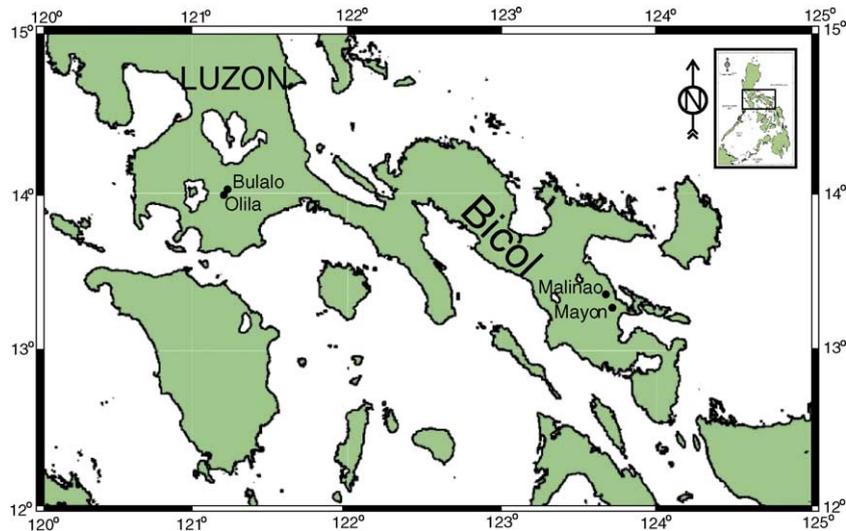*E-mail address:* cbastero@nigs.upd.edu.ph (C.F. Bastero).

Fig. 1. A map showing the locations of the lava deposits studied in this paper. The Malinao and 1993 Mayon lava deposits are found in the southeast of Luzon island in the Bicol region. The Bulalo and Olila domes are found southwest of Luzon.

The aim is to establish the applicability of remote sensing as a tool in estimating SiO_2 content of lavas in tropical regions and to assess its viability in rapid and economic hazards assessment of volcanoes.

2. Methodology

Fluid behavior is distinguished by the manner of their flow. A fluid may be Newtonian where the response to shear stress is flow at rates proportional to the applied stress (Fig. 2) and where the constant of proportionality is viscosity. The other is non-Newtonian behavior where the fluid may have a yield strength. In such flows, it is necessary to overcome yield stress before flow can initiate. Upon flow of the non-Newtonian fluid, viscosity becomes a function of shear stress. The simplest type of non-Newtonian behavior
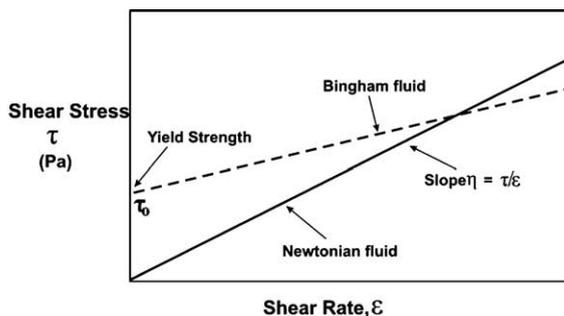

Fig. 2. Graph showing the behavior of a Newtonian (solid line) and a non-Newtonian Bingham fluid (dashed line). The Y-axis is shear stress and the X-axis the shear rate. The yield strength value is the stress required for Bingham fluids to begin flowing.

is the Bingham fluid where viscosity remains constant once shear stress is exceeded. Lava of this kind flows only when it surpasses a critical thickness (Fig. 3).

Based on the physical characteristics of lava deposits and assuming Bingham flow behavior, the yield strengths of lava flow deposits were calculated using Eqs. (1)–(3) (Orowan, 1949; Hulme, 1974; Moore et al., 1978; Lanz, 1999; Thomson and Head, 2000; Warner and Gregg, 2002)

$$Y = \rho g \sin\theta H \qquad (1)$$

$$Y = pg\frac{H^2}{W_f} \qquad (2)$$

$$Y = pg\sin^2\theta 2W_l \qquad (3)$$

where Y=yield strength, ρ=bulk density, g=gravity, H=flow thickness, W_f=flow width, W_l=levee width and θ=topographic gradient.

The above equations are three methods described by Moore et al. (1978) for calculating the yield strength of lava flows. All three equations need the measurement of the density of the lava flow ρ, and input of the acceleration due to gravity g. In addition, Eq. (1) requires an estimate of the underlying slope and the flow thickness. The second equation is independent of slope but needs measurements of the width and thickness of the lava flow deposit. Eq. (2) is similar to the calculation of yield strength of terrestrial glaciers (Orowan, 1949). The third equation is also dependent on