Available online at www.sciencedirect.com

Journal of Volcanology and Geothermal Research 143 (2005) 187–203

Journal of volcanology and geothermal research

www.elsevier.com/locate/jvolgeores

Coupled conduit flow and shape in explosive volcanic eruptions

Karl L. Mitchell*

Environmental Science Department, Lancaster University, Lancaster LA1 4YQ, UK

Received 4 June 2004; accepted 11 September 2004

Abstract

Volcanic conduit flow models generally utilise one of two conduit profile modes, which are referred to as parallel-sided (typically surface choked) or lithostatically pressure-balanced. Their limitations in application to supersonically erupted basaltic and rhyolitic explosive eruptions are investigated. Likely changes in conduit profile over time, due to catastrophic failure resulting from high wall stresses, and abrasive erosion, are investigated using a semi-analytical model. Although time-independent, this model nonetheless reveals likely trends in shape from a simple parallel-sided geometry. It is found that, for rhyolites, early wall failure will occur in all but unusual circumstances, resulting in expansion of the conduit, a reduction in wall stresses, and a trend towards a lithostatically pressure-balanced solution at depth. In both rhyolitic and basaltic eruptions, abrasive erosion results in conduit flaring near the surface, allowing the choking point to descent from the surface into the vent, substantially changing exit conditions and resulting in a trend towards the a lithostatically pressure-balanced solution at the surface. Although a truly lithostatically pressure-balanced system can never be attained, due to the effects of compressibility at supersonic velocities, it is no less valid than the more commonly utilised parallel-sided system for a variety of realistic eruption scenarios and can be a useful guide for potential steady states.
© 2005 Elsevier B.V. All rights reserved.

Keywords: volcanic; eruption; conduit; flow; erosion

1. Introduction

Early models for the ascent and eruption of magma in volcanic eruptions (e.g. McGetchin and Ullrich, 1973; Wilson, 1980; Wilson and Head, 1981; Kieffer, 1982; Slezin, 2003) used either of two conduit profile modes (Fig. 1) to set boundary conditions in order that the system might be solved semi-analytically.

The first, referred to as a parallel-sided eruption (Wilson et al., 1980; Wilson and Head, 1981), utilises a simple circular or fissure shape with no variation of cross-sectional area as a function of depth or time, i.e. it assumes that the walls are perfectly rigid. This assumption allows the modeller to set a boundary condition of Mach 1 at the surface (a condition that I shall refer to as *surface choked*), a circumstance proposed for lunar and terrestrial basaltic eruptions

* Present address: Mail Stop 183-601, Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, CA 91109-8099, USA. Tel.: +1 818 393 4584; fax: +1 818 393 3218.

E-mail address: k.l.mitchell@lancaster.ac.uk.

0377-0273/$ - see front matter © 2005 Elsevier B.V. All rights reserved.
doi:10.1016/j.jvolgeores.2004.09.017

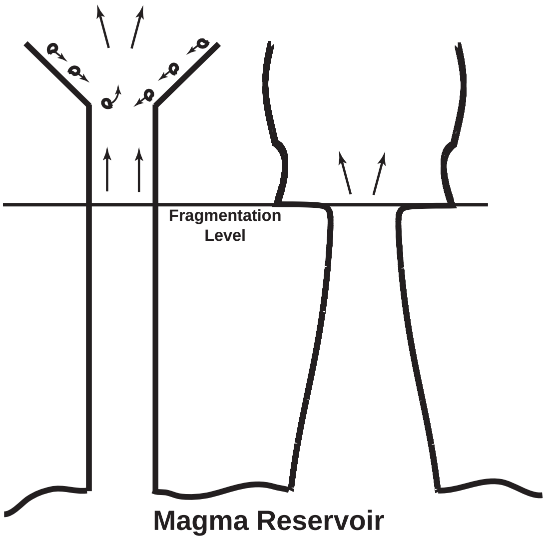

Fig. 1. Schematic representation of parallel-sided (left) and lithostatically (right) pressure-balanced conduit flow modes (not to scale). A collapse crater has been superimposed on the parallel-sided representation (after Kieffer, 1982).

by Housley (1978). A similar assumption can be employed in which the conduit exit pressure equals atmospheric, although this solution is stable only for poorly explosive eruptions. Truly parallel-sided vents with either circular or fissure forms are not observed in the field, although in many cases they can be a fair approximation to the actual shape. In reality, the initial conduit shape is likely to be that of a blade-like dyke (e.g. Rubin and Pollard, 1987), the walls of which are rapidly eroded, sometimes catastrophically, shortly after an eruption begins. A wide range of factors can then influence how the conduit system evolves but, for most eruptions, the system will tend to approximate to either one or more fissures or circular vents, with a degree of flaring near the surface. In situ observations at depth are usually impossible, and so the exact nature of the erosion and deformation processes is difficult to quantify for any given eruption.

The second conduit profile mode, normally referred to as pressure-balanced (Wilson and Head, 1981), deals with wallrock deformation and erosion implicitly, using the assumption that the system has adjusted itself such that stress across the walls is zero. In other words, any local change in flow pressure relative to lithostatic pressure in the country rock is immediately accommodated by wall failure (Valentine and Groves, 1996). For the sake of this work I shall refer to this type of system as *lithostatically pressure-balanced* (L. P. B.), so as not to confuse it with surface pressure-balanced systems, i.e. when flow pressure at the vent equals atmospheric. One problem with this mode is that the implied conduit velocities can be highly supersonic, often Mach 3 or beyond for plinian and similar eruptions, but the L. P. B. solution (Wilson et al., 1980; Wilson and Head, 1981) does not attempt to address the dynamical effects of transonic to supersonic flow (e.g. Courant and Friedrichs, 1948; Kieffer, 1982; Morrissey and Chouet, 1997; Chapman, 2000), which will inevitably result in shocks and waves that are capable of greatly affecting flow properties (discussed further in Section 5.3). As such, the results are highly suspect in regions of the conduit where the velocity approaches or exceeds Mach 1. Also, although vent flaring is observed for explosive volcanic eruptions, the degree of vent flaring predicted using the L. P. B. solution is far greater than observed, often resulting in radii of many kilometres. This effect is even more pronounced on bodies with relatively thin atmospheres, such as Mars and Io, where modelled vent radii can be many tens to even hundreds of kilometres (Mitchell, 2002).

Other papers in this issue (Sahagian et al., 2005) have generally preferred to implement the parallel-sided case in their work, due in part to the problems inherent within the pressure-balanced assumption, and also due to its relative simplicity both in terms of analytical and experimental studies. In some cases, generally when a 2- or 3-dimensional finite element model has been employed, and particularly when modelling real volcanic eruptions with known or assumed vent geometries, more complex geometries have been imposed (e.g. Morrissey and Chouet, 1997). However, the feedback between the conduit flow and the vent geometries is rarely if ever investigated, mostly due to the uncertainties involved.

There are several known mechanisms that can be result in gradual deformation of an erupting volcanic conduit over time facilitating feedback between conduit flow and shape. Thermal erosion and magmatic chilling (Bruce and Huppert, 1989) are particularly relevant for relatively "quiet" basaltic eruptions, and can be used to explain how fissure eruptions often evolve to form discrete circular vents. Sheer-stresses

Download English Version:

https://daneshyari.com/en/article/9531000

Download Persian Version:

https://daneshyari.com/article/9531000

Daneshyari.com