JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 91, NO. B9, PAGES 9407-9446, AUGUST 10, 1986

VOLCANIC PROCESSES AND LANDFORMS ON VENUS: THEORY, PREDICTIONS, AND OBSERVATIONS

James W. Head, III

Department of Geological Sciences, Brown University, Providence, Rhode Island

Lionel Wilson[1]

Department of Environmental Science, University of Lancaster, Lancaster, England

Abstract. Volcanic activity is a fundamental mechanism of heat transfer from planetary interiors, and the characteristics, distribution, and morphology of volcanic deposits provide significant insight into (1) the relation of volcanism and tectonism, (2) eruption style, and (3) the chemistry and volatile content of the eruption products. Eruption styles and processes on the planets are known to be strongly influenced by such factors as gravity, temperature, and atmospheric characteristics. We model the ascent and eruption of magma on Venus in the current Venus environment, taking into account the influence of the extreme surface temperatures (650-750 K) and pressures (4-10 MPa) on these processes. These conditions produce a thermal gradient difference such that the temperature is higher at a given depth on Venus than on Earth, and a pressure distribution difference leading to much smaller ratios of subsurface to surface pressure on Venus than on Earth. Among the more significant consequences of this for volcanic style on Venus is that there will be less cooling of magma in the final stages of ascent and that once the magma reaches the surface, convective heat losses will be much more important than in the subaerial terrestrial environment because of the high atmospheric gas density. In general, however, our treatment suggests that there is no reason to expect large systematic differences between lava flow morphologies on Venus and Earth. On the other hand, conditions on Venus will tend to inhibit the subsurface exsolution of volatiles, and pyroclastic eruptions involving continuous magma disruption by gas bubble growth may not occur at all unless the exsolved magma volatile content exceeds several weight percent. However, Strombolian activity, in which bubble coalescence can cause sufficient concentration of gas to produce intermittent explosions in low-viscosity magmas ascending slowly toward the surface, can occur at much lower volatile contents. If pyroclastic eruptions do occur, pyroclastic fragment velocities and clast cooling will be less than on Earth, and the higher atmospheric pressure and temperature will cause convective cloud rise heights to be considerably lower, and pyroclasts to be much less widely dispersed, than on Earth. For example, eruption cloud heights of 50 km (suggested as a means of raising sulfur dioxide into the upper atmosphere (Esposito, 1984)) could only be reached if exsolved magma volatile contents exceeded 4 wt %, regardless of gas species. On the basis of our analysis, a series of predictions can be made concerning the expected characteristics of volcanic deposits and landforms on Venus. Comparison of these predictions with recent observations from Pioneer Venus, Arecibo, and Venera data support the view that regional pyroclastic deposits are very rare, that magma volatile contents do not commonly exceed about 4 wt %, and that the atmospheric pressure has been about the same as the present value over a time period equivalent to the average age of the northern areas of the northern hemisphere (500-1000 Ma (Barsukov et al., 1986)). The location and geometry of many Venusian lava flows suggest that numerous eruptions had effusion rates exceeding common terrestrial rates and lying more in the range inferred for lunar basaltic flood eruptions (10^4-10^5 m^3/s). Shield volcanoes on Venus are often wide (several hundred kilometer diameter) but are low (less than about 2 km elevation) relative to those on Mars and Earth. Volcano height depends in part on the depth of origin of the magma and the density contrast between the lava and the rocks between the source and the surface. On Venus, typical effective density differences may be less than on Earth because the higher temperature gradient leads to shallower magma sources, and volatile exsolution is inhibited during magma ascent, all factors which could lead to low edifices relative to Earth and Mars. Reduction of the driving density contrast has the further effect of reducing the width of magma-filled cracks, increasing cooling, and inhibiting magma ascent to the surface. Possible implications of this are that dike intrusion may be very common on Venus (thus providing a potentially significant advective/conductive hybrid lithospheric heat transfer mechanism) and that large minimum magma volumes may be required to ensure surface eruptions (perhaps explaining the apparently common occurrence of long lava flows on Venus). The large size of volcanic calderas on Venus relative to other planets suggests that the depth to the source area is small and that caldera formation may be closely linked to magma accumulation at the base of, rather than within, the lithosphere.

[1]Visiting professor at Department of Geological Sciences, Brown University, Providence, Rhode Island.

Paper number 5B5617.
0148-0227/86/005B-5617$05.00

1. Introduction

Volcanism is known to be a significant geological process in the evolution of the terrestrial