THE INFLUENCE OF GRAVITY ON PLANETARY VOLCANIC ERUPTION RATES.

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Introduction: Many lunar and martian volcanoes have produced lava flows which are much longer than any commonly produced on Earth in geologically recent times [1-3]. It is inferred on the basis of various morphological factors that most of these flows, like the Earth's longest flows, are of mafic (basaltic) composition [1]. In cases where the maximum distance that can be travelled by a single lava flow lobe is limited by the rheological changes consequent on heat losses to its surroundings, it is expected that the lengths of flows are an increasing function of the effusion rate at the vent [4, 5], an idea first proposed on observational grounds [6]. In other cases, eruptions may not continue long enough for cooling to be the critical factor in determining flow length [7]; the lengths of flows then correlate best with erupted lava volume [8], and attempts to apply the length/effusion rate relationship lead to a systematic underestimate of the effusion rate [7]. Some of the sinuous rille channels on the Moon and Mars exhibit all of the expected morphological features of depressions formed by thermal erosion of country rocks by lava flows moving at sufficiently high speeds that their internal motions were turbulent [9]. The theoretical relationship between channel length and width and heat transport rate by the eroding flow [9, 10] allows lava effusion rates to be deduced from observed rille lengths [11, 12]. Application of the above ideas to observations of lava flow lengths and sinuous rille lengths on the Moon and Mars implies [5] that many flow units on these two planets were fed by magma discharge rates in the range 10^7 to 10^9 kg/s, to be compared with rates commonly in the range 10^4 to 3×10^6 kg/s for effusive eruptions producing flows with a wide range of lava compositions on the Earth [13]. Thus, there seems to be strong evidence for systematicaly higher mass or volume eruption rates having occurred on Mars and the Moon than on the Earth in magmas of similar composition and rheological properties. We must look to some other property of either the magmas or the environments in which they erupt to explain this situation.

Formation of dikes in planetary lithospheres: Magmas reach planetary surfaces by moving through the lithosphere from their source regions at depths of several to many tens of km as discrete bodies of various sizes [14, 15]. The final part of the motion of any batch of magma reaching the surface takes place through the uppermost, brittle part of the lithosphere where the stress regime restricts the allowed shape of the pathway to that of a dike [16, 17]. The equations describing the cross-sectional shapes of dikes [18-20] can all be reduced by trivial algebraic manipulation to the following forms. For a vertically propagating dike of horizontal length H and width W:

$$H = [\,2\,(Q+T)] \,/\, [\,|dQ/dx + dT/dx|] \quad (1)$$

$$W = [\,\pi\,(1-s)\,(Q+T)^2\,] \,/\, [\,\mu\,|dQ/dx + dT/dx|\,] \quad (2)$$

where x is the horizontal co-ordinate, T is the regional tensional force at the centre of the dike, Q is the pressure in the dike in excess of the local lithostatic pressure. s is Poisson's ratio and μ is the shear modulus for the country rocks into which the dike intrudes. For a horizontally propagating dike of vertical length V and width W:

$$V = [\,2\,(Q+T)] \,/\, [\,|g\,d + dT/dz|] \quad (3)$$

$$W = [\pi\,(1-s)\,(Q+T)^2] \,/\, [\,\mu\,|g\,d + dT/dz|] \quad (4)$$

where z is the vertical co-ordinate, g is the acceleration due to gravity and d is the density difference between the country rock and the magma.

We now point out the following: (a) in a largely vertically propagating magma stream, dQ/dx is likely to be small (otherwise the motion would have a significant horizontal component); (b) the magnitude of the term (Q+T) is likely to be the same on all silicate planets at the start of an eruption since it reflects the stress necessary to initiate dike propagation; (c) the values of s and μ will be similar for the rocks of all mafic volcanic edifices; (d) the values of dT/dx and dT/dz on any given planet will probably be proportional to the gravity. This arises because stresses due to tectonic (ultimately thermally-driven density-difference) forces are directly proportional to the gravity, while the length scales over which T changes will probably be similar for all the silicate planets since they all had similar thermal boundary layer thicknesses at the time when they were most volcanically active [21]. Alternatively, when dT/dx is determined by lateral topographic variations, the gravity is still involved in the same way [20]. Taken together, these observations imply that the only factors affecting the linear dimensions of dikes which vary systematically between the silicate planets are the stress gradients dT/dx, dT/dz and (gd), and that all three of these are essentially proportional to the local gravity.

Implications: The consequences for eruptive processes are profound. Both the widths and lengths of dikes at right angles to the direction of magma movement (whether horizontal or vertical) will be larger on the Moon and Mars than the Earth, in inverse proportion to the gravity. Furthermore, since the width of a dike is the main factor determining the velocity, U, of magma movement within it, magmas will travel at greater speeds on the low-gravity bodies; U is proportional to W^2g in laminar motion and to $(Wg)^{1/2}$ in turbulent flow [22]. Hence in laminar conditions the volume flux, F (equal to U W L for unvesiculated magma at depth in the volcanic edifice) will be proportional to g^{-3}, and in turbulent conditions to g^{-2}.

Thus, typical eruption rates from volcanic vents in structurally similar locations should have been 7 to 18 times greater on Mars than on Earth and 36 to 218 times greater on the Moon than on Earth. Similar factors to those specified for the Moon should apply to the underlying silicate volcanism driving current activity on Io. And mafic eruptive activity on Venus should take place with similar discharge rates to those on Earth. Of course, systematic differences between the properties of volcanic source regions on the various bodies (e.g., lack of substantial shield volcanoes with rift zones on the Moon and Io) imply that additional factors to those discussed above must be important. But we feel that the first-order differences between typical mafic magma eruption rates on the silicate planets are accounted for by the arguments presented.

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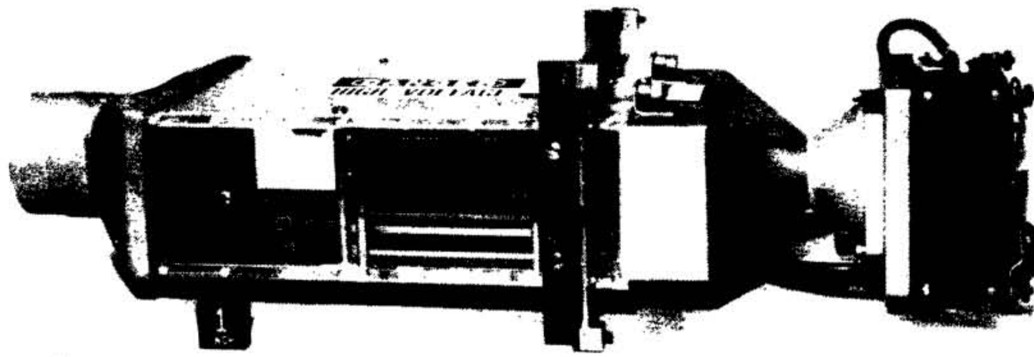
SAMPLING THE SOUTH POLE ATMOSPHERE FOR COSMIC DUST BY ELECTROSTATIC PRECIPITATION. R. E. Witkowski and W. A. Cassidy, University of Pittsburgh, Pittsburgh, PA 15260, and G. W. Penney, Carnegie-Mellon University, Pittsburgh, PA 15213.

A specially designed electrostatic precipitation (ESP) particle collector was constructed and deployed to sample the lower atmosphere of the South Pole, Antarctica, for cosmic dust. Atmospheric sampling was carried out in the clean air sector at the South Pole Station Clean Air Facility. The device was successfully operated over a period of three years; more than 20,000 hours of operating time have been logged [1,2].



ESP Particle Collector. The removable sampling plates are clearly visible in the center section of the device.

Our experience indicates that the ESP method is ideally suited for collecting atmospheric submicron-size particles. It is highly reliable, simple to operate, and does not require constant attention. Most important, this device has demonstrated that it can collect delicate particles in an undamaged state and preserve them as individual grains. Little or no matting of these particles occurs if the sampling interval is chosen correctly. Because the device operates in a "dry" air environment, water soluble material is not lost as would be the case for ice core sampling.

The sample handling system in this collector minimizes contamination after collection and during transport by a special arrangement of isolation shutters and removable sampling plates. Sample preparation or handling in a clean room facility is not required prior to analysis. A drawback is that the carbon films used to suspend the collected samples make it extremely difficult to search for carbon-containing particles.

A variety of particles, some of which may be of both meteoritic and extraterrestrial origin, have been collected and characterized. These samples include particles whose simple compositions may represent sublimates generated in the stratosphere by condensation of vapor species from volatilized infalling micrometeorites and multi-element containing particles that display a chondritic signature which is characteristic of interplanetary dust particles [3].

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