MODE OF EMPLACEMENT OF LUNAR MARE VOLCANIC DEPOSITS: GRABEN FORMATION DUE TO NEAR SURFACE DEFORMATION ACCOMPANYING DIKE EMPLACEMENT AT RIMA PARRY V; J. W. Head[1] and L. Wilson[1,2]. [1] Dept. Geol. Sci., Brown Univ., Providence, RI 02912 USA, [2] Environ. Sci. Div., Inst. of Environ. and Biol. Sci., Lancaster Univ., Lancaster LA1 4YQ, UK.

Abstract: Theoretical analyses, together with the observed style of emplacement of lunar mare volcanic deposits, strongly suggest that mare volcanic eruptions are fed by dikes from source regions at the base of the crust or deeper in the lunar mantle (1). Some dikes intrude into the lower crust, while others penetrate to the surface and are the sources for voluminous outpourings of lava. Still others stall near the surface generating a near-surface extensional stress field. We have investigated the hypothesis that some lunar linear rilles (graben) are the near-surface manifestations of dikes intruded to shallow depths. For a specific example (Rima Parry V) we show that the geometry of the faults implies a mean dike width of about 150 m and depth to the dike top of about 500 m, values consistent with other theoretical and observational data on lunar dike geometry. Localized pyroclastic deposits along Rima Parry V are evidence for the presence of near-surface magma, and are interpreted to be the result of degassing and pyroclastic eruption subsequent to the emplacement of the dike.

Dike Emplacement in the Lunar Crust: Linear and arcuate rilles (simple graben) have been interpreted to be linked to impact basin structure, and to the emplacement of mare deposits in the basins via flexural deformation related to the mare deposit load (2). Linear rilles are generally thought to represent deformation confined to the upper layers of the crust (3) where stresses are concentrated as rocks at deeper levels adjust viscously to long-term applied loads (4). Several linear rilles, however, have volcanic (commonly pyroclastic) deposits associated with them over at least parts of their horizontal extent. A likely situation is that these graben are themselves the surface expressions of stress fields generated by dikes approaching the surface from great depths (5). The surface manifestation of dike emplacement in the crust may be quite different depending on the depth below the surface to which the dike penetrates as it rises. In general, if the dike propagates to the surface and erupts lava, the stress field immediately surrounding the propagating dike will be compressional all the way to the surface and the surface manifestation will be a fracture. If the dike does not propagate to the vicinity of the surface (perhaps stalling at depths greater than several km), then the strain associated with dike emplacement will be insufficient to cause any dislocation in the near surface rocks. On the other hand, there exists a range of intermediate depths of dike penetration at which eruption does not occur, but at which strain associated with dike emplacement influences rocks near enough to the surface that extensional deformation will take place and graben will form.

During the period of mare basalt emplacement, the anorthositic highland crust was underlain by zones of mantle partial melt (6). Buoyant diapirs ascended through the ductile portions of the mantle and become trapped at the base of the crust (a buoyancy trap; 7) or at later times at the base of the thickening lithosphere (a strength trap). For the case of the buoyancy trap, magma stalled at depths averaging ~65 km on the nearside and ~85 km on the farside. Magma remained in bodies at these depths until excess pressure had built up sufficiently to propagate a dike toward the surface. Buildup of excess pressure resulted in dike propagation into the crust, or to the surface producing volcanic eruptions, depending on total excess pressure, volume of magma available, and local crustal thickness (1). The minimum driving pressures needed to propagate dikes to the surface from magma source depths in the range 64 to 100 km is in the range 14 to 20 MPa. The mean width of dikes with these driving pressures and heights lies in the range 150 to 200 m. A value close to 25 MPa may be the most plausible for the driving pressure in dikes leading to actual surface eruptions (1). For dikes propagating from deeper parent magma bodies such as might be related to strength traps at depths close to 300 km, pressures up to 50 MPa and dike widths in the range 600 to 800 m are inferred. The maximum horizontal extent (length) of a dike which propagates through a great vertical distance is likely to be comparable to its vertical height (8), though the disc-like shape of such a dike will mean that the surface outcrop length is likely to be much less than the maximum length at depth.

Lunar Linear Rille - Rima Parry V Example: Rima Parry V, about 50 km in length and 730m-1.8 km wide, cuts the floor and rim of the craters Fra Mauro and Bonpland and has mantling material and a row of small cones along its western margin about midway along its strike. The general surface and subsurface deformation expected as a result of shallow dike intrusion has been investigated (5,9,10). A combination of these theoretical and experimental investigations shows that the location of the boundary faults of any graben formed is dictated by a combination of elastic and anelastic processes. Using the empirical result (10) that the total horizontal extension produced by a dike which extends vertically from a shallow depth to a very great depth is close to 2/3 of the mean dike width, we can use the strain associated with the linear rille graben to estimate dike widths. The typical depth of Rima Parry V is ~54 m, the total extension is ~62 m and the implied average dike width is (1/[2/3]) = 1.5 times this, i.e. ~93 m. An additional estimate of the dike width can be obtained from assessment of the horizontal surface strain per meter of dike width as a function of horizontal position above a shallow dike for various depths to the dike top (10). The distance between the strain maxima is inferred to be similar to the width of the graben, and for Rima Parry V, where the graben width is 1800 m, the implied depth to dike top is ~750 m, and the typical strain per meter width of dike is close to 0.0002. Using a graben width of 1800 m and the horizontal extension of 62 m deduced above, the strain is 62/1800 = 0.034 and so the implied dike width is 0.034/0.0002 = 172 m. Thus, from the two approaches to finding the dike width we have a lower limit of 93 m and an estimate of 172 m. We adopt a final estimate of 150 m from these values. This value is at the lower end of the 150-200 m mean dike widths estimated for dikes with sufficient driving pressure to cause near-surface dike intrusions from magma parent bodies at depths of 64-100 km (1). On the basis of the hypothesis that the length of a dike which propagates through a great vertical distance is likely to be comparable to its vertical height (8), the length of Rima Parry V (about 50 km) and its tendency to narrow at both ends suggests that the parent magma body may lie at a minimum depth of 50 km.

Rima Parry V also displays a row of volcanic cones aligned parallel to the western margin of the graben. These, and associated deposits that mantle the rille topography, occur in a 10 km long segment located about midway along the rille extent (Figure 1). We interpret these to indicate the presence of magma just below the surface in the vicinity of the rille. A combination of chemical evolution due to cooling of magma in the top of a dike and the migration of exsolved volatiles to shallow depths (11,12) could lead to positive buoyancy of part of the melt at the top of the dike, the propagation of fractures to the surface, and the eruption of pyroclastic materials.

Conclusions: On the basis of these considerations, the presence of associated pyroclastic deposits, and the lack of significant effusive eruptions, we conclude that the characteristics of Rima Parry V are consistent with formation by a dike which propagated from great depth to near the lunar surface. Several other linear rilles (e.g., Hevelius, Rima Bode) share some of the characteristics of these two examples and may also represent the surface manifestation of shallow dikes emplaced from parent magma bodies at depth.

References:

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