LUNAR LINEAR RILLES AS SURFACE MANIFESTATIONS OF DIKES: PREDICTIONS AND OBSERVATIONS; James W. Head[1] and Lionel Wilson[1,2], [1]Dept. Geol. Scis., Brown Univ., Providence, RI 02912 USA, head@pggipl.geo.brown.edu; [2]Env. Sci. Div., IEBS, Lancaster Univ., Lancaster LA1 4YQ UK, L.Wilson@lancaster.ac.uk

On the basis of a theoretical treatment for the penetration of magma-filled cracks (dikes) to the vicinity of the lunar surface, and the predicted range of tectonic and associated volcanic features and processes [1] we examine a range of geologic features that might relate to these predictions (Fig. 1) and we assess the likelihood of their formation by the associated processes.

1. NO SURFACE DEFORMATION AND LINEAR RILLES WITH NO EXTRUSION. Some dikes will intrude too deeply to create surface deformation, but many dikes may intrude to sufficiently shallow depths that they will create graben, but there will be no surface evidence of eruptions. These are clearly the most difficult to distinguish from graben formed from stress fields not related to dikes. Several examples are known in which other evidence suggests that dikes exist below the observed graben. Rima Sirsalis, a 380 km long graben in the highlands, is characterized by a linear magnetic anomaly interpreted to be due to an underlying magnetized dike [2, 3]. Thus, magnetometer and electron reflection experiments may provide additional information on the location of buried dikes and the origin of specific graben. The dark-halo impact crater Gartner D is located in smooth bright plains north of Sinus Roris and is superposed on top of a linear rille which has no associated volcanic features. The spectral characteristics of this crater are those of mare material [4]. A reasonable interpretation of this relationship is that the impact event excavated mare material from the top of a dike underlying the graben.

2. LINEAR RILLES WITH ASSOCIATED CRATER CHAINS. One of the most impressive lunar examples of the association of linear rilles and craters of probable endogenic origin is the crater Hyginus and the two rilles leading away from it. These craters are centrally located along the 3-4 km wide linear rilles; some appear to have no rims and are interpreted to be collapse craters, but others appear to have partly raised rims and may be explosion craters. On the basis of the geometry involved, these features are interpreted to form as shown in Fig. 1; rille width suggests that the depth to the top of the dike is ~1.5-2.0 km, a value within the range of depths that gas exsolution would be expected to occur. Thus the production, collapse, and explosive venting of the volatiles could easily explain the range of features seen here.

3. CRATER CHAINS WITH NO LINEAR RILLES. If crater chains can form along linear rilles such as Hyginus, then at least some of the crater chains noted on the lunar surface which are not associated with linear rilles [5] may be due to the degassing of dikes too deep to form near-surface stress fields creating graben, but shallow enough to cause degassing of the magma and venting of gas to the surface to form crater chains (Fig. 1). For example, few linear rilles are seen on the Moon that are in excess of four km width [6]. Although clearly not all linear rilles are due to dike emplacement, nonetheless if we took this value as an upper limit for graben width caused by dike formation, than the relationship of [7] would suggest that the maximum depth at which the top of a dike could still form a graben is about 2 km. The exsolution depth of CO, thought to be responsible for the majority of volatiles in lunar basaltic magmas, is about 3 km [8]. These data would then suggest that, on the average, dikes emplaced to depths between 2 and 3 km below the surface would be too deep to create surface deformation and graben, but deep enough to undergo degassing and venting of the gas to the surface to form pit craters aligned along the strike of the dike (Fig. 1). Such craters might involve both drainage and explosive degassing to create rim deposits. One possible candidate for such a feature is the 113 km long crater chain that lies on the floor of the large farside crater Mendeleev. There are 25 craters in this chain and they range from 1.2-9.3 km in diameter but are typically 2-3 km in diameter. Although crater chains of this type could be of impact origin, an endogenic origin is suggested by the extreme linear trend, low or absent rim topography, and lack of features associated with simultaneously forming impact craters (e.g., birds-foot pattern, septa) [5].

4. LINEAR RILLES WITH ASSOCIATED PYROCLASTIC CONES. In some cases, dikes may propagate sufficiently near to the surface to create a graben, but still not cause significant eruption of lavas (Fig. 1). In this situation, degassing of the upper part of the dike may cause the formation of gas/magma mixtures which might buoyantly rise to the surface or be forced to the surface through overpressurization of the upper part of the dike. In this particular configuration, the distribution of stresses anticipated in the vicinity of the dike tip can cause migration of magma and exsolved gas from the upper part of the dike to locations outward of the main graben bounding faults, a phenomenon likely to explain the distribution of cones at Rima Parry V [3]. Dikes reaching closer to the surface, but still not having associated extensive lava flows, should produce narrower graben, and any pyroclastic cones should be more closely associated with the graben.

5. LINEAR RILLES WITH PYROCLASTIC CONES AND SOME ASSOCIATED FLOWS AND DOMES. Several examples have been noted where narrow linear rilles and v-shaped fractures are associated with larger volcanic cones, domes and small shields. In one such case, narrow linear rilles strike radial to Mare Serenitatis and are interrupted by mare units and two large cones, Isis and Osiris [9]. On the basis of their small size and the juxtaposition of the cones directly along the strike, these graben are interpreted to be formed by dikes that are very shallow (less than a few tens of m) and which have penetrated to the surface in places. In another example, a graben about 12 km in length and less than 500 m in width (and thus less than about 150 m to the top of a possible dike) occurs in an environment with other evidence of near-surface extrusion, including numerous shield volcanoes and a row of pyroclastic cones striking parallel to the rille. Indeed, the rille terminates at the base of one small shield volcano, and the summit crater of the shield lies directly along strike of the linear rille. This appears to be good evidence that the linear rille represents the surface manifestation of a very shallow dike, parts of which have penetrated to the surface to produce a small shield volcano.

6. LINEAR RILLES WITH ASSOCIATED DARK-HALO CRATERS. In many cases, relatively narrow linear rilles show evidence of associated dark-halo craters. The Hevelius rilles display craters of internal origin along their strike where the rille is narrowest (less than a few hundred meters). Linear rilles and v-shaped fractures with associated dark halo craters are also very common in floor-fractured craters [10-12]; rilles are usually less than about 1 km in width, and dark halo craters are located along them. In these cases, the co-location of the volcanic crater and the rille suggest that there is an associated dike. The narrowness of the graben suggest that the top of the dike is very close to the surface. In these cases, the craters and associated deposits are interpreted to be of vulcanian origin, where magma has solidified very near the surface in the dike, gas buildup has caused overpressurization, and the resulting pressure was sufficient to fracture the cap and adjacent country rock, forming an explosive volcanic deposit of mixed juvenile and non-juvenile material [12].

On the basis of these examples, it is clear that numerous features on the Moon can be reasonably interpreted in terms of the predictions [1] of the consequences of the penetration of magma-filled cracks (dikes) to the vicinity of the lunar surface. We are presently documenting the characteristics of these and related deposits in more detail in order to develop further criteria to distinguish them from structures and features formed by other processes.

REFERENCES. 1) L. Wilson and J. Head, *LPSC 27, this volume*; 2) L. Srnka *et al., PEPI, 20*, 281, 1979; 3) J. Head and L. Wilson, *PSS, 41*, 719, 1993; 4) J. Mustard and J. Head, *LPSC 26*, 1023, 1995; 5) D. Eppler and G. Heiken, *PLSC 6*, 2571, 1975; 6) M. Golombek, *JGR, 84*, 4657, 1979; 7) L. Mastin and D. Pollard, *JGR, 93*, 13221, 1988; 8) M. Sato, *EOS, 58*, 425, 1977; 9) D. Scott, *NASA SP-330*, 30-7, 1974; C. Weitz and J. Head, *LPSC 26*, 1485, 1995; 10) P. Schultz, *Moon, 15*, 241, 1976; 11) B. Hawke *et al., PLPSC 19*, 255, 1989; 12) J. Head and L. Wilson, *PLPSC 10*, 2861, 1979.

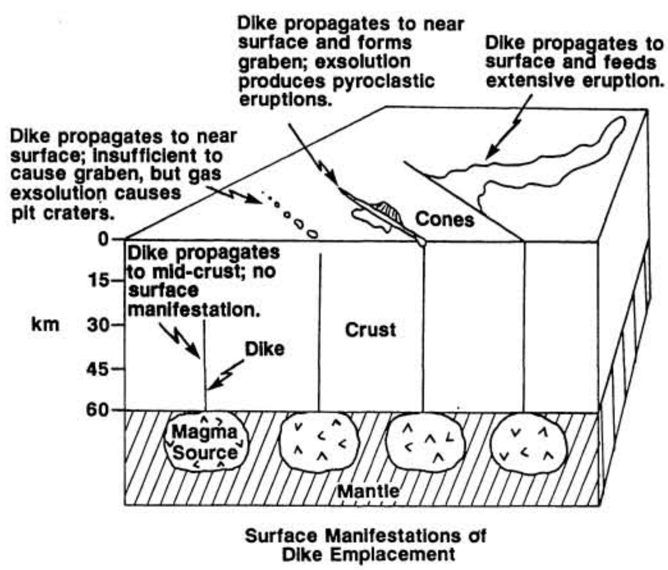

Figure 1. Surface manifestations of dike emplacement.