VOLCANIC FEATURES AND AGE RELATIONSHIPS ASSOCIATED WITH LUNAR GRABEN.

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Introduction and Background

Lunar linear and arcuate rilles (simple graben) form as a result of near-surface deformation [1] and may accompany dyke emplacement within the lunar crust [2]. Volcanic deposits associated with the rille may be evidence of a graben forming simultaneously with the intrusion of a dyke at shallow depth. Most graben occur on the lunar nearside. They are most often associated with maria, crossing from mare to highland terrains or lying within highlands surrounding maria [3].

Graben formation is generally thought to be restricted to the period prior to 3.6 +/- 0.2 Ga [4, 5]. As part of a project to catalogue the geometry of graben [3], their association with volcanic features was investigated. The geology of rocks cut by the graben was determined where possible, and minimum ages were estimated.

Volcanic Features

Photogeologic data gathered from Lunar Orbiter IV images were compared with lunar geologic maps (mainly the U.S.G.S. Atlas of the Moon). However, some difficulties arose because some of the geologic maps pre-date the Lunar Orbiter mission, and were not as accurate as the images. It is apparent that a substantial number of graben have associated volcanic features. The predictions of [6] were borne out by evidence suggesting that at least a third, and possibly significantly more, of the graben sets have volcanic features associated with them.

Observations

Volcanic features associated with the graben include crater chains (some of which, though apparently endogenic, have no associated faults), pyroclastic cones, domes and flows, and dark mantling materials in the form of dark halo craters or more extensive deposits [6]. Many graben have more than one type of associated volcanic feature, for example Rima Ariadaeus has crater chains and a volcanic dome associated with it.

Crater chains associated with graben are the most common volcanic features. They are seen in various forms. They can be within, directly next to, or nearby the rille. They can be placed in any of those locations parallel to the strike of the dyke or at some angle to it. Crater chains cross graben such as Rima Hesiodus and a rille SW of the crater Sheepshanks. In Rima Ariadaeus, crater chains are also seen within the rille, running parallel with the strike of the graben. Some crater chains appear at the end of the graben and are also directly aligned along its strike, for example at Rimae Hippalus I and II. Such features tend to be formed in highland material. The rille Rima Daniell II, is interrupted by a chain of craters along its length, parallel to strike. The crater chains associated with the rilles are nearly all (labelled ‘ch’, ‘C.Ech’or ‘C.Eci’ on the U.S.G.S. geologic maps) interpreted as structurally controlled volcanic vents or collapse depressions. Crater chains labelled as secondary craters (‘Csc’), sometimes appear to be directly associated with rilles, as in the case of Rima Hypatia, which has a crater chain overlain tangentially across its width. This is seen elsewhere and may be interpreted as a volcanic feature associated with the rille. The crater chains are interpreted as collapse craters and some may be explosion craters. This may be due to dykes undergoing degassing and venting; thus the production, collapse and explosive venting of volatiles could easily explain the features [6,7].

Some individual graben have mare domes situated directly next to them: Rima Flammarion and Rima Cauchy II are examples. The domes are labelled ‘lpd’, ‘d’, or ‘Elmd/Eldc’, and are interpreted to be volcanic extrusives similar to terrestrial shield volcanoes. Rima Ariadaeus has an en echelon offset, and at the western end of the offset nearest to Mare Tranquillitatis, a deposit labelled ‘ld’ is found and interpreted as a volcano consisting of a relatively viscous material [8]. Domes associated with graben along strike are interpreted on this basis to be formed by dykes that are very shallow (less than a few tens of m) and may have penetrated the surface in places [6]. Rima Cauchy II has other evidence of near-surface extrusion, such as numerous small shield volcanoes striking parallel to the rille [9]. This is good evidence that the rille represents the surface manifestation of a very shallow dyke.

Rima Parry V has localised volcanic deposits along the length of the rille in the form of volcanic cones [2]. They are interpreted to be of pyroclastic origin [10], and are thought to be the result of degassing and minor eruptions subsequent to magma emplacement at shallow depth. Shallower dykes should produce narrower graben, of which Rimae Parry seem to be examples.

Dark mantling deposits are sometimes seen associated with rilles. They can occur as small deposits i.e. dark halo craters, as patches covering part of a graben, or more extensively covering a large area. The dark mantling deposits could affect the depth measured for a graben, making it appear shallower. It can also affect the age determination, as for the Rimae Littrow, in the Taurus-Littrow region [10, 11, 12]. The narrowness of graben associated with dark-halo craters, such as Rimae Alphonsus, suggests that the top of the dyke is very close to the surface. In those cases, the craters and associated deposits are interpreted to be of vulcanian explosive origin [13].

There are many graben with associated volcanic features, but there are also graben without the volcanic features described. However, many dykes may intrude to sufficiently shallow depths to create graben without producing related volcanic deposits [6, 14]. Graben of this category are difficult to distinguish from those formed by stress fields unrelated to dykes. Rima Sirsalis is an example of a graben without volcanic features, yet it is characterised by a linear magnetic anomaly, interpreted to be due to an underlying magnetised dyke [15]. So, clearly, some graben without obvious volcanic features may still be the result of dyke emplacement.

Apparent Age Relationships

Lunar graben formation is thought to have ceased ~3.6 Ga ago [4]. All graben groups pass through some patches of Imbrian rocks, and the vast majority pass though Upper Imbrian rocks, suggesting that all graben are at least of Imbrian age, and that the majority are of at least Upper Imbrian age. There are also a number of graben which may be at least of Eratosthenian or even Copernican age, as follows. Four graben are clearly seen passing through deposits labelled ‘Em’, that are interpreted to be basalt flows of probable Eratosthenian age; these are Rima De Gasparis II, Rima Callipus, Rima Daniell II and Rimae Littrow. Rimae Menelaus are also apparently of Eratosthenian age; all of these rilles are entirely contained within ‘Etd’ deposits [12], that is volcanic flows and pyroclastics derived in part from the Menelaus rilles. Additionally, Rimae Triesnecker and Rima Hyginus pass through mare material labelled ‘C.Eml’. This is interpreted to be volcanic flows and pyroclastics of Copernican age [17]. The domes that are associated with Rima Cauchy II are dated at Imbrian or Eratosthenian and the volcanic craters also closely associated with the rille are dated as Eratosthenian or Copernican [9]. Thus although Rima Cauchy II passes through Upper Imbrian deposits, it could also be interpreted to be of at least Eratosthenian age by association with younger volcanic features.

Summary

If association with volcanic features is evidence of formation by shallow dyke emplacement, then many graben may be the sites of underlying dykes. This has implications for the bulk composition of the lunar crust and its geothermal history. If the age relations given by current lunar geologic maps are accurate, then graben formation may well have continued well beyond the Upper Imbrian period.

References

[1] Golombek, M.P., JGR, 84, 4657, 1979; [2] Head, J.W. and Wilson, L., PSS, 41, 719,1993; [3] Petrycki, J.A. and Wilson, L., LPSC 30, this volume; [4] Solomon, S.C. and Head, J.W., RGSP, 18, 107,1980; [5] Lucchitta, B. K. and Watkins, J. A., LPSC 9, 3459, 1978; [6] Head, J.W. and Wilson, L., LPSC 27, 519, 1996; [7] Wilson, L. and Head, J.W., LPSC 27, 1445, 1996; [8] Morris, E. C. and Wilhelms, D. E., U.S.G.S. Misc. Investigations, Map I-510, 1967; [9] Wilhelms, D.E., U.S.G.S. Misc. Investigations, Map I-722, 1972; [10] Wilhelms, D.E., The geologic history of the Moon, U.S.G.S. Prof. Paper 1348, 1987; [11] Scott, D. A. and Pohn, H. A., U.S.G.S. Misc. Investigations, Map I-799, 1972; [12] Carr, M. H., U.S.G.S. Misc. Investigations, Map I-489,1966; [13] Head, J.W. and Wilson, L., PLPSC 10, 2861, 1979; [14] Head, J.W., LPSC 28, 541, 1997; [15] Srnka, L.J. et al., PEPI, 20, 281, 1979; [16] Wilhelms, D.E., U.S.G.S. Misc. Investigations, Map I-548, 1968.