Circular structures composed of discontinuous concentric dikes in the Columbia Plateau seemed possible analogs of enigmatic ring structures in the lunar maria (1,2) and were therefore investigated in some detail. The features are relatively small (50-500 m across) and are localized in an exceptionally thick (70-100 m) section of the Roza Member of the Yakima Basalt near Odessa, Washington. A series of two to five concentric ridge segments characterizes most of the structures, the centers of which are high mesas, conical hills, or craterlike depressions. Typically, narrow (1-3 m) outward-dipping dikes with inward-plunging columns border or occur within arcuate ridges of country rock and exhibit well-developed glass selvages on inner and outer surfaces. In some cases dikes are free-standing glass-coated walls separated from neighboring dikes or country rock by moats, suggesting a marked contrast in the susceptibility of adjacent materials to erosion. In several circular structures, few or no dikes at all were identified, and the narrow concentric ridges are normal columnar country rock. Petrographic studies indicate no significant differences in texture or mineralogy between dike rocks and the adjacent Roza basalt, supporting earlier interpretations that the dikes must be autointrusive (3). A gravity survey of three structures by Parks and Banami (4) revealed negative anomalies of 1 mgal.

McKee and Stradling (3) attributed the ring structures to a "sag flow-out" mechanism, whereby upward escape of lava through a chilled crust occurred first at a point source, causing sagging of the crust around that point and consequent formation of peripheral concentric tension cracks, into which molten lava from below was intruded. The discovery of palagonite in the central mounds of three structures, however, suggests a genetic association of this fragile hydrate with the rings and therefore an alternative hypothesis involving phreatic activity.

Palagonite, a friable mixture of hydrate and sideromelane shards, is exhaustively described in the literature of Iceland where it apparently formed when lava interacted with ice or flowed over waterlogged ground, trapping water that reacted explosively with the lava (5). In the Columbia Plateau, large palagonite pillow-lava complexes are common at the bases of flows that entered widespread marginal lakes (6,7,8).

Unlike these well-known occurrences, however, the palagonite associated with the ring structures must have formed after the lava had stagnated and cooled substantially, inasmuch as the concentric dikes intruded undeformed crust on the order of 30 m thick, and no evidence exists for earlier disturbance by contact with water. The field relations evidently require interaction of lava and water at a late stage in the flow's cooling history. I therefore propose that, as a result of the continued disruption of drainage on the plateau caused by the voluminous outpourings of basalt (7), the local ground water table rose, eventually intersecting the confined melt near the base of the Roza in this thick, ponded section. Results of such interaction could have ranged from explosive venting to simple doming or cracking of the crust, with concurrent emplacement of palagonite and tephra in craters and
fractures thus formed. Subsidence of the crust after initial venting could allow intrusion of melt into fractures predominantly concentric to the focus of pressure release, and dikes could thereby have chilled within or adjacent to palagonite as well as country rock. Subsequent catastrophic erosion by the Spokane Flood effectively removed most of the clues to original structure and morphology, scouring out the palagonite and other fragmental material that initially filled the moats and craters, and thus exposing the glass selvages on the marginal surfaces of many dikes. The unique set of circumstances seemingly required for these features may explain their apparent absence in volcanic terranes elsewhere on Earth.

A possible analogy for the genetic mechanism is suggested by the experimental explosion crater "Snowball," formed in alluvium at Suffield Station, Alberta, Canada (9,10,11). Concentric, vertical fractures surrounding the crater were open to the water table and were the loci of mud volcanoes and sand piping. Similar fractures may have formed in the chilled crust of the Roza flow in response to explosive venting, providing conduits for intrusion of molten lava from below that produced the arcuate dike segments of the ring structures.

Although the evidence for phreatic activity precludes direct analogy with ring structures in the lunar maria, a similar mechanism may have operated if lava accumulations were thick enough and stagnant long enough for such rare volatiles as do exist to be concentrated in a diminishing melt volume between chill zones at both top and bottom. Eventual escape of these volatiles—at the juncture of mare and highlands, for example, or over buried topographic highs—could perhaps have resulted in venting through or simple doming and cracking of the crust. Schultz (2) has described numerous domes and dome clusters of various sizes, with and without summit pits; several are associated with moats. Volatiles may have initiated development of some of these small volcanic landforms.

More direct analogs of the Columbia Plateau ring structures and their mechanism of origin may exist on Mars. The evidence for permafrost, water ice, and flowing water in conjunction with vast volcanic plains suggests that palagonite complexes and attendant landforms could well occur. Circular features of uncertain origin have been noted, and detailed analyses of Viking photographs may evoke genetic interpretations similar to that proposed for the unusual Washington structures.

References cited

(2) Schultz, P. H., 1976, Moon morphology: Austin, Univ. of Texas Press, 626 p.
BASALTIC RING STRUCTURES.

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