RADIAL FRACTURE SYSTEMS ON VENUS: CONDITIONS OF FORMATION. Elisabeth A. Parfitt and James W. Head. Department of Geological Sciences, Brown University, Providence, RI 02912.

Magellan images of Venus have revealed the existence of a large number of features which are characterised by systems of radial fractures. A survey of ~75% of the surface of Venus has shown that ~300 such features exist on the planet and that they vary widely in size, appearance and associations (1). Approximately half of the radial fracture systems are associated with large, lobate, lava flows suggesting a volcanic origin for these features (1,2). The basic form of many of the radial fracture systems is like that of terrestrial dike swarms - dikes radiating from a central focus with there being many relatively short fractures and far fewer long fractures. In addition many of the fracture systems radiate from a central caldera-like depression (1). Thus, it seems reasonable to assume that many of the radial fracture systems result from the emplacement of dikes laterally from a central region of magma storage. It is common on the Earth for fractures and graben to form above a growing dike (3,4), the size of the graben which forms being a function of the width of the dike and the depth of its top below the surface (3,4).

On the Earth the size of dikes and their associated fissures and graben varies widely. In places like Hawaii and Iceland typical dike widths are of the order of a few metres or less (5,6), while dike lengths are commonly <20 km but can be up to 100 km (7,8). The narrow width of the dikes and their generally limited lateral extent mean that the graben and fissures associated with their emplacement tend to be small in scale. At the opposite end of the size spectrum, dikes associated with continental flood basalt eruptions and with continental dike swarms like the Mackenzie swarm in northern Canada can be up to 1000 km long (9) and have widths of ≤100 m (10-12). The emplacement of such dikes could cause considerable surface deformation and produce very long and wide surface graben.

The radial fractures seen on Venus vary widely in length but can be as much as 1000 km long, with lengths of hundreds of kilometres being common (1). Many of the radial fractures have a distinct graben form - given the resolution of the images this means that such graben must be in excess of 2 km wide. Thus, by simple comparison with terrestrial dike swarms the scale of the Venus fracture systems is more analogous to continental dike swarms on the Earth than it is to the scale of fractures produced by lateral dike emplacement in places like Hawaii or Iceland.

Theoretical Modelling
Using models of lateral dike emplacement originally developed for terrestrial conditions (2,13,14) the growth of dikes on Venus was simulated for a wide range of starting conditions (2). Two specific styles of dike emplacement were simulated, these are referred to here as: a) Unbuffered emplacement: Magma chambers such as that at Kilauea volcano in Hawaii commonly inflate prior to dike emplacement and deflate while emplacement occurs, the deflation being accompanied by a decline in summit pressure (7). Inflation prior to dike emplacement tends to occur slowly (over periods of months or years), gradually increasing the pressure within the magma chamber to a point where dike emplacement can begin (7,15). This pressure can then be relieved by dike emplacement in a matter of hours. This pattern of slow inflation and rapid deflation occurs because magma is supplied to the Kilauea magma chamber at an essentially constant but low rate so that the pressure within the chamber can only rise slowly (2). Once the pressure within the chamber reaches the critical point where rock fracturing and dike emplacement can begin, growth of the dike proceeds at a rapid rate. The movement of magma into the growing dike can therefore remove magma from the chamber at a rate which is much greater than the rate of supply of magma to the chamber from the mantle. Thus, magma is removed from the chamber much more rapidly than it can be replaced and, as a result, the chamber pressure falls (2). Thus dike emplacement occurs in conditions of declining driving pressure which we refer to here as emplacement under 'unbuffered' conditions. Any magma chamber which is supplied with fresh magma relatively slowly will experience unbuffered dike emplacement conditions.

b) Buffered emplacement: By contrast dike emplacement under 'buffered' conditions occurs
RADIAL FRACTURE SYSTEMS: Parfitt, E.A. and Head, J.W.

when magma can be supplied to the magma chamber at a rate which is comparable to the rate at which magma moves out of the chamber and into the growing dike. Because the rates of inflow into the chamber and rate of outflow into the growing dike are now approximately equal the pressure within the chamber is held essentially constant throughout the emplacement of a dike (2).

Results
These two different conditions under which dikes can be emplaced lead to the generation of very different dikes. In unbuffered conditions the declining pressure during emplacement limits the size to which any dike can grow. Although for very big chambers (equivalent radii of ≤20 km) the dikes can theoretically have lengths in excess of 1000 km, the narrow widths of the dikes (≤ 3.6 m) mean that the magma within the dikes is likely to cool and solidify long before this length is achieved (2,16,17). Actual dike lengths for even the largest chambers are likely to be <<100 km. None of the model dikes grow sufficiently to reach the surface, instead they reach a stable height while their tops are still well below the surface, this combined with the narrow widths of the dikes means that the dikes would not be expected to produce much surface deformation and are certainly unlikely to produce graben large enough to be detectable at Magellan resolution.

By contrast dike growth in buffered conditions can produce dikes with widths of ≤75 m and lengths of >1000 km. Dikes emplaced from chambers at relatively shallow depths grow to reach the surface. Eruptions from such dikes would be expected to produce large volume lava flows at high rates due to the high driving pressure and the large dike widths. Typical lengths for such fissures are a few 10's of kilometres. For somewhat greater depths to the centre the dikes reach a stable vertical height without intersecting the surface and can grow to lengths in excess of 1000 km. The great widths of these dikes combined with the relative close approach of the dike top to the surface means that although these dikes do not produce eruptive fissures they should produce sizable graben at the surface, large enough to be visible in the Magellan images (2).

Conclusions
On the basis of both basic comparison of terrestrial and venusian fracture sizes and the model results it seems that the radial fracture systems on Venus are likely to have been produced in constant driving pressure conditions. The model results suggest that dikes emplaced in these conditions can take on two basic forms - either growing to reach the surface producing large volume lava flows from fissures ≤100 km long, or producing very long fractures and graben at the surface which are not associated with any lava flows. This pattern is consistent with observations made using the Magellan images (1).

References