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RADIAL RIFT AND BLOCK TECTONICS AROUND THE THARSIS BULGE: INTRODUCTIONAL POSTULATION. J. Raitala, JPL, CALTECH, Pasadena, CA 91109 (on leave from Department of Astronomy, University of Oulu, Oulu, Finland).

The crest of the Tharsis bulge displays tensional tectonics especially within the Noctis Labyrinthus area (1). Other adjoining tensional tectonic structures associated with the bulge are the numerous radial fossae grabens, Vallis Marineris valley and other valleys and surface discontinuities. These structures are much more complex than the bulge crest although coupled together.

The origin of the radial structure system can evidently be traced back to the Tharsis bulge uplift. The classical concept of triple junctions could be involved although the radial pattern consists rather of several multiple junctions. The Vallis Marineris canyon could easily be interpreted as resembling a rift which forms an aulacogen. Other fossae graben zones clearly resemble linear rift zones extending outwards from the Tharsis bulge.

Although the Vallis Marineris canyon and radial fossae grabens have been extensively studied, their origin and formation mechanism is still the subject of numerous questions. Possible rift formation is only one point of view and does not explain the rifting mechanism and the radial pattern of these structures around the Tharsis bulge. Both active and passive rifting must be taken into account (2). An active mechanism can be easily accepted in the case of the Tharsis bulge itself, where doming is associated with the mantle plume impinging on the lithosphere and causing uplift and volcanic extrusions. The active volcanic doming and volcanic complex building is coupled with the mantle and lower lithosphere swelling, which in the case of the Tharsis bulge was regional around the deep source of magma generation.

The model of active doming and volcano constructing implies a mantle plume impinging on the base of the lithosphere, lithosphere thinning, the uplift of lithosphere and crust (3) and opening of the extrusion plumbing channels. Very large volumes of hot mantle material are required to thin the lithosphere by heat transfer, magma migration and pressure release melting (3). According to the active mechanism the building of a volcanic complex like the Tharsis bulge is caused by the rising huge mantle plume and adjoining extrusions which tap the generated magma.

The surrounding fossae and valley structures are caused by more passive crustal rifting due to tensional failure of the surface layers. The main rising mantle plume activated and regenerated a failure patterns radial to the centre of activity (4). These radial zones of weaknes are then most easily utilized by the rising mantle plume. Deep zones of weakness regulate the penetration and distribution of hot mantle rock into upper levels while, contrarily, the effective impingement of the hot mantle plume into the lithosphere opens up new weakness zones. Tensional stresses from below the lithosphere make it fail. If the mantle uplift and doming is strong enough to break the lithosphere and crust but does not raise volcanic extrusions some kind of rift tectonics is acquired.

The branches of the main Tharsis mantle plume spread radially aroud the central volcanic area causing 1) radial fault opening, 2) adjoining minor doming and rifting along these fault zones and 3) minor block movements or stress transmissions through the blocks. The lithosphere is cold and dense in respect to the hot mantle rocks of the asthenosphere below and the decreased volcanic activity at the plume branches may instead occur in the form of intrusions than extrusions. The heated and intruded lithosphere is then slightly uplifted and domed which causes tensional opening of the initial crustal failure zone.

There are several main fossae/valley graben zones through the Tharsis bulge area. The SW-NE fossae graben zone evidently controlled the location of the major plumbing system and the formation of major Tharsis volcanoes: Arsia, Pavonis and Ascraeus Mons. There are also some smaller volcanoes at the northeastern Tharsis slope of this zone. Sirenum and Memnonia Fossae penetrate far into the terra highland southwest of the Tharsis bulge while the Tempe and Mariotis Fossae and Kasei Vallis valley system cut large terra highland islands which are surrounded by lava-flooded plains.

The large terra highland block southeast of the Tharsis bulge is bounded by Claritas/Thaumasia Fossae, Noctis Labyrinthus and Valles Marineris. Noctis Labyrinthus is situated at the highest crest of the Tharsis main bulge, the Syria Planum Swell, where the pattern of tensional fractures were created due to the major updoming (1). The Claritas and Thaumasia Fossae are associated with crustal doming as are also the extensional structures of Valles Marineris. The deep excavation of Valles Marineris is not caused solely by the doming although the erosion has evidently been strengthened by block margin tectonics.

There are several Thaumasia Fossae grabens which tend to cut the Solis-Sinai block concentrically to the Tharsis bulge. They do not extend as far as the Vallis Marineris border, however, but an interesting structural phenomenon is the abrupt steep fault-like extension of this zone nortward from the Vallis Marineris and perpendicular to it. Several major floods seem to have their origin within the intersection area of this north-south fault concentric to the Tharsis area north of Valles Marineris.

At the another northwestern side of the Tharsis bulge there is the Olympus Mons volcano and its large lava-plain aureole and adjoining grabens. The Olympus Mons area is beside the Tharsis bulge and can be considered to form a volcanic dome of its own, the Olympus Swell. This swell area has extruded a considerable amount of volcanic material and been active over a long period of time. It is possible to propose that the Syria Planum Swell, Pavonis Mons and Olympus Swell form a NW-SE structural zone which is perpendicular to the NE-SW zone of the main Tharsis volcanoes and adjoining NE-SW fossae grabens. This NW-SE zone is, however, not so uniform and clear and the active crustal faulting associated with it branches into two fossae and valley zones cutting a southeastward stretching crustal block. The plumbing system, and of course the mantle plume connected with the Tharsis bulge has been effective and uniform leaving the Olympus Swell to be of minor importance.

The Alba Patera area has also slightly domed and faulted, as have the Sirenum/Memnonia and Claritas/Thaumasia Fossae. Alba and Olympus Swells have been "active" in a similar manner to the main Tharsis bulge itself. The Alba Swell was associated with old crustal doming and major volcanic extrusions. The fossae graben zones radial to the Tharsis bulge were relatively passive in rifting. There is no well defined relationship with major Tharsis-like volcano-building although the Alba Patera area has a slightly elevated topography. A strong case can be made for claiming that the Alba Patera fossae can be seen to have been caused by a branch plume associated with the early stage of the major Tharsis plume development.

The Sirenum and Memnonia fossae are relatively passive rift branches. Their rifting and faulting can be considered to have been caused by the Tharsis plume extension along a major previous fault zone direction also below the nearby highland areas. The horizontal extension was relatively small. There was no important volcanic activity along this southwestern branch of the Tharsis plume except within the Tharsis area itself near the Arsia Mons volcano (5). The southwestern part of the Tharsis area seems to have been exceptionally active and the Arsia Mons is considered to be the Mars' most remarkable volcano. This enormous activity may be partly explained by the existence of the proposed thick highland lithosphere which dammed off the main impinging plume to within near the centre of the Tharsis area.

The location and orientation (NE-SW direction) of Sirenum and Memnonia fossae indicate that they are closely associated with Tharsis development. It seems likely that the fossae graben formation was the result of stresses developed during the impinging of the plume into the lithosphere. Tectonics of these fossae are related to the crustal block formation as a consequence of the convecting Martian mantle.

The Kasei Vallis' erosional channel just north of Lunae Planum is an example of a valley system radial to the Tharsis bulge. It has been plowed open and wide by surface flows, which have destroyed most of the original radial structures. There are only some fragmental graben branches and patterns to be seen within the adjoining islands and highlands. Kasei Vallis lies along the northern boundary of the Lunae Planum block forming a broad zone between it and the Tempe Terra. The Kasei Vallis fossae has no such well-developed graben pattern as other fossae either because the surface flow erosion destroyed old grabens or the crustal doming was not so effective here and this tectonic zone has such a prominent appearance mainly due to the erosion which effectively opened the initially slight surface faults. The earliest deformation in the valley dates, however, from the tectonic pre-flow era and especially the northern valley boundary is not shaped only by flow. The southern boundary was obviously a linear zone of weakness. There is a controversy as to wether the Kasei Vallis was tectonically active or passive. Some present tectonic structures could perhaps be expained as having been caused by mass removals, but this was surely an effect of minor importance and possibly only re-activated already existing faulf structures, thus giving raise to some well-developed graben patterns beside some most prominent erosional channels. The location of Kasei Vallis in the radial peripheral zone of the Tharsis area suggests quite a passive response of lithosphere movements and surface deformation to the impinging mantle plume is possible. The Kasei Vallis is, however, a well-defined crustal suture between the Lunae Planum ridged terra and Tempe Terra fossae graben highland and could be regarded as a boundary between these highland blocks.

The Tempe Terra is cut by two sets of fossae: Tempe Fossae which form a northeastern extension of the Sirenum Fossae - the main Tharsis volcanic zone, and Mareotis Fossae, which forms part of the northwestern boundary of the Tempe Terra area. Tempe Fossae extends into the cratered plains of Vastitas Borealis. The main doming and rifting of the northeastern periphereal Tharsis plume seems to have occurred within Tempe Terra where lithospheric thinning may be regarded as a cause of horizontal tensional stresses and graben formation. Tempe Terra fossae can be characterized by Tempe Swell formation due to the mantle plume penetration into the lithosphere.

The prominent occurrence of a NE-SW zone may, of course, depend on a pre-existing zone of weakness (6), but a rift may be also self-propagating, which is caused by tensional forces within a rift, extending the rift and causing its propagation outwards at both ends (3). This propagation is further forced by the swells caused by the mantle plume which is guided by the major zones of lithosphere weakness.

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The location of major volcanoes was controlled by tectonic zones but the volcanism then controlled the occurrence and opening of the radial, rift-like fossae and valley structures.