“Trigonometric relationships between the Mars VM Anomalies and the Argyre Impact”

By Peter K Ness and Greg M Orme

An increasing number of planets and moons in our solar system display clear evidence of major faulting and volcanic activity associated with the poles. Rift valleys and volcanism or degassing is common in association with the South Pole with a basin or crater sitting at or adjacent to one or both of the poles – but particularly near southern polar caps. The North Poles seem to attract volcanoes and craters while South Poles attract rift valleys - implying that South Polar regions are affected by some directional force, that does not necessarily affect the North Polar areas. This paper suggests that it may be possible to use these relationships to help unwind complex geological history of a planet or a moon where other methods fail.

Recently discovered hydrothermal activity on Enceladus is associated with faulting and a hot spot near the South Pole[1] (Figure 1), with one prominent rift on Enceladus’ South Pole[2] resembling the shape of cycloids on Europa[3], which also has faulting at its South Pole. Io is also geologically active with numerous volcanoes dotting the landscape and at both poles, but notably the largest resides over the North Pole[4] (Figure 2). Ganymede has a rift valley adjacent to its South Pole (Figure 3) while Triton also has structural controls and faulting adjacent to its

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1 Hurford, Terry A.; Greenberg, R.; Hoppa, G. V., 2006. South Polar Cycloidal Rift on Enceladus, American Astronomical Society. 2006DPS....38.1804H. September 2006. http://adsabs.harvard.edu/abs/2006DPS....38.1804H

2 http://www.dlr.de/saturn/en/desktopdefault.aspx/tabid-208/440_read-2881/

3 Jeannie Riley[a], Richard Greenberg[a], and Alyssa Sarid[a] . 2006. Europa's South Pole Region: A sequential reconstruction of surface modification processes. Earth and Planetary Science Letters Volume 248, Issues 3-4 , 30 August 2006, Pages 808-821 Lunar and Planetary Laboratory, University of Arizona, 1629 East University Blvd., Tucson, AZ 85721-0092, USA. Received 21 March 2006; revised 15 June 2006; accepted 20 June 2006. Editor: S. King. http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6V61-4KHC3CW-3&_user=10&_coverDate=08%2F30%2F2006&_rdoc=1&_fmt=&_orig=search&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=812e38b40c5673f3377f087e9d68251f

4 http://www.neatorama.com/2007/03/13/simultaneous-volcanic-eruptions-on-jupiters-moon/

South Pole[5] (Figure 4,5). The 120 and 130-degree intersections are extremely common. On earth we associate these features with triple points – the points where rift valleys separate preferentially.

Dione has a large crater near its South Pole[6], that is offset from the pole by around 15 degrees (Figure 6), with faulting adjacent to the South Polar Region – as does Iapetus[7]. Large-scale faulting also occurs near Dione's North Pole, whereas Iapetus has a large mountain-like ridge[8] possibly of volcanic origin.

As with Dione and Iapetus, our own moon has a basin adjacent to its South Pole[9] (Figure 7). Earth has rift valleys either side of its South Pole[10] (Figure 8) – again with the same angular relationships. Earth also has a basin at its North Pole, as does Mars. There are major strike-slip faults and degassing at Mars South Pole with an adjacent glacial altered rift-like valley, Chasma Australe – which again is associated with 120 degree inter-angle faults. As with Io, Earth has volcanism at its South Pole. Thus, it would not be unexpected to find similar structures at the South Poles of Venus, Titan, or even planets and moons in other solar systems.

As shown, a large number of moons tend to have craters and faulting at or adjacent to the Polar Regions. This makes sense because planetary objects would tend to be more stable if large craters and mountain chains were located in polar regions.

It is highly unlikely that the relationships just discussed are coincidental. Once a planetary body gains sufficient size its gravity may drag it into a circular shape with flattening in Polar Regions.

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5 http://www.solarviews.com/eng/triton.htm

6 Wagner A., Nuekum G., Denk T., Giese B., Roatsch T. and the Cassini ISS Team. Geology and Stratigraphy of Saturn's satellite Dione observed by the Cassini ISS camera. http://www.planetary.brown.edu/m42/m42_68.pdf

7 http://sci.esa.int/science-e/www/object/index.cfm?fobjectid=36362

8 http://saturn.jpl.nasa.gov/multimedia/images/image-details.cfm?imageID=1270

9 Paul D. Spudis. 1996. Ice on the Bone Dry Moon Lunar and Planetary Institute, Houston, TX. December 1996. http://www.psrd.hawaii.edu/Dec96/IceonMoon.html

10 http://veimages.gsfc.nasa.gov/1492/dtam_south_pole_md.jpg
http://shl.stanford.edu:3455/SouthPole/554

This would naturally lead to faulting and would help remove the wobble from the axial spin Faulting may be exacerbated by craters, or by the weight of icecaps in polar regions, leading to crustal weaknesses and therefore mantle plumes or hotspots to form and rifts to develop adjacent to, or below the poles.

A mountain chain the size of the Himalayas on earth or Tharsis Rise on Mars has little impact on a planet. The affect is like that of a pimple on a basketball. It has negligible impact on the planets spin. However, once craters attain a certain size in relation to the size of the planetary object (e.g. say >1/5 the diameter of the object) a discernable effect may well exist. In order, to remove these discrepancies that affect the stability of the object's spin, large masses over time may well tend to migrate to equators or poles and large craters may tend to do the same.

Mars, like earth has a large basin at its North Pole and a large southern polar icecap cut by faults and surrounded by rift-like valleys. However, Mars also has an anomaly at its equator and like Iapetus it is elongated in the equatorial direction. Iapetus has a fault that covers roughly two-thirds its diameter, which has formed a ridge at the equator. These types of features may not be such a coincidence either. The Mars anomaly is also a fault – but instead of a mountain we have the Valles Marineris (VM) trench, which lies on the Tharsis Rise stretching several thousand kilometers in length.

A large impact clearly caused the Iapetus fault to develop, but with Mars the reason is not so obvious. Looking at a map of Mars today one observes that the Valles Marineris (VM) suddenly terminates at the Three Montes Volcanoes (Arsia Mons, Pavonis Mons, and Acreaus Mons). A huge volume of water seems to have flowed down the VM but there seems to be little evidence of that water today.

In addition, the three volcanoes that comprise the Tharsis Montes seem to have almost perfect mirror image symmetry. In fact, if one links all the major VM faults and all the major volcanoes adjacent to Tharsis Rise one ends up with a series of interlinked triangles all with similar shape and inter-angles (Figure 11). The corners of each triangle tend to form at triple points with interconnecting faults meeting at 120-degree angles. On Mars 120 and 130 degree angles – as on earth are quite common, typically associated with passive margins. A passive margin is a region where plates are moving apart and drop down structures, such as rift valleys form. This does not necessarily imply a mantle plume only than plates have moved apart and the crust has settled.

Analysis of the VM anomalies

All the major volcanoes and structures in the VM area of Tharsis seem to have a common link. This analysis explores that link. The Three Montes all lie along a large N-S trending slip-strike fault, analogous to the San Andreas Fault on earth that has 120-degree intersections with both the VM and the Solis Rift A. This paper refers to this fault as the Tharsis Fault (Figure 12). The analysis shows that objects associated with the displaced triangles shown on the western side of the Tharsis Fault are displaced continuities of the larger triangles on the VM side of the Tharsis Fault. These relationships represent the VM- anomalies.

One of the major features of the VM faulting is that the angles between faults, volcanoes and rift valleys are very consistent. However, if one compares to the rifting and fault angles either at in Tharsis Rise north of the VM there is no obvious relationship. Thus, we can conclude that major volcanoes align exactly with triple points, faults and/or rift valleys because they are linked by the major VM fault-rift relationships.

A detailed analysis of angular relationships between the major faults and volcanoes in the Tharsis region of Mars indicates that the area on the West of the Three Montes may have been displaced north by some considerable distance (Figure 11). The authors are only looking at large-scale regional trends not at local geological features. It is accepted that local geology will sometimes conflict with this regional interpretation due to the large number of overprints in the region (particularly faulting, cratering, but also erosion).

North of the VM we see angular inconsistencies with faults and rifts of the VM-related structures with the Tempe Terra and Lunae Planum, Xanthe areas. These faults are incompatible in trend and inter angles with the other VM-related faults. However, the rifts of Lunae Planum and Xanthe area form at 90 degrees to the VM, so they are transform rift faults, which are vaguely reminiscent of the shapes of the structures we see on Enceladus. The faults on the Chryse Planitia have inter-angles of 120 degrees. Therefore, the terrain north of the VM is older, but the rifts are younger, than the VM.

Figure 13 shows the position of an assumed old pole (Pole A) over Solis Planum, with transform faults dissecting the VM valley. The intersection of the triangles of the Solis A Rift with the VM valley through the central Montes volcano (Pavonis Mons) is 120 degrees, which is not coincidental. Both valleys represent passive margin rift valley spreading edges on either side of an old polar cap.

The position Solis Planum Polar cap adjacent to the VM is interpreted based on a number of criteria:

- Elliptical craters[11]
- The Solis Planum area is flattened either due to the removal of a large weight or due to the sinking of the area as ice has drained down the VM valley.
- The size of the flattened area corresponds to the size of the current south polar icecap.
- The structures on the upper reaches of the VM are arguably glacial in nature.
- Water that flowed down the VM valley is sourced from the west Solis Planum region, the headwaters of the entire VM system. In fact, this is the only location where an icecap could feed water down into the VM. Any other location would mean that water would have to flow uphill.
- A pole at this location would have allowed VM to be fed with water from the pole for tens of millions of years, and it would also allow recycling via a continually replenishing icecap.
- "A study of Martian impact craters with fluidized ejecta morphologies has revealed that the area south of the Valles Marineris canyon system may contain a large near-surface volatile reservoir."[12]
- An ice-rich layer lies closer to the surface (<300 to 500 m) in the Solis Planum region than elsewhere in the equatorial region (~520-572 m) so underlying liquid reservoir, has been present since the region formed in the Hesperian[13].

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[11] K. F. Sprenke and L. L. Baker "POLAR WANDERING ON MARS?" Lunar and Planetary Science XXXI 1930.pdf
http://www.lpi.usra.edu/meetings/lpsc2000/pdf/1930.pdf

[12] N. G. Barlow, C. B. Perez (U. Central Fl.), J. Koroshetz (U. Fl.) "[39.06] A Volatile-Rich Reservoir South of Valles Marineris, Mars" 31st Annual Meeting of the DPS, October 1999 Session 39. Mars Surface: Evidence of Change available online at http://www.aas.org/publications/baas/v31n4/dps99/40.htm

[13] N. G. Barlow, C. B. Perez (U. Central Fl.), J. Koroshetz (U. Fl.) "[39.06] A Volatile-Rich Reservoir South of Valles Marineris, Mars" 31st Annual Meeting of the DPS, October 1999 Session 39. Mars Surface: Evidence of Change available online at

If one draws a line through the base of the VM system it intersects the central of the three Tharsis Montes volcanoes. Note that the separation of the Tharsis Montes volcanoes around Pavonis Mons is a mirror image. The distance between the most northerly Tharsis Monte and this volcano, is offset by almost the exact same distance as Olympus Mons is from the extension of the VM line. This is attributed to movement of the original triple point from which both valleys spread. Thus, the Three Montes represent the current positions of the original triple point intersection of the VM and the Solis Rift A (as shown in Figure 11). The VM canyons are flanked by gravity highs but the canyon system lacks a negative anomaly, broader than the rift, that is associated with upwelling of hot mantle material beneath active rifts on Earth[14].

Given the inter-angular relationships and widths of both rift valleys we can safely assume both the VM and Solis Planum Rift A formed at the same time in response to the weight of the pole at Solis Planum. Hence, both rifts were active for the same length of time since they rifted roughly the same distance. By default, the Noctis Labyrinthus valleys north of Syria Planum and east along the VM margin must therefore be glacial valleys - and Solis Planum may well contain buried ice (which may still be feeding the VM).

Implications of the Argyre Impact

Based on a logical and continuous polar wander path and the associations we see on other planetary objects, the Solis Planum Pole A was most likely the South Pole prior to the Argyre Impact. While the Martian pole was at Solis Planum and while the valleys were both rifting, Mars had an active water cycle for some considerable time. This was sufficient to feed two northerly seas, denoted for the purpose of this paper as the Tharsis Sea (to the NE) and the Amazon Sea (to the NW). Therefore, it follows that Mars must have had a relatively thick atmosphere. The water cycle on a Pre-Argyre Mars revolved between the Solis Planum icecap, the Tharsis sea (which lay somewhere between 10N to 35S latitude), that was being fed by the VM and the westerly Amazon sea (which lay on the equator to the NW).

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http://www.aas.org/publications/baas/v31n4/dps99/40.htm

[14] David E. Smith et al "The Gravity Field of Mars: Results from Mars Global Surveyor" available online at
http://ltpwww.gsfc.nasa.gov/tharsis/smith.mgs.grav.pdf

While the VM and Solis Rift valleys were still forming, the Argyre meteorite collided with Mars at a 20 degrees north from the southern pole (Figure 14). The meteorite impacted with a reasonably low angle trajectory. The size of the impact was roughly four times the size of the crater remaining today, making it arguably much larger than the Hellas impact. Therefore, atmosphere must have been lost into space as a result of the impact. Given time Mars would have eventually recovered the majority of any expelled atmosphere because it would have circled the sun in the same orbital plane as Mars.

The term "snap-freeze" is to describe the geologically rapid change from a normal hydrological cycle “wet Mars” to a relatively “dry Mars” with a thinning atmosphere. The dust from an Argyre sized impact would block out the sunlight for anything up to 10 years or more. With little light getting to the surface, the planet surface would cool down rapidly regardless of any heat generated below the surface or directly above or near the crater.

After the Argyre impact hit dust filled the atmosphere and the Solis Planum icecap was itself covered by up to 10m to 30m of dust - so even if the polar ice had melted it would have simply refroze in place, although there was obviously a lot of leakage down the VM. Once the Solis Planum icecap was covered with thick layers of dust then the icecap was largely removed from the water cycle, so any ice or snowfall would lead to a naturally thinning atmosphere over time. There was insufficient atmosphere maintain a large icecap and an active hydrological cycle, although the icecap probably continued to leak down the VM.

The Tharsis Sea was probably covered with pack ice like see around Antarctica prior to the Argyre impact. The Martian dust is so fine that it will actually float on water. There were few waves on Mars (as no large moon), so nothing other than earthquake activity to break up the ice. Thus we can picture the sea gradually freezing over. If the seas existed, they must now surely be covered in anything up to 10m or more of fine silt layers.

The shock wave from the Argyre impact forced Solis Planum to move the north and west (Figure 15) and rotate in a clockwise motion. The sudden compression snapped the VM on the west of the Solis Planum initiating the Tharsis Fault. As the Tharsis Fault moved north, other rifts opened up behind. This compression may have caused by lithospheric buckling[15]. This

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[15] David E. Smith “The Global Topography of Mars and Implications for Surface Evolution” www.sciencemag.org SCIENCE VOL 284 28 MAY 1999 available online at http://www.ciw.edu/library/solomon/sci_284_1495.pdf

further forced the Tharsis Fault northwards and the VM on the western side of the fault suffered compression between two pairs of rifting valleys. Eventually the strike slip faulting occurred on the Rift A and other rift margin faults (Rift B, C) to the South of Solis Planum, truncating and dislocating the southern extension of the Tharsis Fault west.

On the eastern side of the Tharsis Fault the impact of the Argyre impact may have pushed the VM closed with the rebound then opening the base of the VM as a deep rip or tear in the crust. The compression may also have caused the transform faults on the northern side of the VM to absorb much of the movement. Hence, there should be thrust faults in the Solis and Syria Planum southern cliffs of the VM. This is consistent with the following reference:

"The strain from Syria Planum was transferred along proto-Valles Marineris forming a sinistral transtensional zone which provided tectonic control for later valles formation. At the east end of Valles Marineris, the Coprates Rise is a lithospheric buckle with a thrust fault along the eastern edge. The southern edge of the Thaumasia Highlands as the surface exposure of a thrust fault. The compressional structures of the Coprates Rise appear to extend into the Thaumasia Highlands. The thrust faults likely cut deep into the crust and may represent the décollment for later wrinkle ridge faulting in Sinai and Solis Planum. In this hypothesis, Claritas Fossae represents a dextral transpressional zone and acts as a boundary between the eastern and western halves of the south-Tharsis ridge belt identified by Schultz and Tanaka (1994, JGR 99, p. 8371)[16]".

The N-W rotation of Solis Planum due to the displacement of the Argyre Fault and the opening of the Argyre impact caused the strike-slip transform faults in the VM (initiated by the Argyre impact), to the north of the VM to begin to rift apart (Figure 16). So, even though the terrain of Lunae Planum is probably older than the VM, the rifting is younger.

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16 WEBB, Benjamin M. "NOACHIAN TECTONICS OF SYRIA PLANUM AND THE THAUMASIA PLATEAU" Paper No. 132-0 [2001] available online at http://gsa.confex.com/gsa/2001AM/finalprogram/abstract_28019.htm

Pole B and the Tharsis Montes

The polar cap probably migrated from Solis Planum – back to Argyre, where it remained for some time. Lakes then formed over the pole. Partly filling the Argyre basin with water derived from this polar cap melt back is consistent with Hesperian channels cutting far down into the basin[17]."

The pole then migrated north to Pole B, where the weight forced the crust to fracture. The basement still retains the pre-rift cratering which means that the rifting related to Pole B is due to crustal settling (Figure 17). All the large craters to the south-west of Solis Planum are cut by horst and graben rift faults which trend NW and some are also cut by smaller transform faults. This makes them older than the rift faults and means that crater dating must give a minimum age of the basement rather than the age of the structures – which are considerably younger.

On Mars, many of the craters are deeper than any sediment deposited. Most large craters will therefore not be fully hidden below a sediment blanket unless a significant thickness of material is deposited (at least hundreds of meters). Crater dating in the base of many rifts on Mars must therefore give the same or slightly younger age as compared to the surrounding bedrock, rather than an accurate age. However, where a discernable difference occurs a reasonable estimate of the period a rift was active should be possible to calculate.

This crustal settling due to the weight of the icecap was sufficient to remobilize the southern extension of the Tharsis Fault and possibly initiate rift valleys further to the west (Figure 18-19).

The movement of the Tharsis Fault and other sub-parallel faults to the north led to the original triple points being displaced slightly. Thus, all the current volcanoes are younger than Pole B.

All the volcanoes along or to the west of the Tharsis Fault formed after the majority of rifts to the west side of Tharsis Fault (Figure 13-17) had already opened. The volcanoes all occurred some considerable time after the Argyre impact - probably as much as 20 to 40ma or even longer after the impact – and after the pole had moved from Argyre north to Pole B.

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[17] H. Hiesinger, J.W. Head III
"GEOLOGY OF THE ARGYRE BASIN, MARS: NEW INSIGHTS FROM MOLA AND MOC"
Lunar and Planetary Science XXXII (2001) 1799.pdf
http://www.lpi.usra.edu/meetings/lpsc2001/pdf/1799.pdf

However, the direction and angle of the Argyre impact implies that a slab of crust was probably forced below Solis Planum, and this may have eventually lead to the subsequent volcanism of Syria Planum. The heat may have pumped water down the VM after the Argyre impact. The arrow in Figure 20 shows the direction the falling slab (and hence hotspots) moved. The falling Argyre slab may have broken into several large fragments with the largest part ending up below and to the west of Olympus Mons. Thus, the heat of the hot spot west of the central and south of the most southern Montes may be responsible for sublimation of Pole B.

The most southerly Tharsis Montes (Arsia Mons) was apparently unaffected by the ice sheet, so it occurred after any rifting (crustal settling) or faulting related to Pole B – but volcanism occurred at the earlier triple point (further south) before it was displaced northward (as with the most northern Monte). This proves the Tharsis Fault was displaced north. Any original volcanism and flood basalts may have been partly covered by glaciation related to Pole B[18]. The subsequent heat from this initial volcanism may have caused sublimation and outwash fans to form from sudden polar cap melting (Figure 19) of Pole B, with subsequent flooding responsible for the outwash fans.

The Tharsis Montes formed as magma rose up each intersection of the displaced triple points (inferred from the natural geological order of events). Prior to this, hotspots formed west of Olympus Mons and Alba Patera in response the opening of failed Tempe Rift faults. Figure 20 shows the actual positions of the volcanoes were initially some 100km west of the current locations. A hot spot in the Syria Planum[19] region therefore the initial hot spot related to falling slab from the initial Aryre impact (Figure 22), and the later Olympic Mons and Alba Patera from heat generated from parts of the broken slab as it moved west – some considerable time later.

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18 James W. Head and David R. Marchant "MOUNTAIN GLACIERS ON MARS?: WESTERN ARSIA MONS FAN-SHAPED DEPOSIT SMOOTH FACIES AS ROCK GLACIERS:" Microsymposium 36, MS103, 2002 http://www.planetary.brown.edu/planetary/documents/Micro_36/Abstracts/103_Head_Marchant

19 Evelyn D. Scott "SUB-LITHOSPHERIC 'SUBDUCTION' ON MARS: CONVECTIVE REMOVAL OF A LITHOSPHERIC ROOT. III: SYRIA PLANUM REGION" Lunar and Planetary Science XXXI 1331.pdf http://www.lpi.usra.edu/meetings/lpsc2000/pdf/1331.pdf

While Alba Patera, Olympus Mons and Tholus Mons were still active, some major event occurred that pushed the two hotspots to the east from their present position (Figure 20, 21). This caused a considerable amount of heat to be released and both volcanoes again formed major peaks at their current triple-point positions. The other two Montes volcanoes were not moved east, but may have been displaced slightly north – then all three volcanoes formed at their current location. This follows the natural order of events shown above.

As clearly shown, all the current positions of the VM volcanoes formed after all faulting and rifting associated with the VM anomalies had ceased – with the possibly exception of the Tempe Valley rift faulting. In each case, the magma rose up the 'displaced' triple points. There is every reason to believe that the volcanoes may well still be active today – and if so that implies that the slabs may still be generating some internal heat in Mars (so Mars may not be as dead as believed in the past).

Younger Geology Associations

The Solis Planum is considered to be a younger area, where there has not been as much time for infilling, and the larger-crater population is more completely preserved[20]. The dark area we see in the wake of the Solis Planum polar ice cap (i.e. on the Argyre side) most likely comprises small dunes of iron-rich nodules the same as those near Opportunity. The nodules may have grown insitu as pyrite nodules in the dust layers deposited after the Argyre impact, or in layers left behind in the trailing edge of the polar cap with soils enriched in sulfur. Erosion of the layers would lead to the sulfur being removed and the nodules being converted to maghemite. The same phenomenon of conversion of pyrite to maghemite during erosion of siltstone layers is seen in the Hamersley Ranges near Mount Tom Price in north-west Western Australia in the Roy Hill and Mt McRae Shale Formations[21].

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[20] William K. Hartmann "MARTIAN CRATER POPULATIONS AND OBLITERATION RATES: FIRST RESULTS FROM MARS GLOBAL SURVEYOR" 1998, LUNAR AND PLANETARY SCIENCE CONFERENCE 29 (HOUSTON) available online at http://www.psi.edu/projects/mgs/lpsc.html

[21] Authors first hand experience.

Summary of the Main Angular Associations:

The triangles (Figure 1) show that the angular offset of the rift valleys which separate the bottom and central Tharsis volcanoes equates to the separation on the most northerly Tharsis volcano. The following observations follow:

- The angle between the rift valley south of Solis Planum and the southern Tharsis Monte (Arsia Mons) with the Tharsis Fault (line of three Tharsis Montes volcanoes) is almost exactly 120 degrees, making it a triple point.
- The angle between Pavonis Mons - which lies on the intersection the Valles Marineris Valley - with the same Solis Planum rift valley, is approximately 116 degrees. Therefore, both volcanoes most probably represent the same triple point, which - due to the function of rifting - is now on opposite sides of the same rift valley. This proves that rifts on Mars form as mirror images the same as on earth, implying a mantle driven process.
- The most northerly Tharsis Monte (Acreaus Mons) represents the exact same triple point, but this time it also coincides roughly with the southern side of the displaced Solis Rift A. It is displaced north by the same distance Olympus Mons, which was originally lined up on the VM. This means the western extension of the VM is directly below Olympus Mons and may continue further west.
- It follows from the geometric symmetries that the rift valley that lies between Olympus Mons and Alba Patera must be the northerly extension of the Solis Planum Rift A.
- The magma which created all three Tharsis Montes volcanoes rose up the intersection of the Tharsis Fault and VM and Solis Planum Rift valley perimeter faults after both rifts were cut by the Tharsis Fault – and after the late stage compression event. The volcanism may therefore have occurred following the Tempe Rifting.
- There are trigonometric symmetries and therefore a definite geological relationship between the Solis Planum and VM Rifts – and that relationship is probably the Solis Planum polar cap. For this coincidence to occur the Solis Planum Rift valley must have formed very shortly after, or at the same time that the VM started to rift – since they are essentially the same width. Therefore, the conclusion is that both rift valleys were initiated by the solar cap at Solis Planum for an extended time. The VM is therefore a normal earth-like rift valley.
- Both the VM and Solis Rift A valleys are rift valleys and both had glacial activity imposed. Extensive fan-shaped deposit on the western flanks of Arsia Mons, Tharsis

Rise are consistent with deposition from cold-based mountain glaciers[22]. The VM valley was later compressed. Similar structural relationships and glacial activity overprinting faulting has also occurred in Chasma Australe adjacent to the current southern Martian polar cap.

- Olympus Mons and Ascraeus Mons (the top volcano in the line of the Three Montes) also formed after the fault had moved to its present position. Both pairs of volcanoes: Olympus Mons & Ascraeus Mons - as well as Patera & Tharus Tholus - have been displaced north by the same distance. The reader can measure the displacement on the faults to confirm this. Furthermore, the dykes of Alba Patera line up and are parallel to the line drawn between Olympus Mons and Alba Patera. This dyke swarm continues across to Tempe Terra, so magma intruded and thus is younger than the Tempe Rifts.

One fundamental assumption for this interpretation to hold is that the triangular relationships shown in the figures can only hold it the apexes of the triangles and intersection with volcanoes represents triple points and if the valleys are active rift valleys like we see on earth.

The trigonometric relationships between the Mars VM Anomalies are eloquent proof that plate tectonics can be used to unravel Mars tectonic history.

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[22] J. W. Head , D. R. Marchant "COLD-BASED MOUNTAIN GLACIERS ON MARS: WESTERN ARSIA MONS" Geophysical Research Abstracts, Vol. 5, 02770, 2003
c European Geophysical Society 2003 available online at
http://www.cosis.net/abstracts/EAE03/02770/EAE03-J-02770.pdf