CAN INSIGHT DETECT THE SOURCE REGION OF THE ATHABASCA VALLES FLOOD LAVA?

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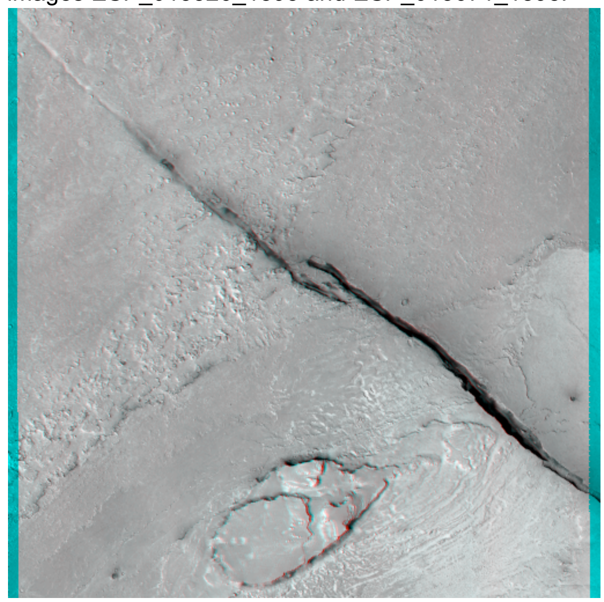
Introduction: The Athabasca Valles Flood Lava (AVFL) is a massive outpouring of lava that took place in the last few million years [1,2]. The source of the magma must retain some partial melt underneath the Elysium Planitia region of Mars. Next year, the InSight mission is scheduled to land nearby [3] and it may be able to detect this melt as a seismic low velocity zone. Here we discuss the existing constraints on the characteristics of the magma source region.

The Athabasca Valles Flood Lava: The AVFL has a volume of ~5000 km^3 and extends ~1400 km to the southwest and southeast from the Cerberus Fossae fissure vents [1]. At peak discharge, the flow reached a depth of ~100 m in the upper reaches of Athabasca Valles, then drained, leaving a coating of lava only a few meters thick [2]. This great depth and the ~30 km width of the main channel produced a peak lava flux around 10^7 m^3/s with flow in the turbulent regime [1]. The average lava flux was undoubtedly much lower than the peak value, but the eruption duration should have been only of the order of weeks [1]. The final stages of this deflating flow are detailed in high-resolution images of the lava surface, showing numerous phreatovolcanic constructs which were translated atop the rafting lava crust [2]. The lava surface is almost devoid of impact craters other than secondaries from the Zunil crater to the east. While there are large uncertainties in using crater size distributions to date such young surfaces with numerous secondaries, the model ages are between 2-5 Ma [3,4] and there is no doubt that this is the youngest large lava flow on Mars. Thus the age, volume, eruption duration, and vent characteristics of the AVFL are quite well-constrained. It is reasonable to expect these values to translate into some useful bounds on the characteristics of the volcanic plumbing system and source region.

Where was the Magma Chamber? The sudden removal of this much magma would be expected to leave an easily observable effect at the surface. 5000 km^3 is equivalent to a ~20 km diameter sphere or a ~40 km diameter cone at the angle of repose. More relevant is the fact that this is also the volume of the largest caldera on Olympus Mons [5]. Yet no significant collapse structure is evident in the image or altimetry data of the region. However, it is difficult to rule out a broad gentle depression <100 m deep because of the local topographic variations. The only clear evidence of post-eruption deformation are a few extensional fractures that parallel the Cerberus Fossae vents at a distance of 50-80 km. There also are some small wrinkle ridges in Cerberus Palus that may deform the lava, perhaps as a result of loading by the emplaced lava.

Figure 1. A prominent extensional fractures on the floor of Athabasca Valles that formed syn-eruptively with the AVFL. The 6-km-wide anaglyph is made from HiRISE images ESP_013526_1895 and ESP_013671_1895.



The lack of visible ground deformation indicates that the magma chamber is deep and broad. It should also have only partially emptied during the eruption of the AVFL. Typically, the chamber builds up pressure until it can drive magma to the surface and the eruption stops when this over-pressure is relieved. The pressure drop should be of the same order as the buoyancy forces: $\Delta\rho\, g\, H$ where $\Delta\rho$ is the density difference between the magma and the country rock, g is gravitational acceleration, and H is the depth of the magma chamber. $\Delta\rho$ should be ~300 kg/m^3 though there is a factor of 2 uncertainty in this value for Mars [e.g., 6,7].

We investigate the constraints on the depth and size of the magma chamber with simple, analytical, models. The first, the Mogi Model, assumes a point or deep spherical source for the surface deformation [8,9]. Table 1 shows that no shallow magma chamber is allowed and the magma must have ascended from a depth >100 km, suggesting the source is magma that pooled at the base of the lithosphere.

However, the Mogi Model does not properly predict the distance between the vents and the extensional fractures. This is likely to be due to the over-simplicity of this model. If we consider a somewhat more physically plausible sill-like body, the magnitudes of the displacement vectors are only 10-20% different [8]. However, the transition from compression to extension is located about ½ the distance from the center of the magma chamber. For a 150-200-km-deep magma body, this shifts the predicted extension to 60-80 km from the vents, an excellent fit to the observations. These models suggest the magma body is roughly 30,000 km^3 in volume. If it is a few kilometers in vertical extent, it should be of order 100 km in lateral extent. While these results are robust as order of magnitude estimates, they could be substantially refined with more capable numerical tools such as TEKTON or COMSOL.

Table 1. Mogi Model results for ground deformation in response to erupting 5000 km^3 of magma. Deeper magma chambers can be more pressurized, permitting smaller diameters.

Depth to magma chamber	Diameter of magma chamber	Maximum depression	Compression-extension transition
50 km	52 km	210 m	54 km
100 km	45 km	83 m	87 km
150 km	40 km	44 m	120 km
200 km	37 km	27 m	155 km

Predictions for InSight. It is unlikely that InSight will detect a large enough number of seismic events to directly resolve this magma chamber. However, the chamber is likely to be fed from a much larger region of partial melting. The array of very young volcanic features across central Elysium Planitia support the idea of a very broad magma source region in this area. We predict that InSight will find seismic arrivals from bearings ~060-090 have significant attenuation, especially for the S-waves, coupled with reduced seismic wave velocities. The degree of attenuation and the V_P/V_S ratio are sensitive indicators of the degree of partial melting [e.g., 10]. If this prediction turns out to be incorrect, that will indicate that the magma was transported extreme distances laterally, also an interesting and important result. Either result should be very useful for putting the heat flow measurements in appropriate regional and global context.

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