Exploring Latitudinal Changes in Lobate Debris Aprons as a Function of Local Geology

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Lobate debris aprons (LDA) on Mars are essentially debris-covered glaciers, as shown by radar data (Holt et al. 2008; Plaut et al. 2009) They are indicators of paleoclimate in that they show evidence of flow, which is not possible under current climactic conditions. LDA are present only in the mid-latitudes of Mars between 30º and 60° north and south. They appear on the edges of sharp slopes, such as massifs, cliff faces, and crater walls (Figure 1). Neither ice nor liquid water is currently stable at the surface of Mars in the mid-latitudes, offering further evidence that LDA must have formed in a different climate than the one that obtains today. As such, understanding the conditions of formation for LDA can offer insight into the Martian climate at some point in the past. Deuteronilus Mensae/Protonilus Mensae is an area with an abundance of LDA which show a latitudinal trend in the presence or absence of subsurface reflectors as seen in radar data (Berney 2013, in progress).

If the assumption by Holt and Plaut that all LDA are composed of near-pure, massive water ice covered by a thin, insulating layer of dust holds true, all LDA should have at least a surface reflection and a basal reflection. Radar reflections occur when the energy encounters a change in material properties – in this case, between ice and the Martian rock beneath. However, in Deuteronilus Mensae many LDA do not show any basal reflection, particular in the eastern part of the region. This lack of subsurface reflectors may be due to some difference in local geology, such as a difference in the composition or thickness of the thermally insulating layer covering LDA. By examining the spread of LDA with and without subsurface reflectors in radar data, it should be possible to discover whether the latitudinal trend is a function of local geology. If no correlation appears between local geology and topography, and the presence of subsurface reflectors, further study is required to understand what differences in the composition of LDA themselves may be indicated by this lateral trend in subsurface reflectors.

Figure 1: Perspective image of a Lobate Debris Apron against a massif. Image courtesy of Dr. Ernst Hauber and modified by Dr. Jack Holt.

In order to contrast the locations of LDA containing subsurface reflectors and local geology, I first obtained a geologic map shapefile of Mars from the USGS Pigwad website and loaded it into ArcGIS (Figure 2).

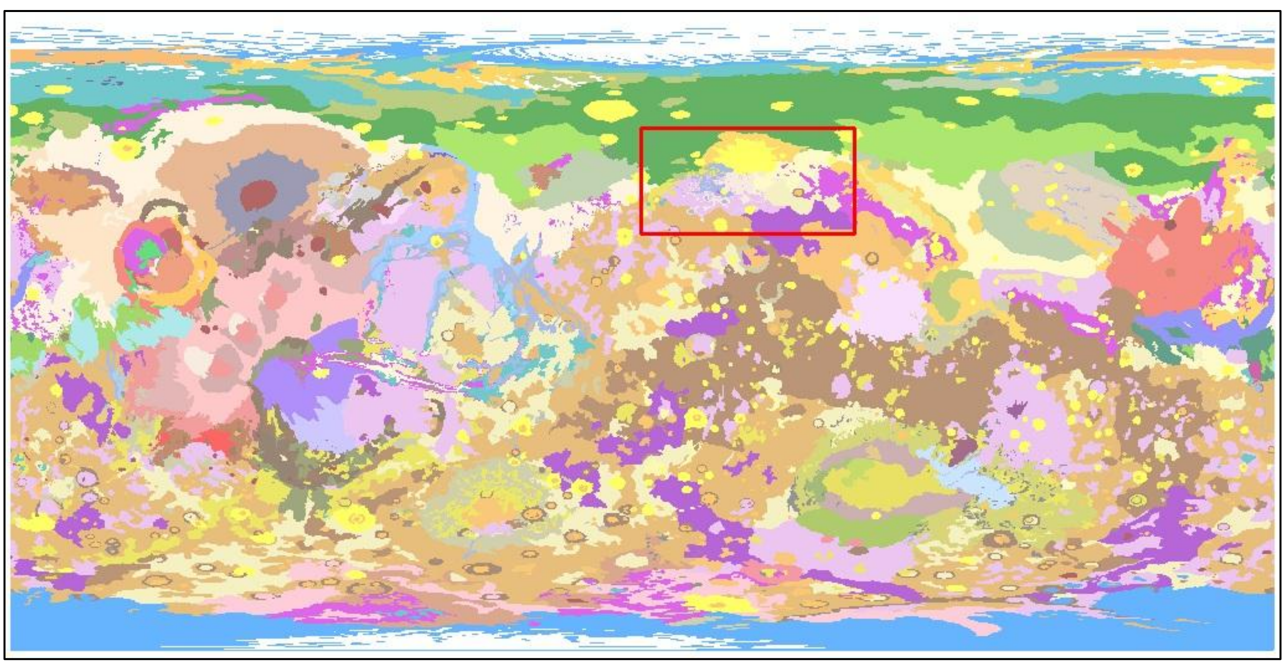

Figure 2: Geologic map of Mars. Area of interest (Deuteronilus Mensae) is outlined in red.

The area of focus for this study is Deuteronilus Mensae. In order to focus on this subsection of Mars, I created a Map_Area feature class and within that feature class a Map_cut polygon which surrounded the Deuteronilus Mensae region. I then used my Map_cut polygon to clip my geologic map of mars to the Deuteronilus Mensae locality (Figure 3).

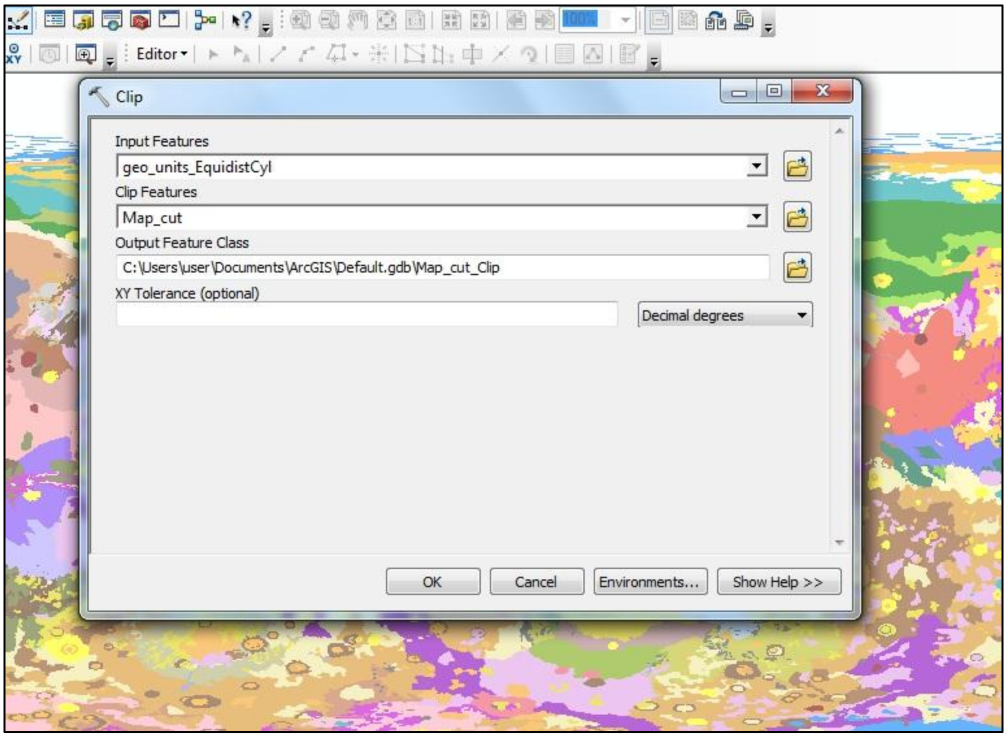

Figure 3: Clip tool, used to focus on Deuteronilus Mensae section of a geologic map of Mars.

I named the resulting shapefile Units_clip (Figure 4). I then clipped the accompanying shapefiles outlining the geologic contacts and structures on the map, using the same method.

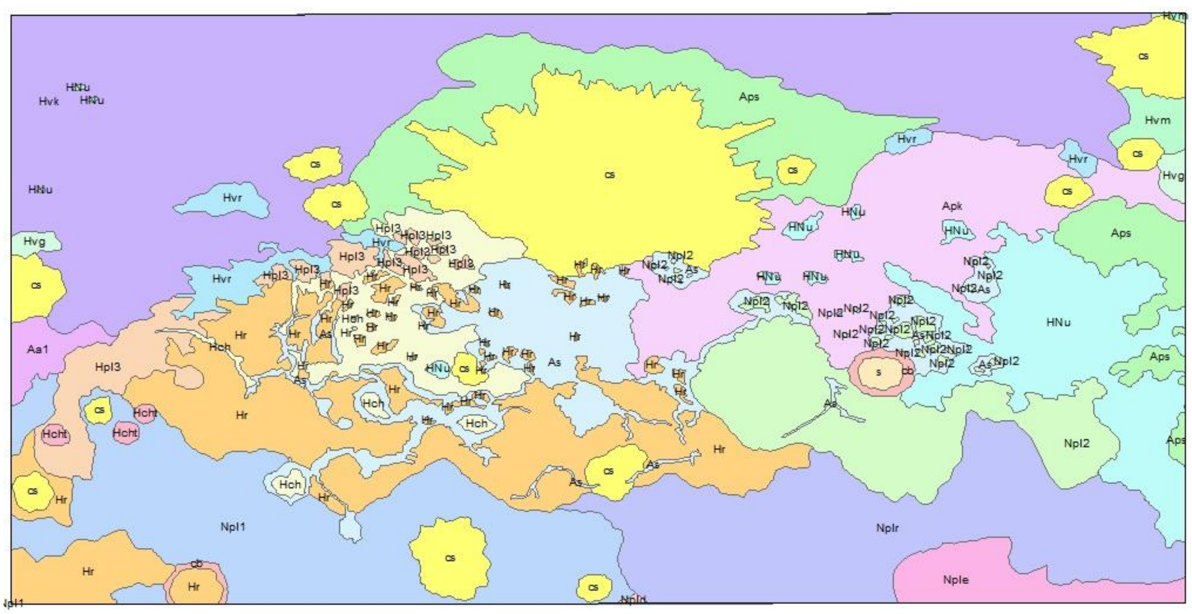

Figure 4: Geologic Units mapped in the Deuteronilus Mensae region, as clipped from a larger geologic map of Mars.

Next I downloaded 100m-scale imagery of Deuteronilus Mensae, specifically two mosaics of Thermal Emission Imaging System (THEMIS) daytime infrared imagery. The mosaics were available in 30ºx30° grids courtesy of Arizona State University. I had intended to georeference the mosaics to my Map_cut shapefile, but instead acquired worldfiles for each mosaic. I combined the two mosaics using the Mosaic to New Raster tool so that I had coverage over the entire Deuteronilus Mensae area and named the new image dm_mosaic (Figure 5).

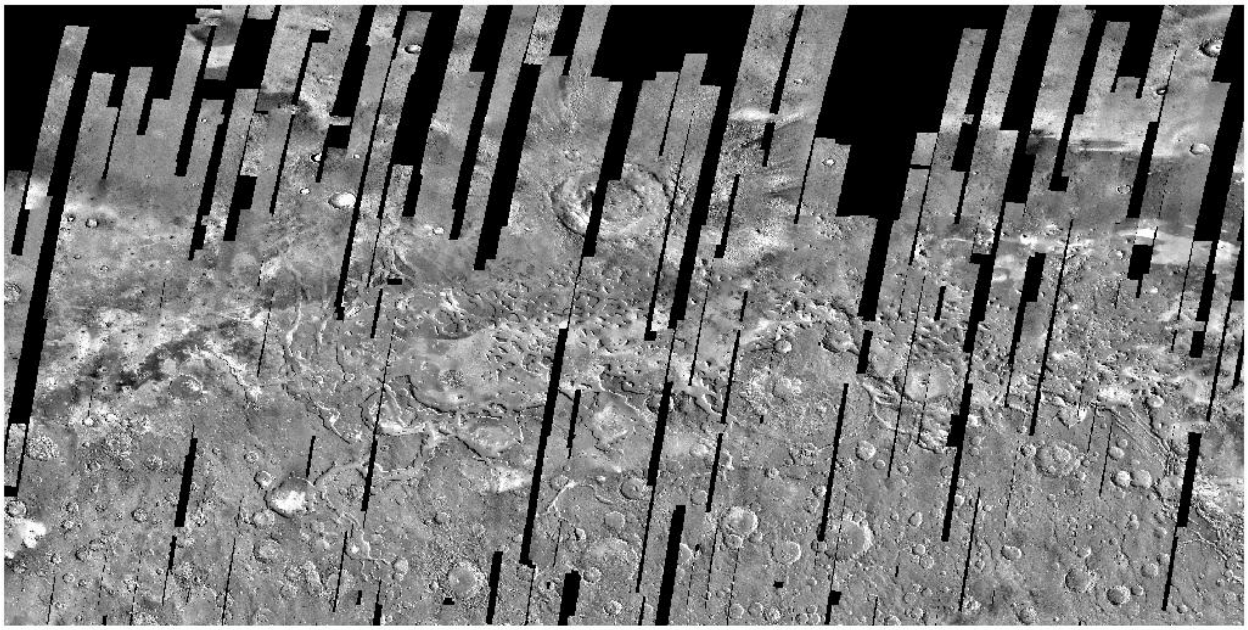

Figure 5: Mosaic of THEMIS imagery covering a 30 x 60 degree area, including Deuteronilus Mensae. Black areas indicate locations with no coverage.

The purpose of acquiring such high-resolution images was to examine the local surface near LDA in detail, in order to spot complications like high surface roughness that could prevent a signal from returning to the Shallow Radar (SHARAD) instrument on the Mars Reconaissance Orbiter (MRO). Figure 6 displays how a zoomed-in look at specific LDA can identify possible issues for radar returns.

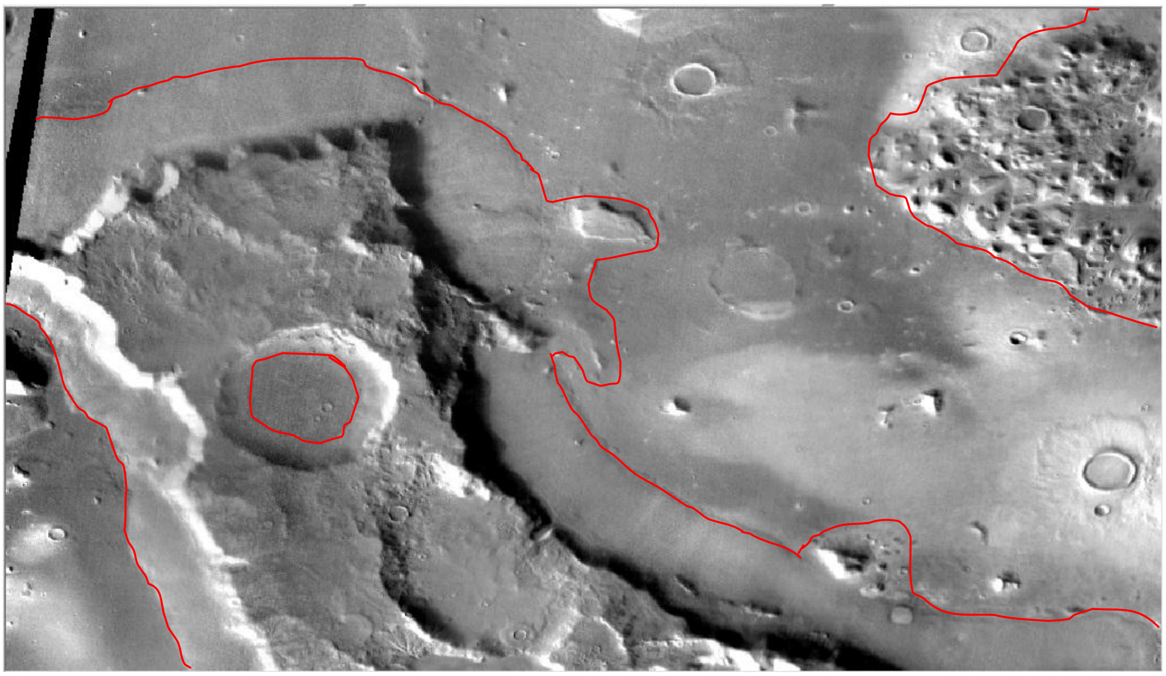

Figure 6: LDA on the edges of cliff walls (bottom left and center) with relatively smooth surfaces vs. LDA between freestanding, clustered massifs (top right). Distal edges of LDA are roughly outlined in red. Rough topography as in the top right of this image can scatter radar signals and prevent them from returning to the satellite.

The next step was to download a Digital Elevation Model of Martian topography, based off of Mars Orbital Laser Altimeter (MOLA) data. USGS provided a DEM for all of Mars, and I clipped that down to my Map_cut polygon (Figure 7).

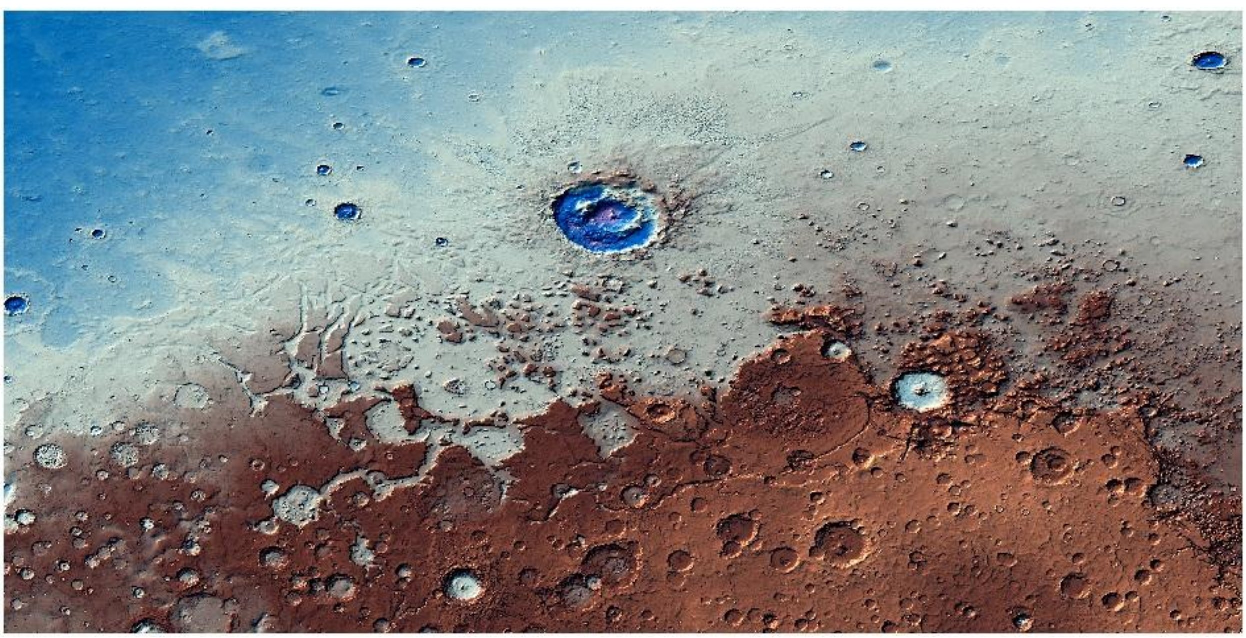

Figure 7: DEM of Martian topography in the Deuteronilus Mensae area, based off of MOLA data. Brown indicates higher elevation, blue indicates relative lows.

The last data I needed to add to my map was the locations of SHARAD orbital tracks and the subsurface reflectors themselves. The orbital tracks had already been combined into a shapefile by Anthony Egan at SWRI and a grad student in my research group, Charles Brothers at UTIG. I loaded and clipped the orbits shapefile to the desired area (Figure 8).

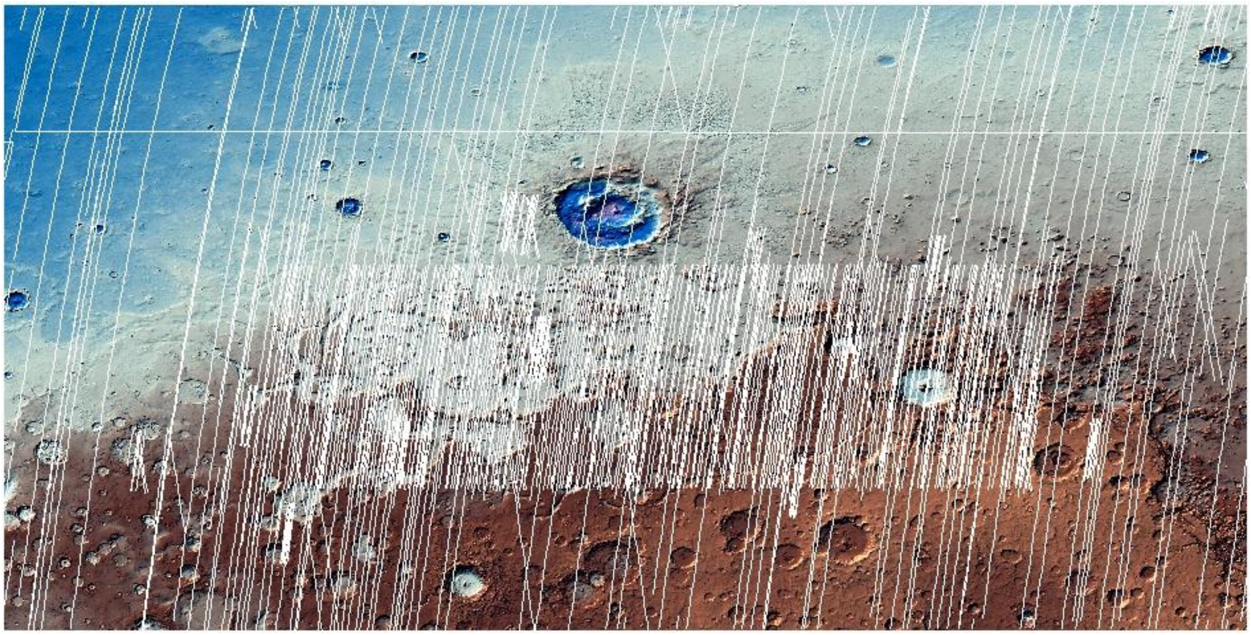

Figure 8: MOLA topography with SHARAD coverage. White lines represent orbital tracks.

With Charles' help I exported my picks for subsurface reflectors from DecisionSpace and ran them through scripts to output point data indicating the locations of subsurface reflectors in vertical as well as horizontal space. Because LDA are associated with high relief features, first returns in the radar often represent an off-nadir reflection from a clifftop or massif rather than from the LDA itself (Figure 9).

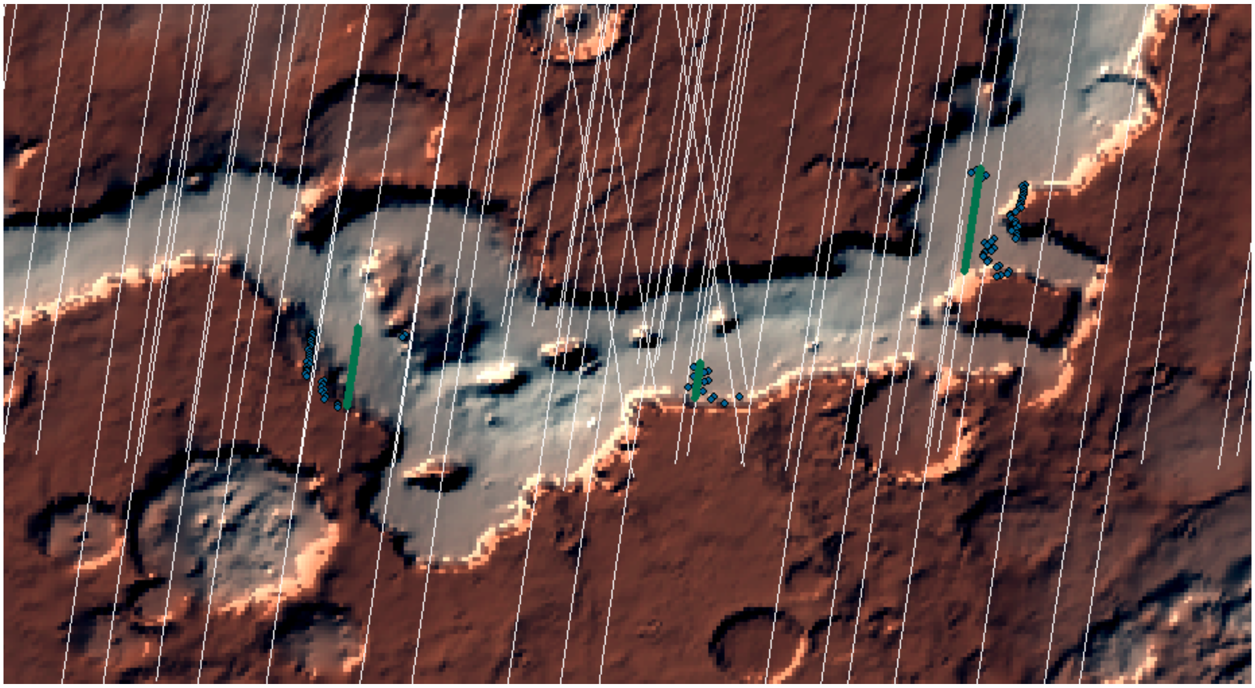

Figure 9: Off nadir positioning in blue vs. nadir positioning in green. Note how blue positions tend to cluster at cliff edges and most likely do not indicate true positioning of material changes (reflectors) in LDA. White lines represent SHARAD orbital tracks and background topography is a DEM from MOLA data.

I chose to display subsurface reflectors only in nadir position because the first return signal was affected enough by the high local relief that the positions are highly skewed. On a relatively smooth surface the off-nadir positioning would be more accurate, but in this area nadir positioning is most likely closer to the truth.

At this point all the data I intended to use had been loaded and I could compare the locations of subsurface reflectors to local geology and geography. Due to the subjectivity of radar interpretation, I symbolized four different categories of subsurface reflectors, with color reflecting the robustness of the interpretation (Figure 10). Green or sub1 reflectors indicate data that definitely cannot be explained as an off-nadir reflection from some surface feature, rather than a true subsurface reflector. Purple or sub2 reflectors are very scarce and indicate a second certain reflection with the ice, perhaps a material change within the ice where sub1 most likely represents the base of the LDA. Blue or sub_d reflectors indicate subsurface reflectors in which the interpreter was not completely sure that the radar reflection was not from some off-nadir feature, and orange or sub_u reflectors do not have a good surface pick due to the roughness of the surface topography.

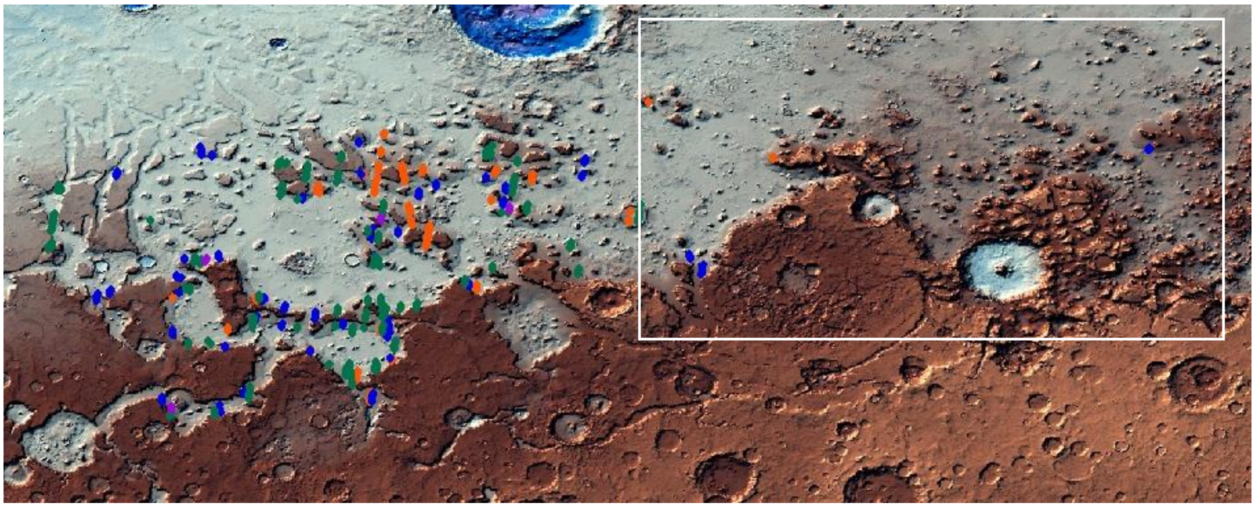

Figure 10: Interpreted radar subsurface reflectors, colored by certainty. Note the change from abundant reflectors to the west to hardly any in the eastern portion of Deuteronilus Mensae. White box indicates area shown in Figure 11.

The change does not appear to be as straightforward as fewer LDA in the eastern portion of the area. Figure 11 shows the western half of Figure 10, in which LDA are clearly visible and yet display few to no subsurface reflectors.

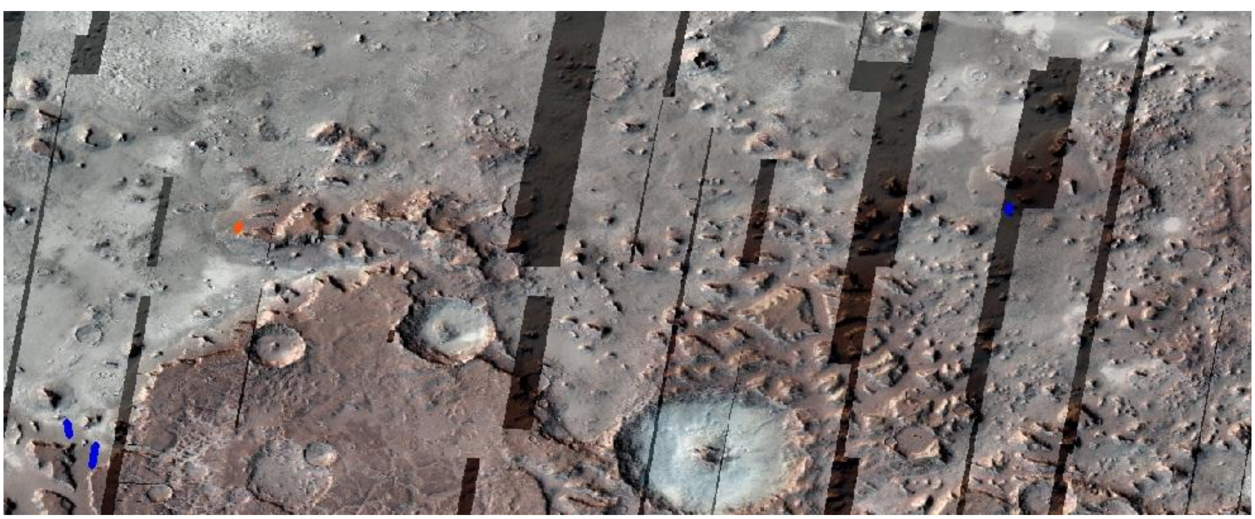

Figure 11: MOLA color transparently covering THEMIS imagery of LDA. Reflectors symbolized as above. Note LDA particularly along cliff faces which show no subsurface reflectors. Also note that no green sub1 reflectors appear in the eastern part of Deuteronilus Mensae.

On comparing mapped geologic units to the locations of subsurface reflectors, an immediate correlation appears (Figure 12). The cliffs in the western portion of Deuteronilus Mensae are primarily composed of "ridged plains material (Hr)". The LDA themselves along with much of the nearby surface are termed "slide material (As)" or in some cases "older channel material (Hch)". To the east, however, cliffs are primarily composed of "plateau material, subdued cratered unit (Npl2)" or occasionally "Undivided material (HNu)". LDA-rich areas are still characterized as As, but floor material equivalent to Hch in the west is characterized as "knobby plains material (Apk)" in the east. There is a definite change in morphology between east and west of the broad geologic area.

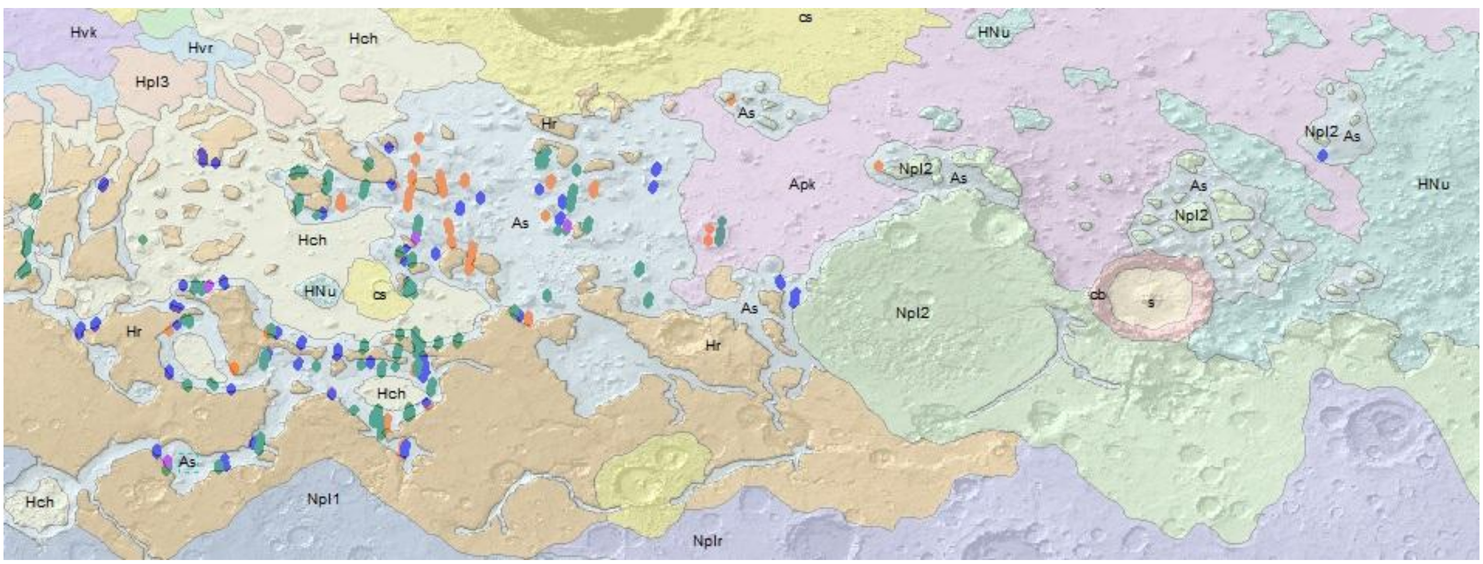

Figure 12: Geologic map transparently covering MOLA DEM. Note difference in geologic units and preponderance of subsurface reflectors from west to east.

The marked subsurface reflectors almost invariably plot on top of the unit marked as As, or slide material. This suggests good congruency between picked locations for subsurface reflectors and the geologic evidence that the map creator used to define his or her units. The causes for this change in morphology between east and west are not clear, but it does correlate well with the geographic spread of subsurface reflectors, indicating that some correlation exists between geologic unit and presence of subsurface reflectors.

Topography shows much less correlation with the change in subsurface reflectors. Cliff face LDA in the west appear similar in elevation and geometry to those in the east, but subsurface reflectors are much less common in the east. LDA, as observed before, appear against the edges of steep slopes like cliff faces and crater walls; but no noticeable difference is observed between the height of cliff faces near LDA with subsurface reflectors and those without. Further study will hopefully shed some light on what other factors may influence the presence of subsurface reflectors in radar data as observed in lobate debris aprons.