Isaac Smith
December 7, 2009
GIS course project

Analysis of Stratigraphic layers in the Northern Ice Cap, Mars

[1] Problem Formulation

In this project I want to answer one question, namely, how do stratigraphic layers, or layer packets, deposit with respect to elevation and slope of the previous surface. I hypothesize that elevation has little to do with deposition, while slope will yield results of poleward facing slopes have thicker layers while equator-ward facing slopes will have thinner layers. The results from this are easily quantified by plotting thickness vs. elevation and thickness vs. slope. Local and regional slopes on the cap are heavily influenced by large curvilinear depressions called spiral troughs.

This topic is in line with my PhD proposal and research goals. To answer this I need several things: a GIS ready DEM of the Martian Northern Ice Cap obtained from the Planetary Data System, also available from USGS (Figure 1); elevations of several reflectors in radargrams from the SHAllow RADar instrument, SHARAD, which is onboard Mars Reconnaissance Orbiter, MRO (Figure 2); corresponding locations of those reflectors geo-referenced; and knowledge I've learned in this class.

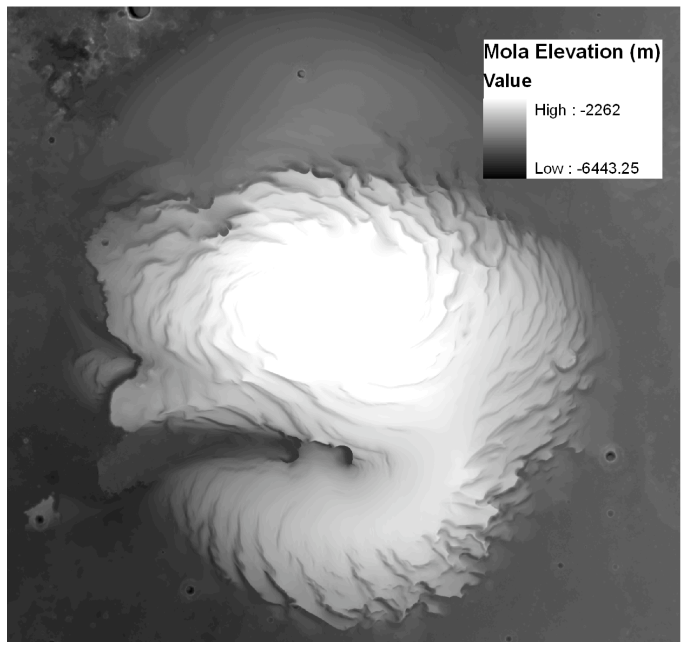


Figure 1: DEM of North Polar Ice Cap on Mars. This cap sits in a global low elevation. Elevations on Mars are recorded with respect to the average elevation, thus the cap's elevations are all negative.

[2] Data Collection and [3] Data preprocessing

To obtain the Aero-referenced point file I first looked at the location in space from which the observations were taken. The coordinate system was appropriately matched with that of the DEM to get accurate locations and measurements. The DEM is in Mars Polar Stereographic.

SHARAD records in time, so each reflector has an exact location and associated time measurement within a resolution of about 30 nanoseconds. This resolution corresponds to about 9 meters travel in ice. Reflectors were picked in a seismic interpretation program called GeoFrame. This work ended up being more than 50% of my time spent. The data, once interpreted is exported as text, where we can manipulate it. First, it must be converted to depth since that is more applicable. The known velocity of electromagnetic waves in nearly pure water-ice is 1.78x10^8 m/sec. With that the z-position with respect to the space craft is known and then converted to an Aero-centric elevation relative to Mars' average elevation. Since the northern ice cap sits at a topographic low, the elevations are below 0. Second, the data were converted to .shp files by using a freeware program found online.

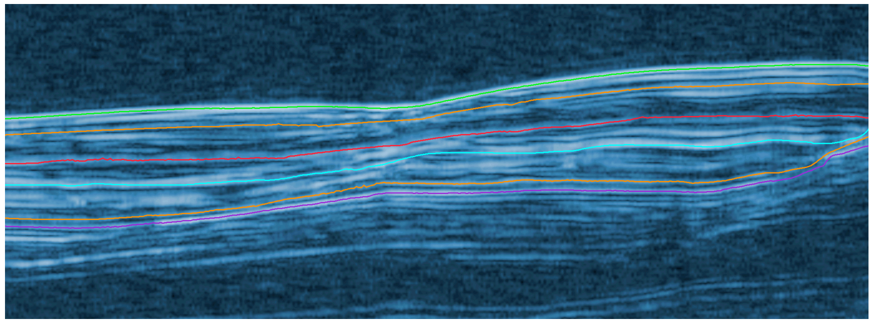


Figure 2: Sample radargram with interpreted horizons. From below the layers go as 107 (purple), 108 (orange), 110 (light blue), 115 (red), 119 (orange again), and surface

Five reflectors from 50 observations were chosen because of their consistent

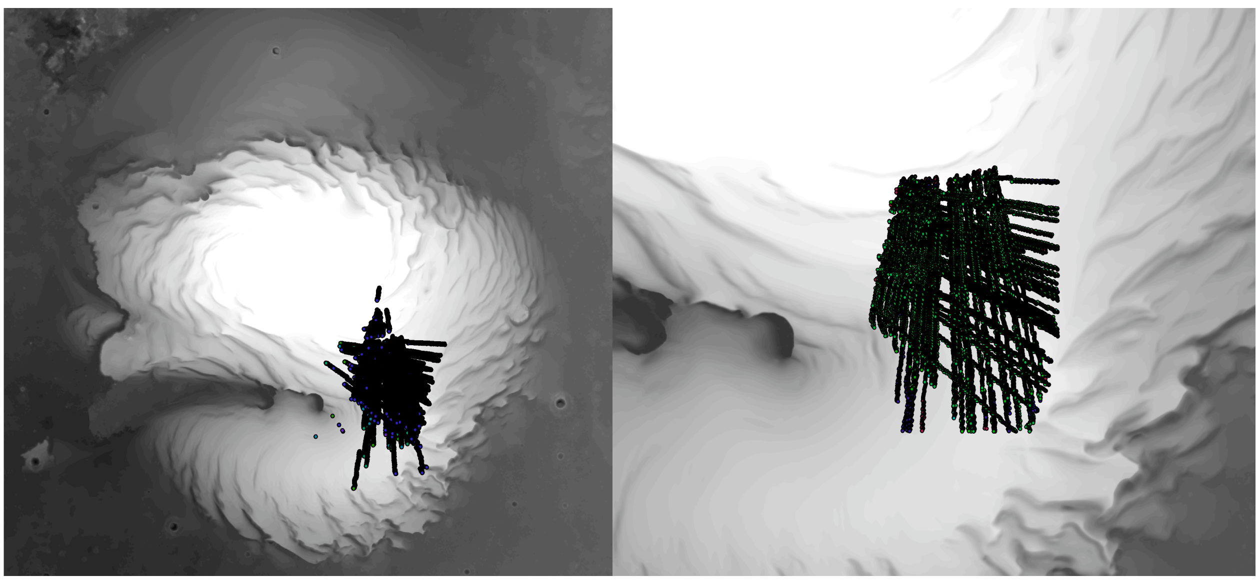


Figure 3: Left: Point files for all 5 subsurface horizons were imported and displayed on GIS. Some are found stray while others extended beyond the survey area. Right: final trimmed point files within the survey area.

high quality reflection and traceability. They also covered the survey region completely. The survey region is about 30,000 square kilometers, approximately the area of the state of Maryland.

Next, the unedited point files were imported into GIS and placed in their locations (Figure 3a). Since the point files extended beyond the area of interest they had to be edited. Also, some points were not located correctly and had to be pruned. Once the point files were appropriately trimmed and in place it was convenient to display each in a recognizable format by changing the symbology based on the z component (Figure 4a).   This was done for each horizon before proceeding and helped to recognize the locations of the buried troughs. Immediately, one can see that the current surface troughs are closer to the pole than their protogenitors.

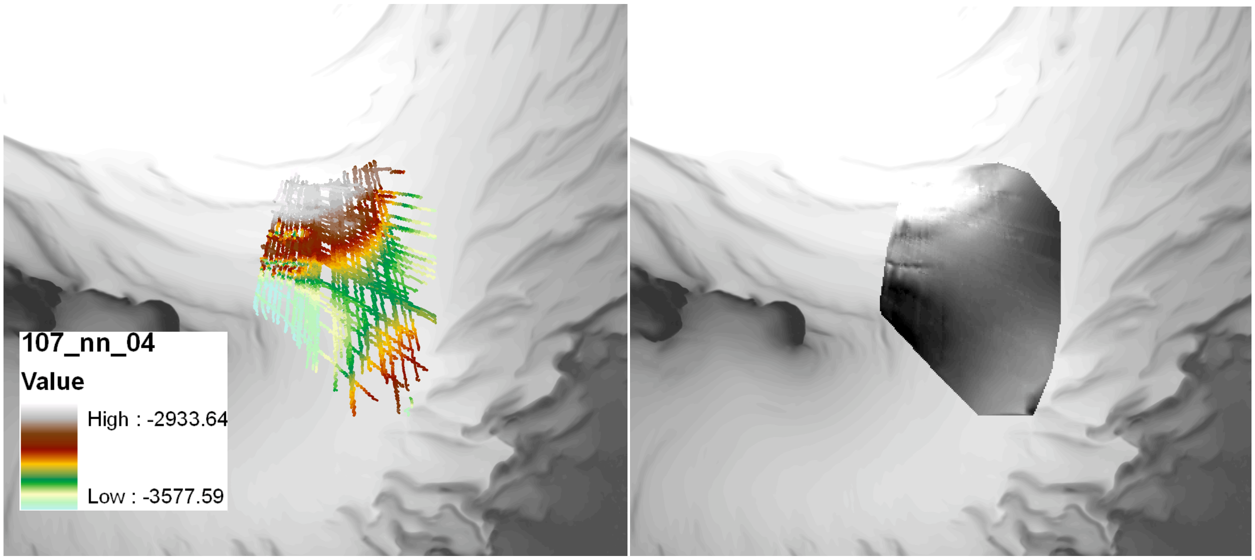


Figure 4: Left: Layer 107 point files symbolized with color. Right: gridded interpolation for layer 107 without color.

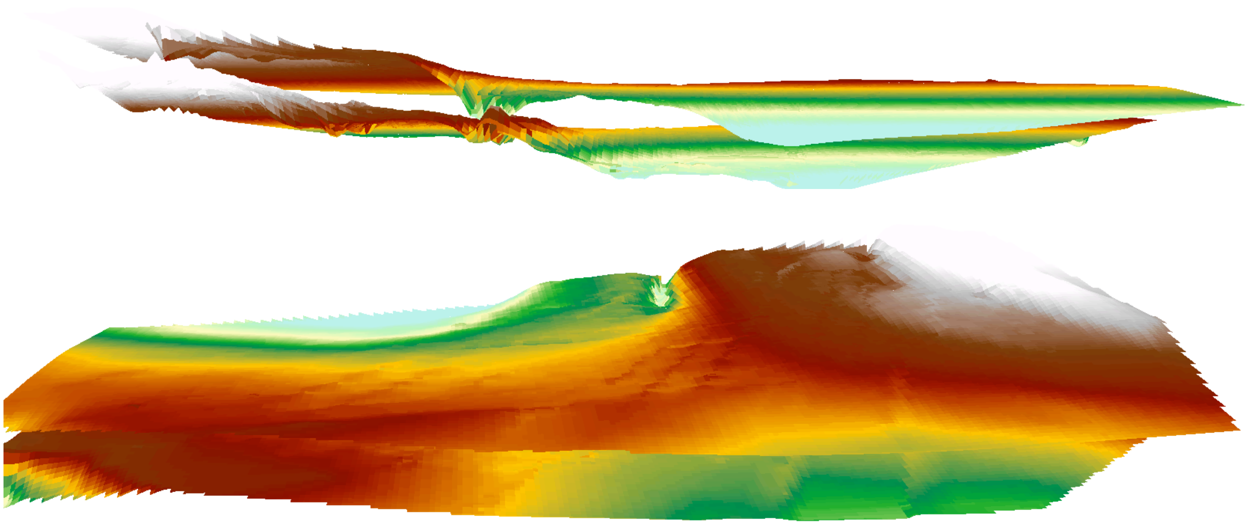


Figure 5: Above, view of layers 107 and 119 seen from west at eye level. Right, oblique view of interest area looking down and toward west. Figures are vertically exaggerated 40x, and color scheme is same at in Figure 4.

Gridding the points was the next step in being able to pick elevation profiles. That was done by choosing the Natural Neighbor interpolation in GIS. This interpolation appears to do a good job of maintaining the locations of the input data without giving too much of an angular surface in between. The result is seen in Figure 4b. This too was done for each reflector. The layers were then put into ArcScene for better visualization, Figure 5a and 5b.

[4] ArcGIS processing

Now that the vertical data are gridded and in place the GIS processing can begin. Thickness profiles with respect to location from a scarp, to elevation, and to slope are required, so first the thickness profiles must be made. This was easily done by using the Raster Calculator within the Spatial Analysis tool. I did it for each adjacent horizon.

- Surface - 119
- 119 -115 (Figure 6)
- 115 - 110
- 110 - 108
- 108 - 107

The range of thicknesses varied depending on which two layers were chosen. 107 and 108 were very close and thus have a small difference map, while 108 and 110 were much farther apart (see figure 2). This was not ideal but necessary in having enough data to make a grid. Further work will expand this are both west and north.

Another requirement was a slope map of each grid. Again, this is easily made by using the Slope Calculator within the Spatial Analysis tool. A slope map of layer 119 can be seen in Figure 7.

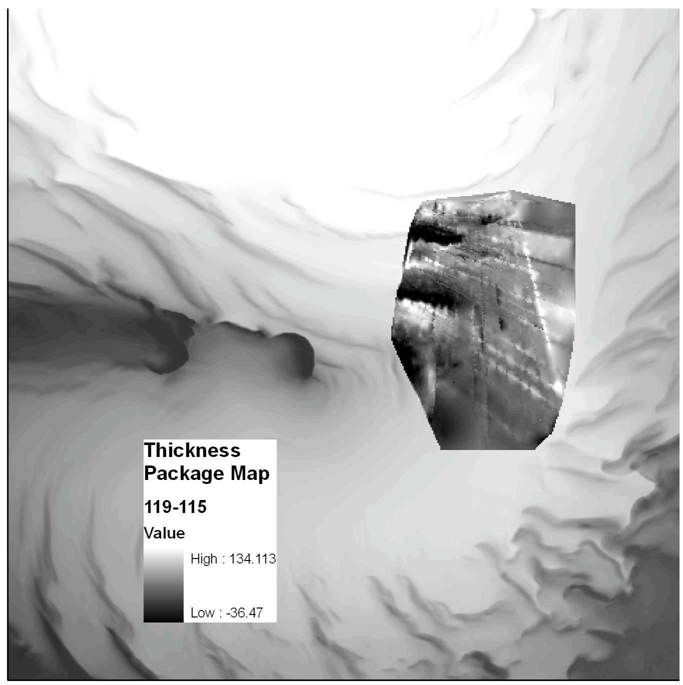
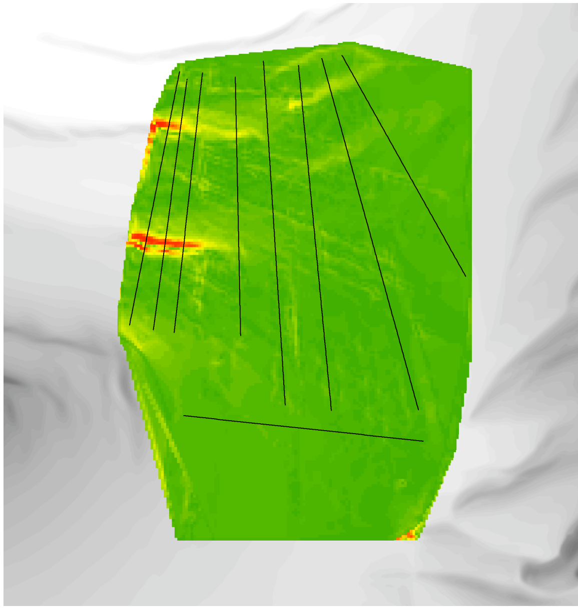


FIgure 6: Difference map between layers 119 and 115. Difference measured in meters. Negative values are due to layer interpolations overlapping, even though great care was taken to avoid this.

Now that all the data are ready, we can begin finding thickness profiles in relation to elevation, slope, and distance from the scarp. Also in Figure 7 the eight chosen profiles can be seen. Seven profiles radiate from the pole in a pattern similar to mapped wind streaks (this was not quantitatively done but rather by grossly generalizing the regional wind patterns). The eighth profile was chosen due to it's location. In the southernmost region of the grids there is very little change in surface (and subsurface) slope, elevation, or thickness (again this was noticed qualitatively) and is an ideal place to find a “control” area with which to find average thickness of layer packages away from strong topographic changes and to compare with those same packages in the more interesting region.



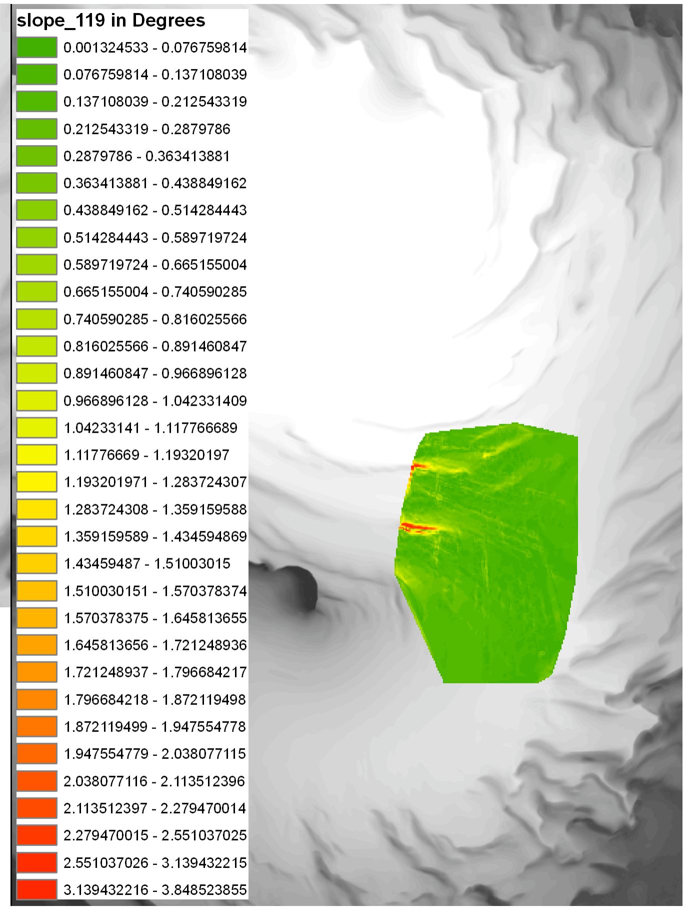
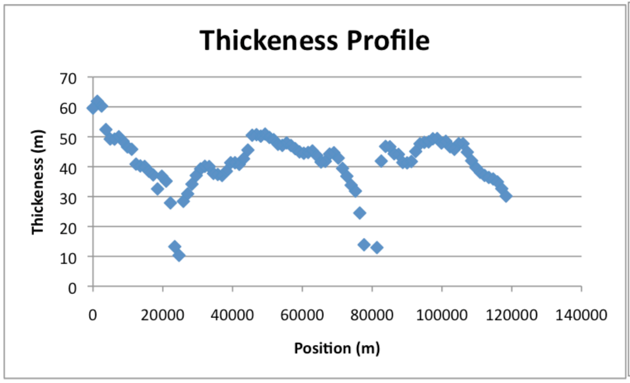


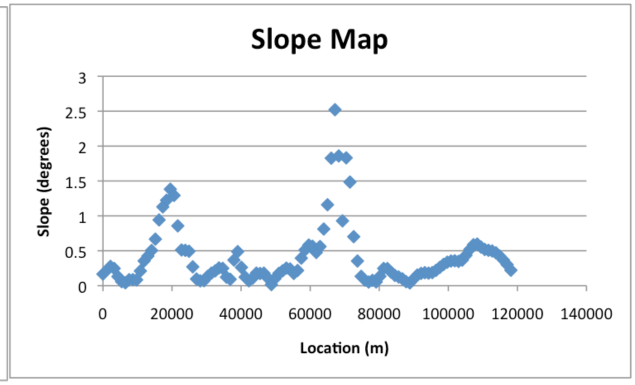
Figure 8: Slope-map of layer 119. Left: Slope-map with eight chosen profiles. The 7 vertical profiles are designed to follow regional wind patterns. The lower-horizontal profile is used as a control. Right: Larger view with scale-bars. Units are in degrees.

The profiles were painstakingly added 8 times for each layer. This amounts to 8 x (5 + 5 + 5) = 120 times. The same profiles were used every time by carefully locating the end points and pasting them for each new measurement. This time the 3-D Analyst tool was used by “Creating Profile Map”. An example profiles for each of elevation, slope, and thickness can be seen in Figure 9. Accordingly, since we are looking for thickness vs. slope and thickness vs. elevation, Samples can be found in Figure 10.

Figure 9 illustrates the what 3-D analyst can do. Along each position in the profile a record of each elevation, slope, and thickness to the next higher reflector is mapped. From this we can relate thickness to slope and elevation. One difficulty in this process is that, even though the same start and end points existed for each profile, a different set of locations exists (means different number of records for each profile and different points in betwen). This means more interpolation!

Actually, what I did was even more painstaking than the original work. I zoomed in until GIS couldn’t handle any more and then lined up the end points. This gave exact positions that matched between the three profiles. The two plots in Figure 10 took 20 minutes to make, and I need 14 of those total. Needless to say, that is not included in this report. See me after Christmas if you would like to see a few more of them. We need to work on another way of doing this!!





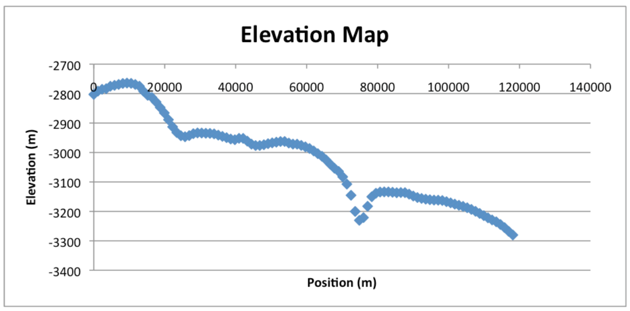


Figure 9: Top: Elevation of Layer 119 along the second profile from left in Figure 8. Numbers are negative because the Polar cap is below mean elevation on Mars. Middle: Slope map along same profile. Bottom: Package thickness between surface and layer 119 along same profile.

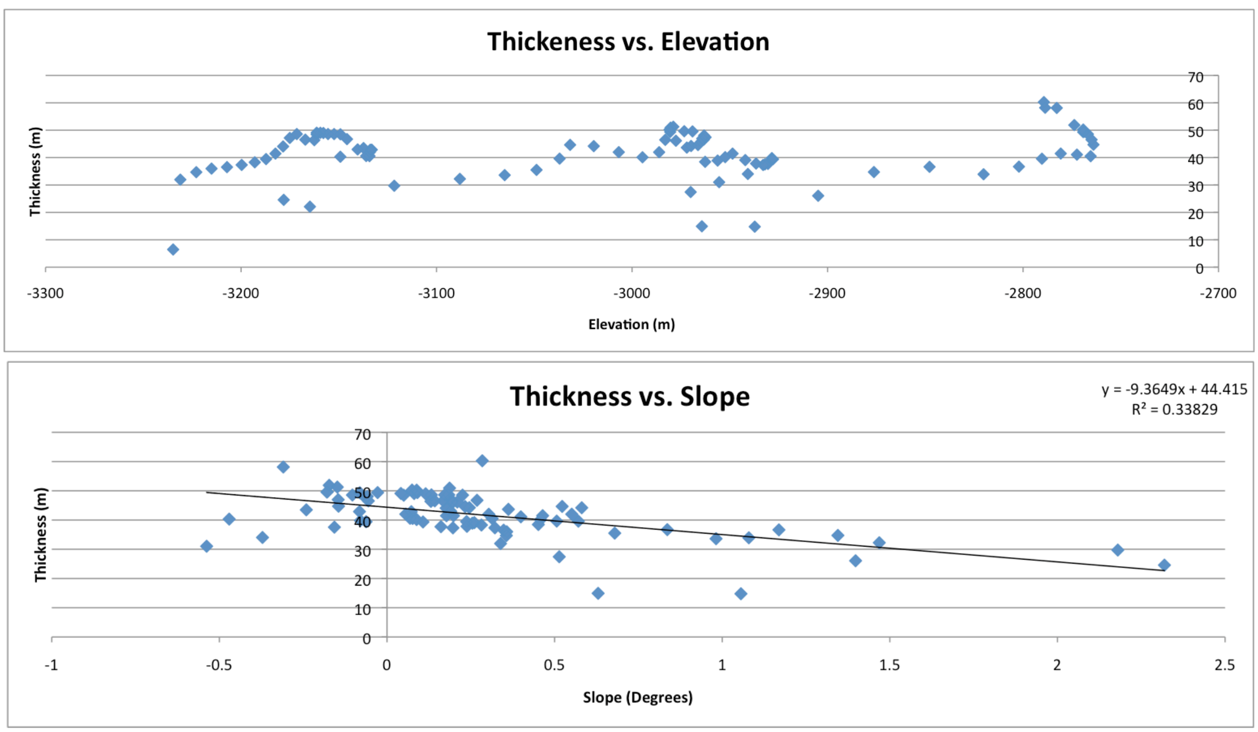


Figure 10: Thickness variations in meters plotted against Elevation, meters, (above) and Slope, degrees (below); negative slopes indicate pole-facing slopes, and positive slopes indicate equator-ward-facing slopes.

[6] Write-up

Here I want to find a relationship, if it exists, between sedimentation rate and slope or elevation of the previous surface. To reach that point I needed to pick enough data points in a seismic interpretation software, GeoFrame, to interpolate a surface. For that I chose 5 reflectors and the surface. I used a DEM downloaded from the Planetary Data Systems as the top surface since it was more accurate than my own. My points started out as x-y data in latitude and longitude. They had to be converted to meters for the stereographic projection. That step, and the step to convert the reflector time to depth was done with one code written by an undergrad in our research group, Prateek Choudary. Then another script, found online, converted the x-y-z data to shape files in the coordinate system we chose.

Once all of the data were in GIS I began interpolation of the layers to create surfaces. These surfaces represent a former surface of the ice cap, on that has been covered by deposition. My intent, of course, is to find the amount of deposition, so the difference between two adjacent layers was found by using the raster calculator tool. Also required were slope maps, and the Spatial Analysis took was used there. With elevation, slope, and thickness I was able to find the answers to my questions. Eight profiles in total measured those attributes of the 5 layers. Seven profiles followed regional wind patterns, and the eighth was used as a control to find the average deposited thickness between two reflectors. It will be used for future studies. Samples of the results are above in Figure 9. Figure 10 completes the project by plotting thickness vs. slope and thickness vs. elevation.

Figure 10 shows that there is no trend of thickness vs. elevation. It appears as if elevation has nothing to do with the deposition rate. However, the plot of thickness vs. slope does have an interesting trend. Slopes facing southward have less deposition than horizontal or northward facing slopes. This conclusion (while still young and poorly supported) supports my hypothesis that elevation makes little difference in layer thickness, while slope will play a big part.

[7] Work accomplished and lessons learned.

I would like to say here that this project took a substantial amount of time. Nothing went right the first, second, or third time. This was the fourth generation of the data, and each process took me many times to get it right. Some of that was unavoidable. While picking horizons in the seismic interpretation software small errors result in very noisy plots. It took several times of re-interpreting those observations to get a nice looking elevation grid for each of the 6 reflectors I chose. I learned early on that the interpolation software is only as good as what you give it. This meant I had to make interpretations that weren't visible in the data. I didn't make up any data, but this does introduce a source of error.

Other lessons learned are document your work. I definitely learned as I went, but sometimes those lessons are best learned after several attempts. Of course documenting the errors you made and solutions to problems saves time and effort for future work. The most tedious part of this exercise was getting the profile lines to match up. In fact, if I had done it for all of the lines, I expect it would take me another week minimum. There has got to be a better way.