Radio-Echo Sounding of the Internal Layering in the North Polar Layered Deposits on Mars

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Report for the Antarctic Science Bursary

Project Summary

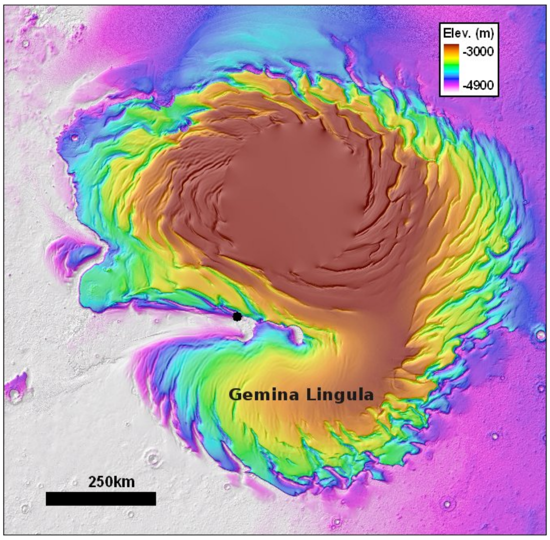
Thanks to the generous support of the Antarctic Science Bursary I was able to visit the Jackson School of Geosciences, University of Texas at Austin (UT) to work with Dr. John W. Holt. The purpose of my visit was to study radar data from the North Polar Layered Deposits on Mars and the project represented a novel tie-in to my Ph.D. research about radio-echo sounding data from Pine Island Glacier, West Antarctica. During the three months I spent at University of Texas I carried out a comprehensive mapping and analysis of data retrieved by the Shallow Radar instrument from the polar ice on the Martian North Pole. The dataset shows numerous internal layering and bears many similarities to the dataset from Pine Island Glacier. The results from my visit to UT will contribute towards a better understanding of the role of water ice in the Martian climate and the processes influencing the water ice deposits.

Martian Polar Ice

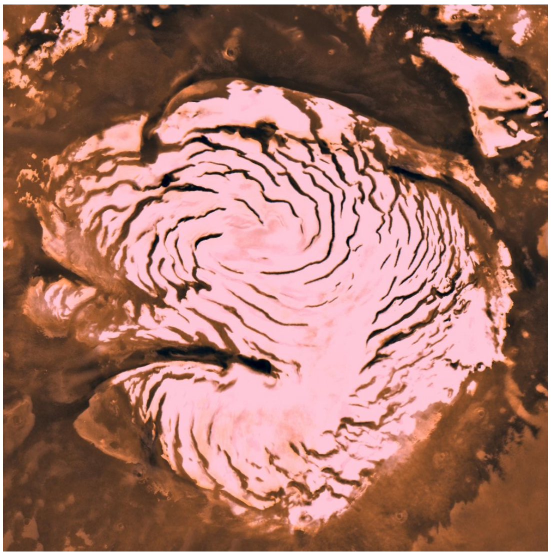
In recent years measurements have documented that Mars has numerous water ice deposits and an active atmospheric circulation of water (e.g. Boynton et al., 2002; Smith, 2004; Holt et al., 2008). It is also clear that conditions on Mars are in some respects quite different to those on Earth with an average atmospheric pressure of less than 0.1 % of the Earth's. Furthermore, the temperature at the poles during winter is below -150°C which means that the atmosphere, that mainly consists of CO_2-ice, freezes and snows out on the surface. Such extreme cold temperatures cannot be found anywhere on Earth but the Antarctic continent is the closest we can get.

The polar layered deposits on the south and north poles on Mars are the largest reservoirs of surface water on the planet. The North Polar Layered Deposits (NPLD) consists of more than 90% water ice (mixed with frozen carbon dioxide and dust) and the interaction between atmosphere and ice plays an important role in the climate system on Mars (e.g. Clifford et al., 2000; Smith, 2004). According to crater counts the surface of the NPLD is geologically young ($< 100\,\mathrm{Ma}$) and some resurfacing processes could be present (Herkenhoff and Plaut, 2000). The NPLD is approximately 3 km thick at its highest elevation point (Putzig et al., 2009) and the surface is cut through by troughs and scarps in a spiralling pattern (see Figure 1). High resolution images from, for example, the HiRISE instrument show layering with different albedo exposed in the troughs and similar layering is visible in the newly acquired radar data (Figure 2). The processes behind the formation of the layers are unknown, but some studies suggest that they are linked to orbital variations (Laskar et al., 2002; Phillips et al., 2008).

The impact of ice flow on the overall shape of the NPLD is still widely debated. Studies have concluded that the upper part of the NPLD shows no evidence of flow (Fishbaugh and Hvidberg, 2006) and that surface mass balance alone can produce the topography (Greve et al., 2004; Greve and Mahajan, 2005). However, a study by Winebrenner et al. (2008) found evidence for relict flow lines in the southernmost part of the NPLD called Gemina Lingula (GL). Since one of the key aims of this project was to find evidence of influence of ice flow on the NPLD, it was therefore decided to focus on GL. An increased



(a)



(b)

Figure 1: *(a) Elevation (in colours) of the NPLD (MOLA Science Team). The negative elevation values are due to the fact that the northern hemisphere on Mars has significantly lower elevation than the southern hemisphere. (b) Viking image of the NPLD (NASA/JPL/USGS). The ice and the troughs are clearly visible as dark areas against the white seasonal ice cover.*

understanding of the processes that are or have been influencing GL will lead to added insight into the past and present Martian climate.

Radio-Echo Sounding

Radio-echo sounding (RES) has been applied to ice masses on Earth for decades primarily in order to extract information on ice thickness. Radar surveys of ice takes advantage of the fact that cold ice is largely transparent to electromagnetic waves in the high frequency and very high frequency bands and that the radar signal will be reflected at interfaces with changes in dielectric properties (e.g. Evans, 1961; Drewry et al., 1982). The largest changes in dielectric properties occur between air and ice surfaces, ice and bedrock, and in the internal layers within the glacier. The layering is caused by changes in permittivity and conductivity of the ice and it is generally agreed that the layers are isochrones i.e. layers of the same age (Robin et al., 1969; Fujita et al., 1999). Since the stratigraphy of the internal layers is the combined result of internal flow mechanisms and surface accumulation the layers represent an important tool for reconstructing the past flow history of the ice (Rippin et al., 2006; Bingham and Siegert, 2007).

While surveys on Earth are conducted either from the ground or from an aircraft (e.g. the so-called "SPRI-NSF-TUD" surveys (Drewry, 1983)) the datasets retrieved from Mars are unique in that they are acquired from satellite. Currently two missions have instruments on board that specifically maps dielectric interfaces; Mars Express and Mars Reconnaissance Orbiter. The Mars Reconnaissance Orbiter (MRO) was launched in 2005 and carries the SHAllow RADar (SHARAD) sounder on board with the aim of mapping and interpreting surfaces marking changes in dielectric properties especially those related to changes in water content (Seu et al., 2007). SHARAD operates with a 20 MHz centre frequency and a 10 MHz bandwidth, a frequency comparable to RES surveys conducted in Antarctica (e.g. Jacobel and Welch, 2005). The resolution across and along track is on the scale of one kilometre whereas the vertical

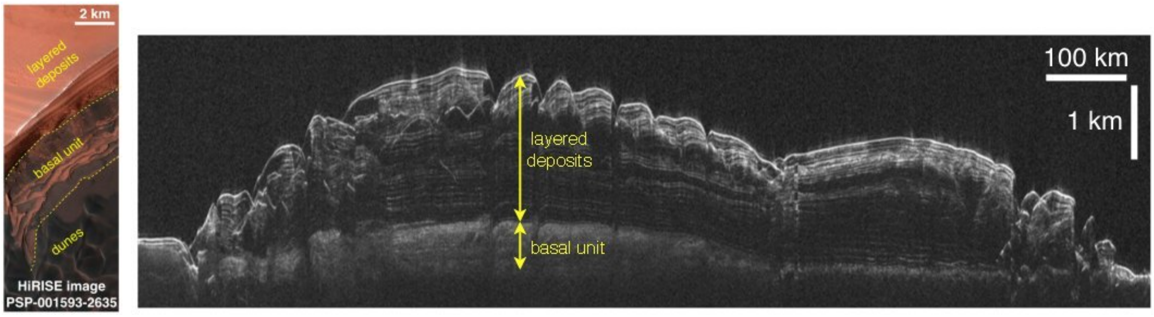


Figure 2: *Left: HiRISE image showing the layered deposits, the basal unit and the dunes. Right: SHARAD radargram (depth corrected) showing internal layers and basal unit (from Putzig et al., 2009).*

resolution is 15 m in free space and less in materials such as ice and rock. As part of its mission SHARAD has retrieved numerous radargrams from the NPLD. Studies based on these data have shown that to a good approximation the NPLD can be assumed to have a dielectric constant equivalent to that of pure water ice (Grima et al., 2009), which give a vertical resolution of less than 10 m. For more details on SHARAD please refer to Seu et al. (2007).

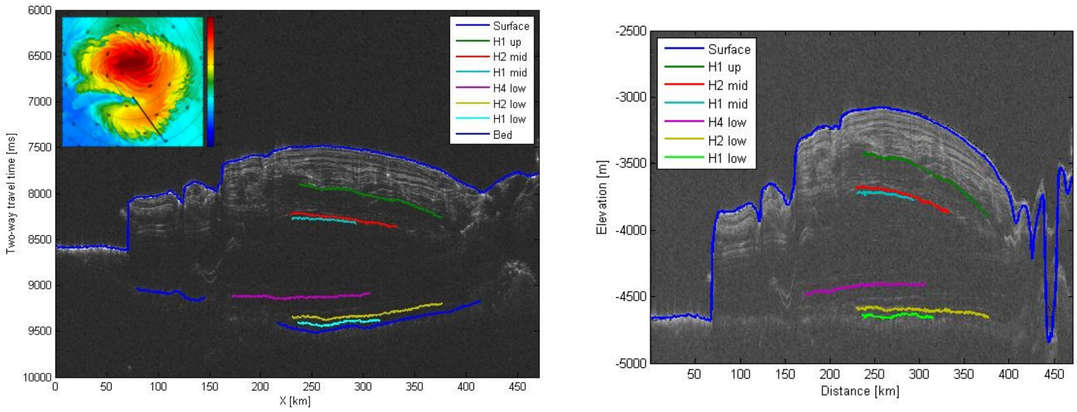
Methods

The majority of the radargrams retrieved from the NPLD show layer packages interspersed with areas of little or no internal reflectors. We analysed over 80 lines crossing Gemina Lingula and traced six different internal horizons. The six horizons were picked on the basis that they were easily identifiable in the majority of the data and were on average present in over 80% of the radar data considered. Figure 3 shows an example of a typical SHARAD radargram with the six horizons traced in colours. The left figure shows the radargram in time domain and the right figure the corresponding depth corrected version (see Holt et al., 2008, for more information on the depth conversion).

The observed layers were then compared to the results from a three-dimensional ice flow model. The model assumes that the shape and the mass balance of the NPLD are constant in time and then calculate the internal layers as they would appear in a flowing ice cap. It uses the slope of a smoothed surface topography, where troughs and scarps have been filled in, to calculate the balance velocity of the ice. Then the shape and age of the layers are calculated as an advection equation assuming an isothermal ice cap of 150K and an accumulation of 1 mm/yr (see Hindmarsh et al., 2009, for details on the model).

Results

The internal horizons were clear and consistently visible in the majority of the SHARAD tracks (each horizon was present in over 80% of the radargrams analyzed). Overall, in the tracks where horizons could be identified the horizons were smooth and followed bed and surface topography with almost no sudden dips towards the bedrock or the surface of the ice. At the outer edges of GL the horizons were often obscured by surface clutter and difficult to trace. The horizons in the Western part of GL had a significantly lower elevation than the same horizons in the Eastern part and the overall trend for all horizons was a gradual increase in elevation going from west to east. The bedrock was visible in most radargrams and it was always practically flat, except when moving from GL towards the main part of the NPLD where the bedrock appears to slope upwards. The angles of the lower horizons were consistently different from the top layers.



(a) SHARAD data as it appears in the time domain.

(b) Depth corrected SHARAD data.

Figure 3: *SHARAD acquisition line no.490701000. The coloured lines show the six horizons that were traced in this study. Note the packages in the upper part of the ice containing multiple layers.*

Comparison between the observed layers and the ice flow model showed that the overall fit between modelled and observed layers is reasonable. Generally, horizons in the upper part of the ice fit less well than horizons in the lower part. Furthermore, the upper horizons achieve a better fit in the western part of GL while the fit for the lower horizons has a less distinct geographical variation.

Discussion and Conclusion

Internal horizons from over 80 SHARAD radargrams were analysed with the purpose of describing their stratigraphy and the possible influence of ice flow. All the horizons that were traced were smooth, and displayed no dips towards surface or bedrock, indicating that the horizons have been formed in an accumulation area and that the areothermal heat gradient is homogeneous.

The difference between upper and lower layers may be explained by the existence of an angular unconformity previously identified within GL indicating a time gap (Holt et al., 2010). Only taking into account individual layer geometry, our comparison between modelled and observed internal layering indicates that it is possible that ice flow has influenced the shape of NPLD. However, in the Eastern part of GL the layer geometries do not fit the modelled horizons unless the radar layers represent an ice sheet that extended much farther south or had a non-uniform accumulation pattern.

Although the ice flow model assimilates the layer stratigraphy the fact that the lower layers are nearly flat lying, could also be consistent with uniform deposition and a lack of flow and does therefore not necessarily imply influence from ice flow.

Publications and Conference Presentations

N. B. Karlsson, J. W. Holt, R. C. A. Hindmarsh and P. Choudhary: *Internal Layering of Gemina Lingula, North Polar Layered Deposits, Mars, and the Case for Ice Flow*, Lunar and Planetary Science Conference (2010)

N. B. Karlsson, J. W. Holt, R. C. A. Hindmarsh and P. Choudhary: *The North Polar Layered Deposits on Mars: The Internal Layering of Gemina Lingula and Implications for Ice Flow*, European Geosciences Union General Assembly (2010).

N. B. Karlsson, J. W. Holt and R. C. A. Hindmarsh (in prep.): *Testing for Flow in the North Polar Layered Deposits of Mars using Radar Stratigraphy and a Simple 3D Ice Flow Model*

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