DETERMINATION OF BOTH DEPTH AND ICE CONTENT OF SUB-SURFACE ICE IN THE POLAR REGIONS. W. Boynton[1], K. Kim[2], D. Drake[3], R. Reedy[2], D, Janes[1], K. Kerry[1], R. Williams[1], K. Crombie[1], and the GRS Science Team, [1]Univiversity of Arizona, Tucson AZ, [2]University of New Mexico, Albuquerque NM, [3]Techsource, Santa Fe NM.

Introduction: Our preliminary estimate of the ice content in the south polar region of Mars [1] showed that at -72 deg latitude the combined neutron and gamma data from the Gamma-Ray Spectrometer [2] implied an ice content of about 35% by mass, buried beneath a dry layer about 40 g/cm^2 thick. At that time, which was shortly after arrival at Mars, we had to normalize our data to "ground truth" and chose 1% H_2O for a water content at the Viking-1 landing site (for neutrons) and 1% H_2O for the entire band between +/-30 deg latitude (for the H gamma rays). We now know that the regions to which we normalized the data have substantially greater H_2O content, which implies a greater sub-surface ice content in the polar region.

In more recent work we renormalized the neutron data from the neutron spectrometer (NS) component of GRS [2] based on the observed flux of neutrons over the thick seasonal CO_2 cap, but this normalization lead to large systematic calibration errors in determination of H_2O in the polar regions [3]. Additionally we showed [4] that the polar regions in the north, based on epithermal neutron data from the HEND component of the GRS [2], were consistent with 50% to 75% H_2O covered by an ice-free layer 40 g/cm^2 thick. This result, however, was only one of a wide range of models that were consistent with the observations.

Using Si gamma rays to constrain ice content and depth. With only one measurement, it is impossible to both determine the depth to the ice layer and its H_2O content; we have two unknowns and only one equation. In principle we should be able to combine neutron and gamma-ray data as was done in [1], but the calibration/normalization errors in the data from the NS make that approach problematic.

In this work we make note of the fact that Si is an element that does not vary by much from place to place on Mars in the middle latitudes, and it is reasonable to expect that the Si content of the dust (non-ice) component of the polar terrain is not significantly different from that seen in the middle latitudes. The amount of ice found in the polar regions is so large that it can substantially lower the Si content just by dilution. In addition, the ice content will disturb the neutron flux beneath the surface, where the gamma rays are generated, such that the measured orbital fluxes of different Si gamma rays are good diagnostics of both the depth to the ice layer as well as its ice content.

Model calculations. It is not possible to invert the orbital GRS observations directly to determine the ice content and depth. Instead, we calculate the expected flux of different gamma rays using a Monte Carlo code called MCNPX. In figure 1 we have plotted the flux of one of the gamma rays from Si generated following the capture of thermal neutrons.

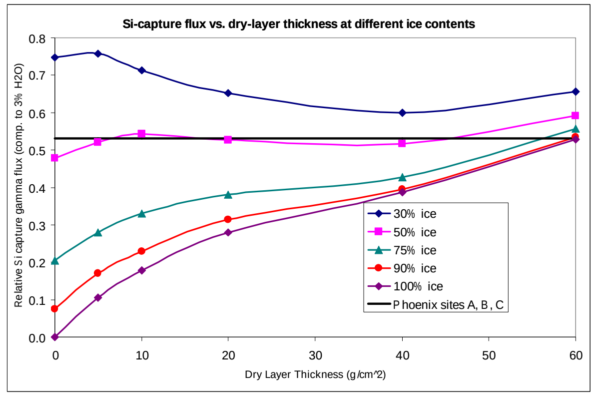

Fig 1. MCNPX model calculations of layered soils. Models have different thicknesses of a dry layer (3% H_2O) on top of an ice-rich layer with different ice contents. It can be seen that the flux of gamma rays from Si is substantially less than that expected (1.0 on this scale) from a dry layer with no ice under it. The lowered flux is due to both the dilution of the dust by H_2O as well as the influence of the H on the distribution of thermal neutrons. The horizontal line shows the average Si flux determined for 3 of the 4 Phoenix landing-site search areas.

It can be seen that for ice-rich layers that have a very high ice content, the flux of Si gamma rays produced via thermal neutron capture decreases monotonically as the dry layer thickness gets smaller. For ice-rich layers with a lesser H_2O content, the Si gamma ray flux reaches a minimum and then increases again as the dry-layer thickness gets smaller. Note also that even for a very thick dry layer of 60 g/cm^2, the effect on the Si flux is substantial, reducing it by 35% to 50% from that expected of an infinitely thick dry layer.

Results of model calculations are shown for a different gamma-ray of Si in figure 2. This gamma ray comes from Si nuclei that are excited due to interaction with fast neutrons. It can be seen in this case that there is a very different dependence of the gamma-ray flux on the nature of the buried ice layer compared to the Si gamma rays that come from capture of thermal neutrons (fig. 1).

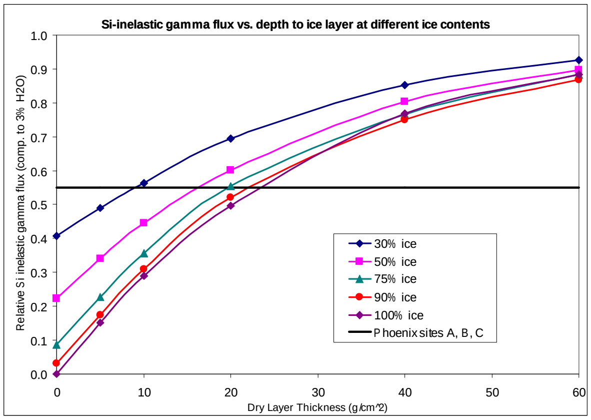

Fig 2. The results of the same model calculations as shown in figure 1 except for a Si gamma ray that is generated following interactions with fast neutrons. Note the very different dependence of the flux of this Si gamma ray as compared to that of figure 1.

The model results shown in figures 1 and 2 can be combined to show the dependence of the Si gamma rays on both H_2O content and dry-layer thickness (DLT). These results are shown in figure 3.

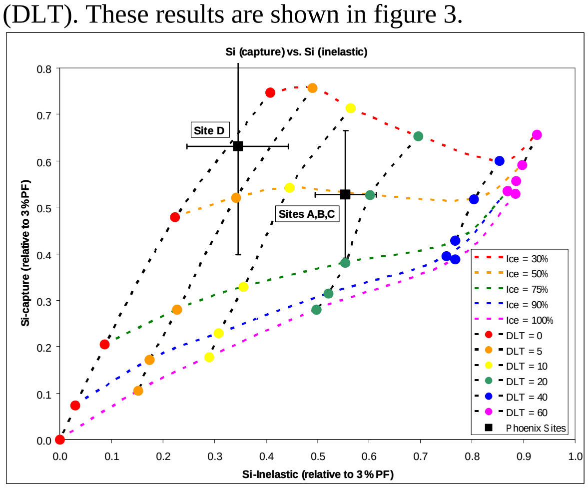

Fig 3. Combination of results from figures 1 and 2. The observations from the four Phoenix landing-site search areas are shown. Sites A, B, and C are similar enough that their observed gamma-ray fluxes were averaged to reduce the statistical uncertainty (shown as 1-sigma).

It can be seen that the data from the search areas for possible landing sites for the Phoenix mission are consistent with 50% ice (shown by the orange, nearly horizontal dashed line) but require different dry-layer thicknesses (shown by the different colored dots). The observations at the Phoenix landing sites cover an area smaller than the footprint of the GRS, so the statistics are rather poor. In essence what figure 3 is showing are parameters related to the flux of both fast and thermal neutrons. The NS and HEND components of the GRS allow the flux of neutrons in these energy ranges to be measured directly in orbit, but the thick (for this purpose) Mars atmosphere makes it very difficult to relate the orbital fluxes to the fluxes beneath the surface, which are more diagnostic of the distribution of H_2O.

The results in figure 3 do not include the most direct measure of the distribution of H_2O, the gamma ray that comes from H itself. If we combine the model calculations for the Si gamma ray made from capture of thermal neutrons with that of the gamma ray from H (also made from capture of thermal neutrons), we get the results shown in figure 4.

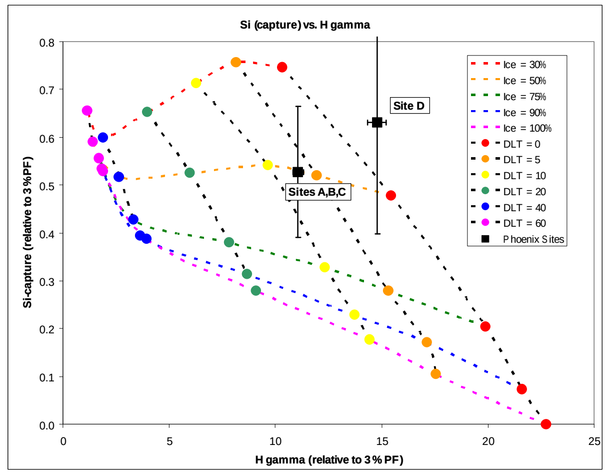

Fig 4. Combination of results for Si (capture) gamma rays and H gamma rays. These data more tightly constrain the H_2O content to values around 50%, at least for site D.

Taking 50% H_2O as the nominal amount in the ice-rich layer, we can use the flux of H gamma rays to determine the thickness of the dry layer in the north polar region. This result is shown in figure 5. A similar analysis of the south polar region shows a higher nominal H_2O content on the order of 75%.

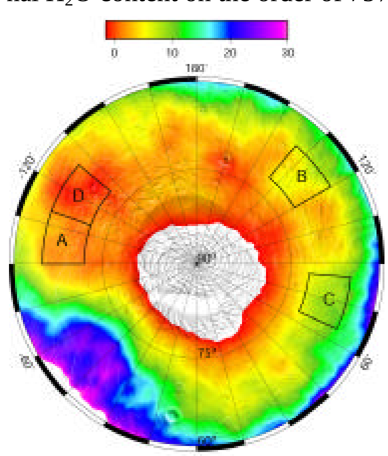

Fig 5. Map of the north polar region of Mars showing the thickness of the overlying dry layer (in g/cm^2) assuming the H_2O content of the lower layer is 50%. The four Phoenix landing-site search areas are shown.

[1] Boynton W. V. et al. (2002) *Science, 297,* 81-85.
[2] Boynton W. V. et al. (2004) *Space Sci. Rev., 110,* 37-83.
[3] Feldman W. C. et al. (2004) *JGR, 109,* E09006.
[4] Mitrofanov et al. (2003) *Science, 300,* 2081-2084.