SURFACE AGES AND RESURFACING RATES OF THE POLAR LAYERED DEPOSITS ON MARS.

K. E. Herkenhoff[1] and J. J. Plaut[2], [1]U.S. Geological Survey, 2255 North Gemini Drive, Flagstaff AZ 86001, USA (kherkenhoff@flagmail.wr.usgs.gov), [2]Jet Propulsion Laboratory, Mail Stop 183-501, 4800 Oak Grove Drive, Pasadena CA 91109, USA.

Introduction: The martian polar layered deposits (PLD) are probably the best source of information about the recent climate history of Mars [1-8], but their origin and the mechanisms of accumulation are still a mystery [9]. The polar layers are sedimentary deposits that most planetary scientists believe are composed of water ice and varying amounts of wind-blown dust [3-5], but their composition is poorly constrained [10]. Interpretation of the observed polar stratigraphy in terms of global climate changes is complicated by the significant difference in surface ages between the north and south PLD inferred from crater statistics. While no craters have been found in the north PLD, the surface of the south PLD appears to have been stable for many of the orbital/axial cycles that are thought to have induced global climate changes on Mars.

Using medium-resolution Viking imagery, Plaut *et al*. [8] found at least 15 impact craters in the southern layered deposits and concluded that their surface is 120 ± 40 million years old. In contrast, Cutts *et al*. [2] found no fresh impact craters larger than about 300 meters in summertime images of the north polar layered deposits.

Observations: Instead of using summertime images, in which differences in surface albedo are difficult to differentiate from shadows cast by topographic features, we studied springtime images. These images show a surface that was covered by a blanket of carbon dioxide frost. This effectively removes the albedo differences and makes topographic features like impact craters stand out clearly. We found no impact craters on the north PLD or ice cap. The images studied cover 74% of the layered deposits and residual ice cap, with resolutions from 20 to 95 meters per pixel. We have confirmed that craters that are 3 pixels across can be recognized in images of adjacent, older terrains taken during the same orbit as the images of the layered deposits, indicating that the martian atmosphere was very clear at the time these images were taken. We examined the features interpreted by Sakimoto and Garvin [11] as impact structures, and interpret them as either semicircular scarps or partly buried craters in the subjacent units. We therefore conclude that there are no craters larger than 300 m in diameter in the area of the north PLD studied.

Model Results: The absence of impact craters larger than 300 meters in diameter indicates that the surface of the north polar layered deposits is geologically very young. We modeled the production and obliteration of an impact crater population on the layered terrain using the modeling techniques developed by Plaut *et al*. [8]. The absence of craters allows placement of an upper bound on the age of the surface of the north PLD, or alternatively, to constrain a minimum rate of vertical resurfacing. We consider two cratering rates, a "nominal" rate of twice the lunar rate (R(20) = 5.6) and a "high" rate of four times the lunar rate (R(20) = 11.2). The "high" rate is justified for these sparsely cratered surfaces, because the higher rates are derived from observations of current and recent (< 1 Ga) phenomena (*i.e*., current populations of impactors, recent cratering events on Earth, Moon and Mars [12]). A cumulative crater size frequency power law of -2 slope is used to extrapolate this rate to smaller sizes.

Ages. We first consider the layered deposit surfaces as production surfaces, with no ongoing crater removal process. We use the observed lack of craters on the north PLD to place an upper bound on the age of the surface. Over an extended period of time, cratering at the "nominal" rate should produce a crater >300 m diameter on an area the size of the layered terrains examined in this study (0.8 million km^2) every 49,000 years, on average. The absence of any craters >300 m diameter, combined with a "counting error" of ±1 crater, allow us to place an upper bound on the crater production age of this surface at 98,000 yr (twice the average interval between impacts larger than this size). In other words, a surface 0.8 million km^2 in area, older than about 100 ka, would be expected to accumulate at least one crater of sufficient size to be detected in the Viking images we examined. Applying the high cratering rate, the upper bound for the age is 49 ka. Considering Poisson statistics, the surface is younger than 3 times the average impact interval, at the 95% confidence level. For the nominal rate, this age is 147 ka and for the high rate, 74 ka.

We applied the same cratering rates to re-evaluate the production ages of Plaut *et al*. [8] for the south PLD. The rate used by Plaut *et al*. [8] is equivalent to an R(20) value of 0.75, far below even the more conservative estimates for the current cratering rate on Mars. Plaut *et al*. [8] were primarily concerned with the long term history of the south polar region, and they included an exponentially decaying heavy bombardment cratering term in their modeling. In the present study, we are examining the youngest polar terrains, and thus assume a constant cratering rate that is consistent with observations of the current and recent flux of objects in the inner solar system. The resulting surface age, assuming the nominal cratering rate, is 14.5±7.2 Ma. The south PLD surface age obtained using the high cratering rate is 7.25±3.6 Ma.

Resurfacing rates. The crater populations can also be modeled as the result of a vertical resurfacing process (either deposition or erosion) that removes craters at a steady rate proportional to crater depth. In this model, an equilibrium is achieved between crater production and obliteration. Rapid crater obliteration rates are required to remove craters from the layered deposits, making the original "age" of the surface inconsequential, since crater production and obliteration come rapidly to equilibrium. Such an equilibrium condition produces a cumulative crater size frequency power law of -1 slope. Ignoring for the moment the poor statistics of small numbers, the presence of a 300 m diameter crater on the area of the north PLD that we examined would be consistent with vertical resurfacing that operates at a rate no faster than 1165 m/m.y. (1.165 mm/yr). The observed lack of craters larger than 300 m diameter, considering again a ±1 crater counting statistic, implies that resurfacing occurs at a vertical rate at least twice this rate (2330 m/m.y., 2.33 mm/yr). Assuming the high cratering rate, the corresponding resurfacing rate for the north PLD is 4660 m/m.y.. These values are of the same order, but somewhat higher, than the deposition rate of 1 km/m.y. estimated by Cutts *et al*. [2].

The south PLD obliteration rate cannot be any higher than that which allows the small craters to be preserved. Hence, we estimate the average resurfacing rate on the area of south PLD studied by Plaut *et al*. [8] as 60 +18/-23 m/m.y., or 0.060 +0.018/-0.023 mm/yr. Assuming the high cratering rate yields a south PLD resurfacing rate of 120 +36/-46 m/m.y., or 0.120 +0.036/-0.046 mm/yr.

Discussion and Conclusions: The north polar resurfacing rate of 1165 m/m.y. is much greater than the resurfacing rate of 60 m/m.y. derived for the south PLD, suggesting that the north PLD are currently an active site of deposition and/or erosion, while the south PLD have been relatively stable over the past 10 m.y. or so. Furthermore, the inferred average surface age of the south PLD (at least 10^7 years) is much longer than the timescales of theoretical orbital/axial variations (10^5 to 10^6 years [14]) that presumably have forced the climate changes that are recorded in the PLD. The area of the south polar layered terrain studied by Plaut *et al*. [8] has therefore not been greatly modified by global climate changes over the last 10 million years or so. The lack of impact craters on or near the south polar residual cap suggests that the surface of the residual cap may be much younger than the rest of the south PLD, but its age and resurfacing rate cannot be accurately quantified without better image data.

The surface ages of the north and south PLD, based on the observed crater densities on their surfaces, differ by at least 2 orders of magnitude. Similarly, the resurfacing rates derived from our model of steady-state crater obliteration are at least 20 times higher in the north PLD than in the south PLD. The implications of these results for the origin and evolution of the polar layered deposits are that most of the south PLD have been relatively stable over the past few million years, while the north PLD have been the site of rapid deposition and/or erosion during the present epoch. The large differences in age and resurfacing rate are probably caused by the ~7 km elevation difference between the poles, which is expected to affect the transport and stability of dust and volatiles in the polar regions [15]. However, the details and relative importance of the various processes involved and their influences on the geologic history of the PLD are not understood. We favor the hypothesis that deposition of PLD has continued steadily in the areas of both polar regions that are covered by perennial ice caps, but has been discontinuous in other areas. Deposition of layers may have occurred over the entire area of the south PLD until about 5 m.y. ago, when the obliquity of Mars no longer exceeded 40°. We look forward to acquisition of new orbital observations of the Martian polar regions from the Mars Global Surveyor and surface investigations by the Mars Polar Lander that are likely to greatly enhance our understanding of the polar layered deposits and the climate changes that they record.

References: [1] Murray, B. C., (1972). *Icarus* **17**, 328-345. [2] Cutts, J. A., *et al*. (1976). *Science* **194**, 1329-1337. [3] Cutts, J. A., *et al*. (1979). *J. Geophys. Res*. **84**, 2975-2994. [4] Squyres, S. W. (1979). *Icarus* **40**, 244-261. [5] Toon, O. B., *et al*. (1980). *Icarus* **44**, 552-607. [6] Carr, M. H. (1982). *Icarus* **50**, 129-139. [7] Howard, A. D., *et al*. (1982). *Icarus* **50**, 161-215. [8] Plaut, J. J., *et al*. (1988). *Icarus* **76**, 357-377. [9] Thomas, P., *et al*. (1992). In *Mars*, University of Arizona Press, Tucson, pp. 767-795. [10] Malin, M. C. (1986). *Geophys. Res. Lett*. **13**, 444-447. [11] Sakimoto, S. E. H. and J. B. Garvin (1999). *Lunar Planet. Sci*. **XXX**, Abstract #1993 (CD-ROM). [12] Shoemaker, E. M. and C. S. Shoemaker (1996). In *The New Solar System*, Sky Publishing, Cambridge, pp. 259-274; Brandenburg, J. E. (1995). *Earth Moon Planets* **67** 35-45. [13] Thomas, P. (1982). *J. Geophys. Res*. **87**, 9999-10008. [14] Kieffer, H. H. and A. P. Zent (1992). In *Mars*, University of Arizona Press, Tucson, pp. 1180-1218. [15] Jakosky, B. M., *et al*. (1993). *Icarus* **102**, 286-297.