RECENT CLIMATE CHANGE DETECTED ON MARS: IMPLICATIONS FOR THE PLANETARY ICE BUDGET.

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Introduction: The north polar layered deposits of Mars (NPLD) are widely considered to contain the best record of recent climate on the planet [1,2]. Studies of stratigraphy within the NPLD have revealed non-uniform layers that record climatic processes such as accumulation, erosion, and wind transport [3-6].

The abundance of detail detected in the subsurface by the shallow radar instrument (SHARAD) on Mars Reconnaissance Orbiter provides evidence of changes in accumulation rates of ice and dust, and other climate forcings, such as wind and insolation [2,7-9], but no direct climate signal has been well-defined to date. Modeling evidence suggests that large quantities of ice may be transported to the NPLD from lower latitudes mantling deposits, and vice versa, on cycles that parallel changes in obliquity [10-12].

Here we present evidence that the NPLD has accumulated a ubiquitous capping layer ~100 m thick. Stratigraphic evidence from many locations (Figs. 1 and 2) shows that the previous state was interrupted at a cap-wide unconformity and increased accumulation. Many stratigraphic features were either buried or changed properties at this unconformity, clearly distinguishing the two periods. We find that this period likely corresponds to an observed and modeled period of desiccation at mid-latitudes, transferring ice to the pole, that began 400 - 350 kyr ago [10].

Methods: Approximately 2,600 SHARAD observations of the NPLD have been collected. We interpret these radargrams in various regions to look for systematic changes in accumulation pattern. A potential source for misinterpretation, clutter, is mitigated by comparing acquired radargrams to synthetic ones which predict echoes from off nadir locations and by choosing orientations with little clutter [6].

Stratigraphic evidence: We observe striking contrasts in accumulation in many regions of the NPLD. The contrasts include uniform 'blanketing' of former deposits (Fig. 2a), migration reversal and burial for topographic undulations (Fig. 2b), unconformities detected by SHARAD (Fig. 2c, 2f, and 2h), burial of migrating spiral troughs (Fig. 2d), and burial of topographic promontories (Fig. 2e and 2g). These contrasts are generally 80-120 m beneath the surface, but locally the unconformity reaches 220 m in depth.

The material that resides above the unconformity is the most recently deposited on the cap, and we call it a recent accumulation package (RAP). The RAP is consistently observed throughout the NPLD (Fig. 1). Near the highest latitudes on the NPLD, the RAP overlies a disconformity, and detailed mapping by SHARAD is required to trace the reflector [6]. Based on descriptions, the RAP likely corresponds to unit ABb3 first detected by Tanaka *et al.* [13].

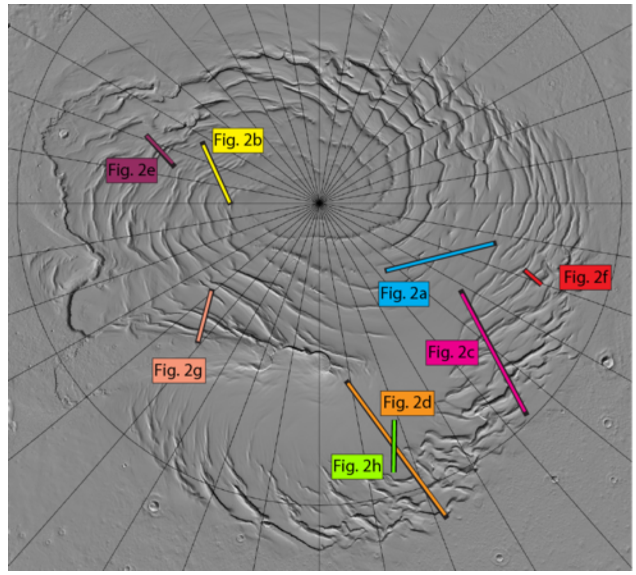

Fig. 1: Location map of images in Figure 2*.The Recent Accumulation Package (RAP) is detected in most regions of the NPLD.*

Head et al. [10] modeled ice accumulation at varying obliquity states and found that prior to ~400 kyr ago ice would have have been removed from the north pole and deposited as a mid-latitude mantle. Since around 400 kyr ago, "*water ice in the mid-latitudes has been slowly and steadily removed from this reservoir by diffusion, sublimation, and atmospheric transport processes; it was deposited in the polar regions, creating the uppermost layers in the polar cap…*" Head et al., went on to suggest that this material, once transferred to the poles, would become the "*uppermost layers in the polar cap*," up to "*several tens of meters*".

We use a nominal accumulation rate of 0.3 mm / Earth year [14] to estimate the time required for RAP deposition. At this rate 260 kyr - 730 kyr are required to accumulate 80 - 220 m, but this was an average, and faster rates are possible for short periods. Using the thickest portion of the RAP, 220 m, and an age of 400 kyr, implies a rapid accumulation rate ~0.6 mm per year, nearly double the published average. 400 kyr is well bounded by the 260 - 730 kyr nominal age estimated here, and we interpret the RAP to be the predicted uppermost layers in the north polar cap [10].

We measure the thickness of the RAP over the entire NPLD and find a volume of 82,000 km^3, roughly equivalent to a global layer 60 cm deep, similar in magnitude to the 1 m global equivalent predicted by [10]. This volume represents the northern portion of **the planetary ice budget**. Any ice accumulation at the south pole would increase this ice budget.

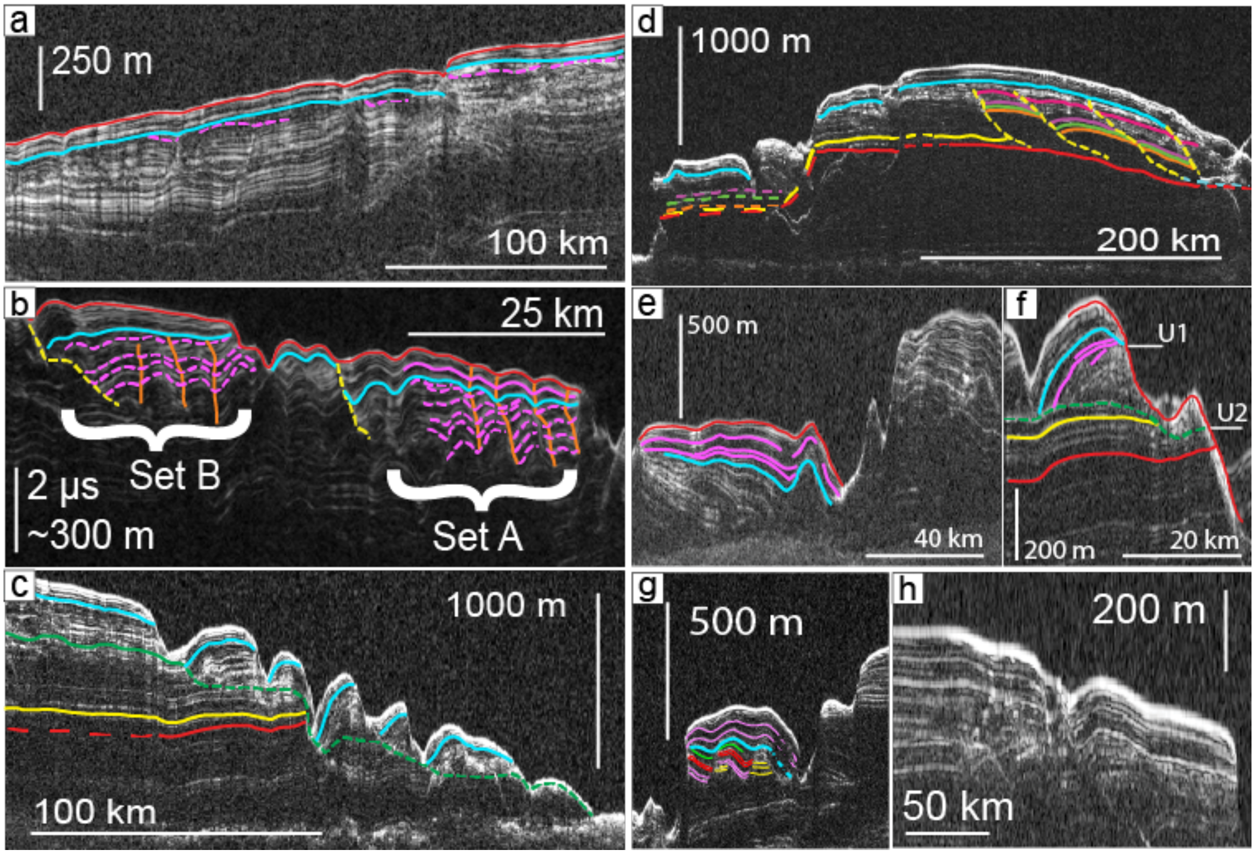

Fig. 2. SHARAD Observations showing evidence for a rapid change in climate. *In all figure sections, an unconformity (turquoise) associated with the RAP is present. Locations detailed in Figure 1. a) Portion of radargram 1998901. b) Portion of radargram 2007101. Stratigraphic signatures of migrating undulations change dramatically at the RAP. Set A reverses migration direction, whereas Set B disappear. c) Portion of radargram 885602. d) Portion of radargram 725402. Troughs in Gemina Lingula migrated southward during several hundreds of meters of accumulation, until becoming buried. They have no surface signature [6]. e) Portion of radargram 556602. A promontory is partially buried by ~100 m of ice [6]. f) Portion of radargram 761602. An unconformity (U1) separates the RAP from lower NPLD. Another unconformity is present (also shown in (c)), but no corresponding change in climate is yet defined. g) Portion of radargram 2265701. Central promontories were buried by ~100 m of ice. h) Portion of radargram 1247002. An unconformity, revealed by an especially bright reflector, is present within 100 m of the surface.*

Conclusions: Our detailed mapping of reflectors with SHARAD has found evidence for a major climatic change approximately 100 m beneath the surface. An unconformity at this level matches predictions of a rapid desiccation and transfer of lower latitude ice to the north pole [10]. Mapping reveals that between 80 and 220 m of ice, depending on location, cover a majority of the NPLD, having been deposited relatively quickly after a period of low accumulation. The stratigraphic signature of this recent accumulation package varies by region (Figs. 1 and 2).

This result, combining observations with predictions from modeling, is the first to tie a stratigraphic level to a date and provides a new constraint in our understanding of NPLD development and their age, including a water budget for the planet.

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