A CLIMATE SIGNAL IN SCALLOPED CLIFF FORMATIONS IN THE OUTCROPS OF THE NORTH POLE OF MARS. A. G. Nair[1] and I. B. Smith[1 2], (akhila91@yorku.ca); [1]York University, 4700 Keele St, Toronto, ON M3J 1P3; [2]Planetary Science Institute, 1700 E Fort Lowell Rd STE 106, Tucson, AZ 85719, United States.

Introduction: The North Polar Layered Deposits (NPLD) of the Planum Boreum region of Mars are stacked layers composed mostly of water ice and dust and record an extensive history of past accumulation and erosion [1]. These layers are sometimes exposed at the surface by troughs and scarps [2]. Understanding this exposed stratigraphy in an outcrop is enhanced by combining geomorphologic details from imagery with subsurface stratigraphy detailed in radar data.

Our study aims to detect locations where radar and imagery data can be used to learn more information about what makes the radar reflections and possible climate records. Of interest are scalloped cliffs that are associated with angular unconformities and potentially bright radar reflectors.

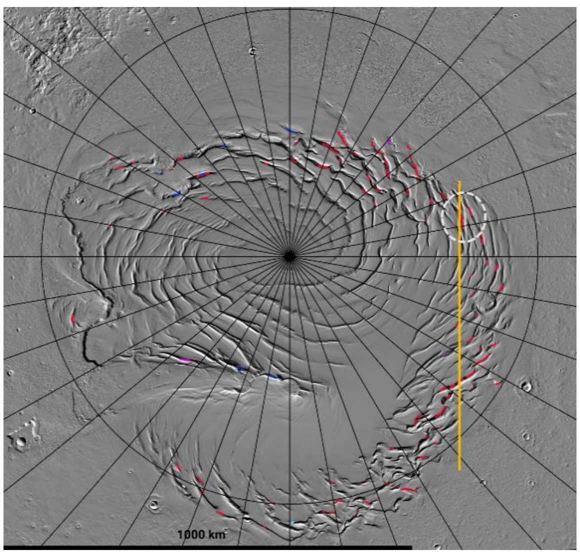

Figure 1: Map of identified scalloped cliff (red lines) locations in NPLD and ground track of Figure 2.

Data and Methods: We mapped "scalloped cliff" features (fig 3b) in outcrops of the NPLD exposed by the troughs using the High-Resolution Imaging Experiment (HiRISE) and Context Camera (CTX) imagery. The HiRISE red band has an image resolution of 31 to 33 cm/pixel and a swath width of ~6 km whereas CTX images have a resolution of 6 m/pixel and a swath width of ~30 km [3]. We used the software JMARS and HiVIEW to visualize the topography of the study area in the imagery. All identified scalloped cliff locations are cataloged with the image ID and location coordinates details. We use a three-dimensional (3D) Shallow Radar (SHARAD) dataset [4] to understand the stratigraphy of the NPLD. After mapping the scalloped cliffs in JMARS with shapefiles, they are converted to a SeisWare format for comparison with a 3D SHARAD data volume [4] for integrating the topography features with the subsurface stratigraphy. A well-chosen radargram can connect distant locations on the NPLD in a single profile, a huge benefit of the 3D data.

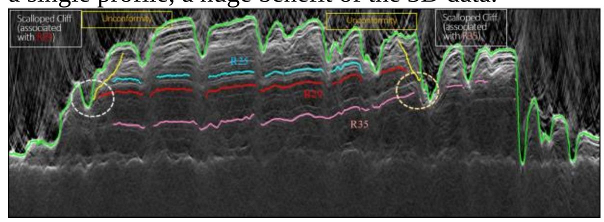

Figure 2: Radargram (orange line in Fig. 1) indicating the exposed reflectors (white circles) with scalloped cliff and an unconformity (yellow lines).

Preliminary Observations: We have identified and mapped 90 scalloped cliffs across the NPLD using the imagery, highlighted in red (Fig. 1). The spatial distribution of identified cliff's location suggests that the scalloped cliffs are more concentrated in the Gemini Scopuli region of the Planum Boreum of Mars (Fig. 1). The cliffs are located more towards the periphery of the NPLD in comparison to the middle region (Fig. 1).

We observe that, in some locations, SHARAD reflectors of NPLD reach the surface (Fig. 2.), providing an opportunity to investigate if any stratigraphic anomalies are present to form a reflection. We compared the elevation of the outcropping reflections to exposures at the same elevations and found unique surface morphology of cliffs that immediately overlie angular unconformities (Fig. 2, 3a.). The cliffs often express scalloping or waviness (Fig. 3.). These scalloped cliffs of the NPLD extend over kilometers, and we observe that most of the cliff formations immediately overly stratigraphic unconformities. We observed a color difference between the material of the cliff and the bed below, and a few scalloped cliffs show the presence of block Falls on their cliff faces (Fig. 3b.)

Some outcrops express a single cliff (Fig. 3a.), but most of the outcrops have multiple cliffs at varying elevations. Lower NPLD sections, immediately above the Basal Unit, are the most likely to express multiple cliffs, (Fig. 3b.).

Interpretations. Cliff morphologies formed after a period of erosion left a lag deposit that was less resistant to erosion than the layers above or below. Subsequent deposition of more resistant material was then undercut by removal of the lag, thus creating a bench-cliff stratigraphy (Fig. 4.). We see evidence of darker material and bench-slope patterns at the cliff bottoms. The scalloped shape is due to wind scouring at an angle (Figure 3b). It is not a coincidence that these correspond

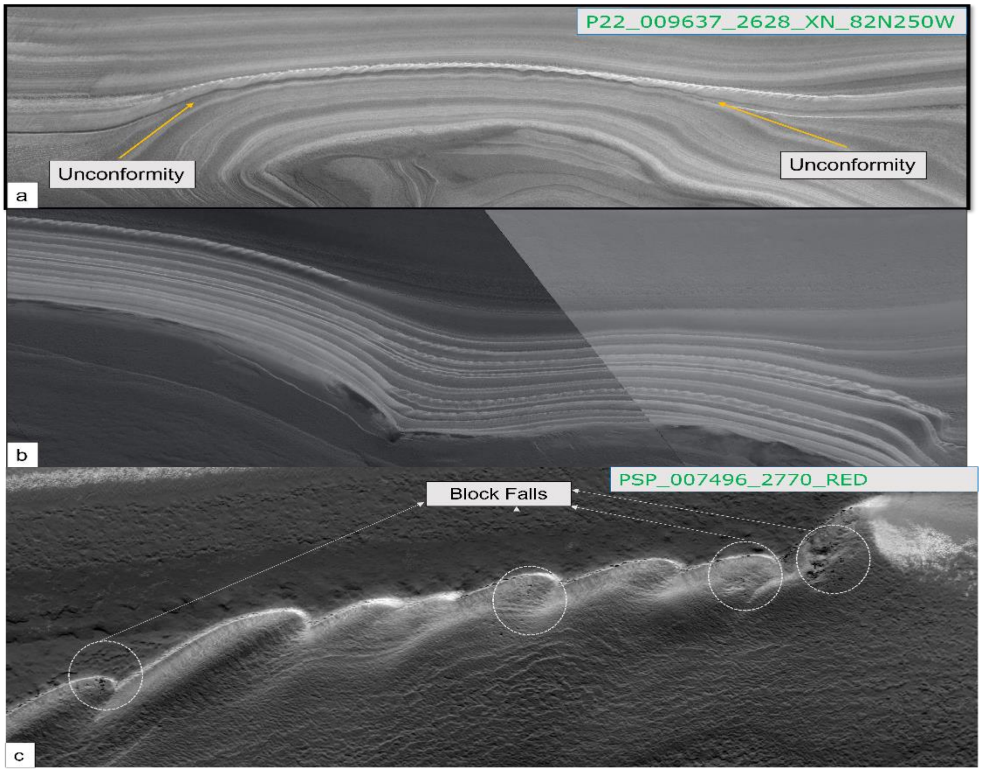

Figure 3: a) Single-scalloped cliff associated with unconformities. b) multi-scalloped cliff in an outcrop c) Scalloped cliff with block falls on the cliff face.

in position to SHARAD-observed reflections. Some bright reflections may indicate the presence of relatively erodible beds, possibly at lag deposits, between resistant units [5].

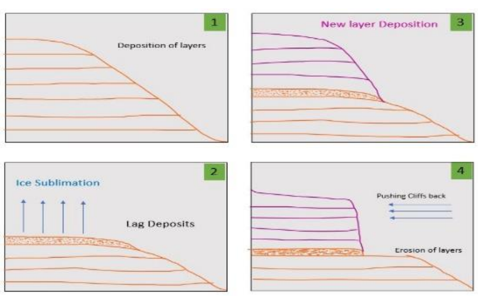

Figure 4: Cartoon depicting the formation of scalloped cliffs.1) Deposition of layers 2) Ice Sublimates from top layer 3) On top of lag deposits new layers deposit 4) Softer layer (Lag deposits) starts to erode pushing the cliffs back

Conclusions: Integrating radar and imagery is an improved method to understand the NPLD formation and the different geological features associated with it. We identified 90 scalloped cliffs across the NPLD and most of them immediately follow a stratigraphic unconformity. Many of these correspond in location and elevation to where bright reflectors in the radar data reach the surface.

Future Work: We aim to connect the radar sounder observations of subsurface layering to layering exposed at outcrops, especially at unconformities, to get a deeper understanding of the scalloped cliffs on the surface morphology and the elevation. We will also inspect corresponding 2D radargrams at every identified scalloped cliff for improved vertical resolution over the 3D volume. Since the angular unconformities associated with the scalloped cliff are repeated in the images, we believe this pattern should be repeated in the radargram as well. We aim to identify the elevation from the MOLA data and from the SHARAD data of each scalloped cliff to establish the connection between the exposed reflector in the NPLD outcrop.

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References: [1] Phillips R. J. et al. (2008) Science, 320(5880), 1182-1185. [2] Smith I. B. and Holt J. W. (2015) JGR Planets 2014- JE004720. [3] Becerra P. et al. (2016) JGR Planets, 121, 1445-1471. [4] Foss F. J. et al. (2017) The Leading Edge 36, 43–57. [5] Lalich D. E. et al. (2019) JGR Planets, 124, 1690–1703.