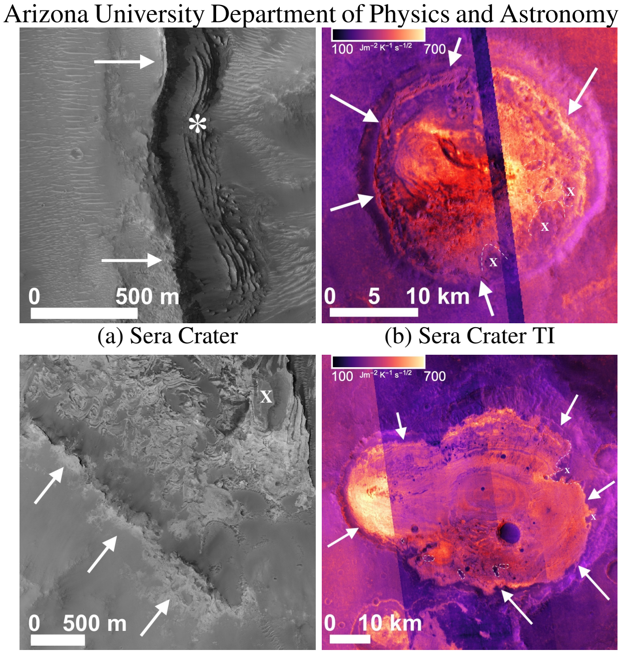
Scarp associated with Martian Layered Deposits in Arabia Terra Andrew M. Annex[1], Ari H. D. Koeppel[2], Cong Pan[2], Christopher E. Edwards[2], and Kevin W. Lewis[1]. [1]Johns Hopkins University Department of Earth and Planetary Sciences, (annex@jhu.edu), [2] Northern Arizona University Department of Physics and Astronomy

Introduction: The Arabia Terra and Meridiani Planum regions of Mars contain many indications of ancient aqueous alteration and sedimentary geology that are thought to be Noachian to Hesperian in age (*1*). One of these features are layered rock units that are found preserved within the interior of numerous craters throughout the region. Previous works have observed these units to express layered morphologies varying from "stair-step" to butte formations and express quasi-periodic bedding responding to Milankovitch forcing (*2*). We have previously described observations of heterogeneous dip corrected layer thicknesses, with a sharp gradient observed over approximately 70 km between Sera and Alofi craters. We now describe a new observation of a scarp-like feature contained within these craters that appears to have the same lithology of the layered units and may mark the youngest unit of deposition preserved in these sites. The scarp might record the climatic change that ended further deposition of layered units within these craters over the whole region.

Methods: HiRISE and CTX images were acquired through the PDS Geosciences node and Digital Terrain Models (DTMs) were produced using the Ames Stereo Pipeline (*3*) following methodologies established by Mayer and Kite (*4*). Additional exposures of the scarp were mapped in the regional CTX mosaic produced by Dickson *et al.* (*5*). Imagery and DTMs were then visualized and mapped in QGIS and in NASA DERT. Measurements of elevation were made using open source python packages including rasterio, geopandas, and the scientific python stack. Orientations of the ridge units as determined by point samples were determined using ordinary least squares techniques developed by Lewis and Aharonson (*6*).

Layered Units: The layered units have been described to exhibit parallel and horizontal bedding of light toned material that is weakly lithified and inferred to be composed of small particles due to the lack of talus accumulation within the craters (*2*). The layers are individually meters to tens of meters in thickness producing sequences hundreds of meters in thickness. We have in prior works measured the thicknesses of the strata within 9 craters in the study region. We found that craters west of 0.5 degrees longitude were observed to have on average layers of 13 meters in thickness and those east to be on average 3 meters in thickness (*7*). This observation may support differential erosion exposing discrete sections of stratigraphy common to the whole region.

Scarp exposure: The layered deposits have been studied using HiRISE images primarily located near the crater centers, but some images have captured portions of the crater walls. These images revealed features not previously described, a scarp-like feature that encircles the interior of the crater wall that is of similar lithology to the layered units contained in the interior: light toned with polygonal fractures. The scarp appears to overlay all observed layered units mapped before, which tend to be located towards the interiors and at lower elevations, and the scarp is laterally continuous across long extents of the circumference of the craters. In Sera crater the layers embedded in this feature are found to conform to underlying topography (see figure 1) and are of similar thickness to those found in the crater interior through interpolation of HiRISE imagery over a CTX DTM. This contradicts suggestions that the layering is lacustrine in origin.



(a) Sera Crater (b) Sera Crater TI
(c) Yelapa Crater (d) Yelapa & Izamal TI

Figure 1: Left Column: HiRISE images ESP_055227_1890 and ESP_015958_1835, Right Column: THEMIS thermal inertia scaled from 100 to 700 $Jm^{-2}K^{-1}s^{-1/2}$ mosaics from Christensen *et al.* (*8*) overlaying CTX mosaics from Dickson *et al.* (*5*). White arrows: scarp feature, $*$: embedded layers, White dashed lines and **X**: dusty mesa unit.

The top level of the scarp tends to form broad surface exposures of the light toned lithology with increasing dust cover towards the crater wall. In these regions, few unambiguous signs of layering are present in contrast to clear layering present closer to the center. Additionally, toward the interior of some craters mesas capped with low thermal inertia, low albedo dusty surfaces are preserved at lower elevations than the scarp top that appear similar to those noted in Meridiani Planum by Ed-

Name	Lon	Lat	Dip °	Azimuth °	Thickness (Meters)
Firsoff	350.6	2.7	0.21	48.6	**747**
Danielson	352.9	7.9	0.71	73.0	**1394**
Banes	355.6	10.7	0.32	60.9	545
Jiji	258.2	8.7	0.61	16.9	623
Sera	358.9	8.8	0.79	109.1	**536**
Alofi	359.9	9.8	1.00	-87.7	429
Wulai	1.0	10.2	0.60	-23.6	**629**
Yelapa	1.1	3.8	1.21	134.5	**266**
Kaporo	14.4	-0.2	1.55	62.2	**623**

Table 1: Table of measurements for all sites. Azimuths reported in degrees from East (counter clockwise). **Bold** thickness measurements are for sites in which the crater floor unit has not been positively identified.

gett (*9*). This raises the possibility that layered material did not completely infill the craters up to this level, and that the top most layer draped downward towards the crater interior which was, in turn, caped by the dusty mesa unit (see figures 1b, 1d). In HiRISE imagery, the top of these dusty mesas have smooth textures indicative of dusty surfaces and have meter-scale impact craters, in contrast to layered deposits stratigraphically below these mesas. Alternatively, this dusty mesa unit may have formed geologically recently, and the scarp layer extended across the full diameter of the crater and afterward experienced significant erosion.

Measurements: The scarp was observed in the following crater locations: Firsoff, Danielson, Banes, Jiji, Sera, Alofi, and Wulai craters using HiRISE, CTX, and THEMIS thermal inertia mosaics. The scarp unit was found to have non-zero dips ranging from 0.2 to 1.5 degrees. No obvious trends in azimuth are reported, the azimuths recorded for Jiji and Sera craters are non parallel despite being adjacent craters. This could rule out the top of the scarp forming a regional depositional horizon, however post-depositional settling and compaction could explain this variability crater to crater.

If the level of the scarp is the upper-most layer of sedimentary material, then the total deposit thickness can at a first order be measured as the vertical distance between the scarp and the contact of the interior layered deposits and units inferred to be the crater floor (see table 1). The crater floor units are distinguished by changes in lithology and the presence of impact craters infilled by overlying layered units. For those craters without an identified crater floor, the deposit thickness measure provides a lower bound for the total deposit thickness. The average of the positively identified deposit thickness was 532 meters, which is close to the number reported for the inter-crater layered units (*10*).

THEMIS thermal inertia data for the region was examined from compiled mosaics generated by Christensen *et al.* (*8*). In some sites, the scarp feature was correlated with elevated thermal inertia values relative to surrounding terrain in the mosaic ranging from 300 to 600 $Jm^{-2}K^{-1}s^{-1/2}$ depending on dust mixing and slope orientation. This could indicate larger than sand like particles or particles that are lithified to some degree (*11*). In other locations the scarp appears to be capped by a dusty surface with lower albedo and thermal inertia, with portions extending into the crater, forming isolated mesas overlaying the layered units (see figures 1b, 1d). More detailed and carefully calibrated thermal inertia data is needed to directly compare inferred particle sizes of the scarp unit to the interior layered deposits and between exposure locations to investigate spatial trends of the scarp lithology in the region as multiple variables such as slope, atmospheric dust opacity, and albedo can influence reported thermal inertia.

Conclusions: In Arabia Terra, a scarp-like feature not previously described has been observed to occur in craters that also contain layered deposits. The properties of this scarp feature have been examined for insight into the nature of the layered deposits. The scarp was found to have consistent lithology, possibly indicating common origin and formation across the region. However, differing orientations between adjacent impact craters were measured. From these observations we produce the following conclusions for what the scarp feature represents for the geologic history of the region:

1. The scarp records a potentially planar surface of the last layer deposited or preserved, possibly recording the end of favorable climatic conditions required to form the layered units.
2. The inconsistency in measured orientations (dip and azimuth), the layering conforming to local topography, and non-planar surfaces of the scarp rule out a common lacustrian origin.
3. Alternatively, post-deposition compaction and settling could have altered orientations significantly to produce the observed inconsistencies.

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