POTENTIAL HOT SPRING DEPOSITS IN VERNAL CRATER, MARS: EXCEPTIONAL CANDIDATES FOR FUTURE EXPLORATION. D. Z. Oehler[1], C. C. Allen[2], G. R. Osinski[3]. [1]Planetary Science Institute, Tucson, AZ, USA, doehler@psi.edu; [2]NASA - retired; [3]Univ. Western Ontario, Ontario, Canada.

Summary: Elliptical features in Vernal crater **(Fig. 1)** [1] may reflect Noachian to Hesperian *hot springs*. These could be of unique astrobiological importance, as *hot springs* not only may host some of the earliest evolutionary lifeforms but can also precipitate minerals that preserve evidence of that life [2-9]. Moreover, the features in Vernal crater may have been part of a major intra-crater trend of hot springs and could provide a rare example of exposed epicenters of spring activity. These deposits would be exceptional candidates for future, small missions utilizing robotic sensors or landers.

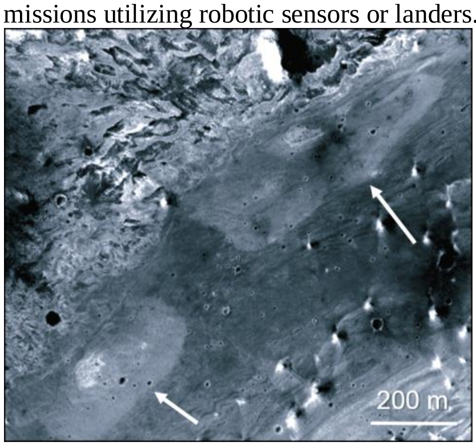

Fig. 1. Elliptical features (arrows) in Vernal crater (HiRISE image PSP_010420_1855_RED). North is up.

Introduction: In 2008, the elliptical features in Vernal Crater **(Fig. 1)** were compared to artesian spring deposits [1]. However, consideration of a hot spring origin is warranted, as several examples of impact-related hydrothermal systems on Mars have been reported recently [10-12], and one from Home Plate in Gusev crater, has been compared specifically to hot-spring biosignatures [13-14].

There is also growing evidence that *land-based hot springs* (as opposed to sub-sea hydrothermal vents) may have hosted life's origin [5-7] – a possibility stemming from work suggesting that hot springs associated with volcanic land masses may have ionic compositions and wet/dry cycles ideal for reactions necessary for the formation of primitive cells from prebiotic precursors [8-9].

New data are now available which allow re-assessment of the Vernal features. These include a HiRISE Digital Terrain Model (DTM) and a Mars analog, the 23-km Haughton impact crater in the Canadian Arctic, which has been reported to host impact-generated hot spring/fumarole deposits [15-16].

Plans are being developed for future, smaller Mars missions using helicopters, drone-based sensors and robotic landers (e.g., [17-19]). These present the possibility of investigating a variety of settings - some riskier than appropriate for expensive missions but offering opportunities to assess sites of unique astrobiological potential. Vernal crater is one such site.

Background: Vernal crater is a 55-km diameter Noachian crater in SW Arabia Terra (6°N,4.5°W). The two elliptical features occur in the southern portion of the crater, within a section of exposed bedding **(Fig. 2)**.

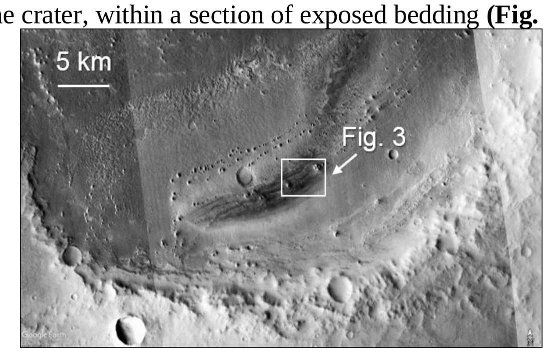

Fig. 2. SW Vernal Crater, CTX mosaic (Google Earth). Dark material is exposed bedding containing elliptical features.

The elliptical features [1] consist of concentric halos of high but varying albedo, where the highest albedo in each occurs in a small central zone that mimics the shape of the larger anomaly. Each feature is also traversed by circumferential fractures. Several similar tonal features extend for 5-6 km, on stratigraphic trend with the elliptical features. Hypotheses considered for the origin of the elliptical features included springs, mud/lava volcanoes, pingos, and effects of aeolian erosion, ice sublimation, or dust, but the springs alternative was most compatible with all the data [1].

New Observations: The HiRISE DTM shows that the elliptical features occur on the flank of a 20 m high, ridge **(Fig. 3)**. The ridge is coincident with the exposed, dark bedding illustrated in **Fig. 2**, indicating that the dark bedding is bedrock that parallels the crater rim.

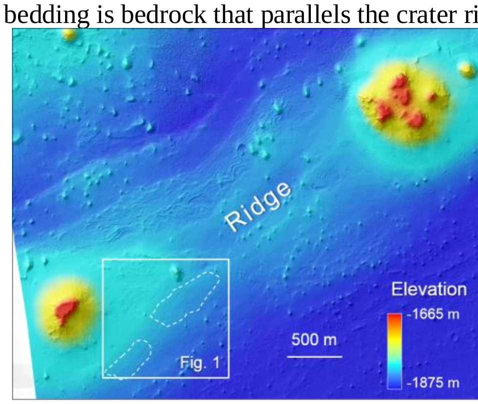

Fig. 3. HiRISE DTM of area shown in Fig. 2. Dashed ovals denote the elliptical features. DTM created by HiRISE team using ESP_011844_1855 & PSP_002812_1855.

The crest of this ridge contains the largest and highest knobs in the crater, each with relief ~110–120 m. Dust cover on the ridge appears to be relatively low, as fine fractures and details of bedding are observable in HiRISE images **(**e.g., **Fig. 1)**, and some CRISM data show responses on the ridge.

The elliptical features are generally flat on the ridge flank, occurring at an elevation of ~ -1832m, ~ 825 m below the crater rim. The elliptical features appear to post-date the ridge, as they crosscut the ridge bedding.

For comparison, the structural interpretation of Mars analog, Haughton crater, is shown below in **Fig. 4.**

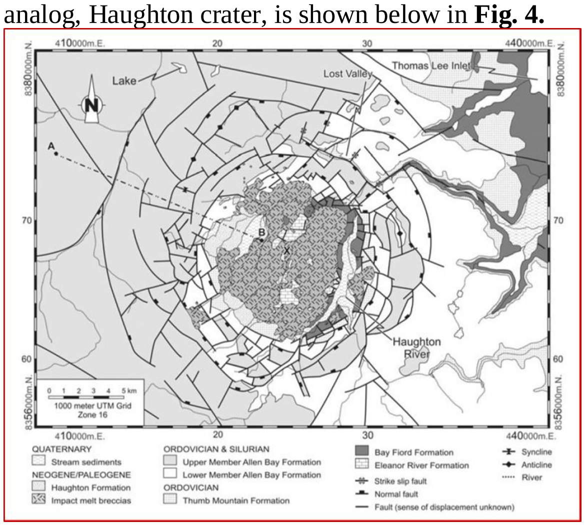

Fig. 4. Haughton crater, showing rim-parallel faults. tilted fault blocks, anticlines, and synclines (from [20].

Discussion. The morphology of the elliptical features (curved boundaries, concentric halos, central zones that mimic the shape of the larger anomalies) suggests point sources of fluid influx from which fluid reaction fronts extended outward. Alternative hypotheses seem less likely, as it is difficult for other processes to account for the morphological details [1].

If the elliptical features were once spring *mounds*, they may have been eroded to their nearly flat relief, as are extinct springs on Earth [1]. Such erosion may have removed overlying strata, providing a relatively rare exposure of this type of ancient deposit.

The location of the elliptical features on a rim-parallel ridge could support their interpretation as remnants of hot springs. By analogy, Haughton crater has rim-parallel ridges of faulted blocks [20] in locations in the crater like that of the Vernal ridge **(Fig. 4),** and faults within Haughton ridges are thought to have been conduits that fed 70+ hydrothermal pipes and spring/fumarole deposits [15-16] **(Fig. 5)**.

The ridge in Vernal crater could reflect a similar, impact-related, trend of faulted, rotated blocks, with the tonal anomalies resulting from mineral deposition as thermal waters 1) cooled during ascent up faults of the crater rim and/or 2) evaporated/froze at the surface. The somewhat similar tonal anomalies that extend along the ridge for 5-6 km suggest a major trend of ancient spring activity. The occurrence of the largest knobs in the crater on the ridge crest suggest *focused* fluid injection into the ridge - a possibility that could have enhanced cementation and erosion-resistance of those knobs (hence their large size and height) and would be consistent with spring development along the ridge.

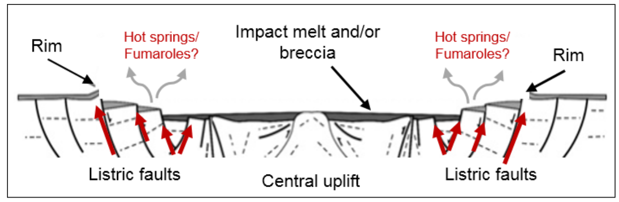

Fig. 5. Cross-section of complex crater, showing potential conduits of fluid movement (red arrows). Adapted from [16].

If the elliptical features represent impact-related hot springs, their formation would have begun shortly after the Noachian impact and continued until the crater was filled to at least 825 m of the rim. That period may overlap with the time on Earth when earliest life was developing, ~3.5 Ga. If similar life was emerging on Mars, evidence may be preserved in carbonates, sulfates, or opaline silica that are common in terrestrial hot springs [2-4] and hydrothermally altered impacts [15, 21], and could be detectable with sensors in helicopters or drones.

Conclusions: New data from a HiRISE DTM and comparisons with a Mars analog, Haughton crater, support the concept that the elliptical features in Vernal crater are remnants of impact-generated hot springs. These features have relatively low dust cover and would be favorable for low altitude characterization of mineralogy, textures, or terracing that could aid in their interpretation. Future drones might also scoop samples that could be returned to a lander for microscopic and organic analyses. The elliptical features in Vernal crater could thus be of major astrobiological significance.

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