CAVE BREATHING IN A TERRESTRIAL ANALOG ATYPICAL PIT CRATER– INSOLATION INDUCED CONVECTIVE COOLING.
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Introduction: Caves are subterranean voids that provide access to both surface and sub-surface geology [e.g. 1], as well as unique microclimates that are often exceptionally stable and benign relative to surface conditions. It has been proposed that Martian caves may preserve evidence of past life or currently harbor extant life [e.g. 2,3]. Caves may provide shelter for future human Mars explorers, protecting them from extreme temperatures and radiation [e.g. 4-6]. Caves may provide access to resources necessary for human exploration, especially water ice [5]. The suitability of caves for the preservation of past life, evidence of extant life, or human exploration and utilization will greatly depend on the cave's microclimate. Many factors can influence cave microclimates such as thermal conduction of geothermal heat, cave breathing (the exchange of inside and outside air), cold-trapping and evaporation/condensation of volatiles within the cave. This abstract focuses on one component that may contribute to cave breathing when the cave entrance is located in an Atypical Pit Crater (APC).

APCs: Atypical Pit Craters (APCs) exhibit a distinctive set of morphologies and thermal characteristics that set them apart from the commonly observed bowl-shaped pit craters. Instead of bowls, APCs interiors are cylindrical or bell-shaped with vertical to overhanging walls that extend down to their floors without forming substantial talus slopes. APCs are generally circular in plan view, and their maximum diameters are over an order of magnitude smaller than those of bowl-shaped pits [7]. Most APCs (~70%) have depth to diameter (d/D) ratios of >0.5, and several exceed d/D ratios of 1.5. Bowl-shaped pit craters often form in chains, and only a handful of these chains (both regionally and globally) contain APCs. Roughly 25% of all currently identified APCs formed within chains of bowl-shaped pit craters. APC diameters are usually less than a quarter of their bowl-shaped neighbors but tend to have comparable depths. It is important to note that although most pit chains on Mars formed along faults and/or in the floors of fault-bounded grabens [8], the pit chains that contain APCs consistently lack apparent spatial associations with grabens or normal faults. Most APCs are solitary, without accompanying pit chains, and are usually kilometers away from other collapse features. An example of a Mars APC with a possible cave entrance is shown in Fig. 1.

Analog Site: The Big Island of Hawai'i has a few terrestrial analogs for APCs. One of these, Owl Pit (also known as Wood Valley Pit Crater (WVPC) cave), formed above a dike located along Kīlauea's southwest rift zone on the island of Hawai'i [9]. Access to the dike is through a ~50 m deep collapse pit followed by an additional 50 m of scrambling through a connecting cave network. Dikes, unlike lava tubes which form near the surface, are usually inaccessible for study. This cave is unique in that its entrance is located at the bottom of a collapse pit (or Atypical Pit Crater) similar to some features observed on Mars [e.g., 7-8,10-11].

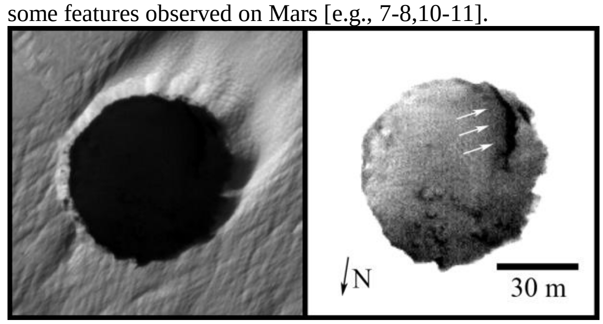

Figure 1: HiRISE Image ESP_016622_1660. Top: A view of the APC without stretching. Bottom: A view of the APC floor where the arrow points at a possible cave entrance. Modified from [7] Credit: NASA/University of Arizona.

Data Collected: We collected temperature (rock and air), humidity, and pressure data at the cave entrance (located at the bottom of the pit) (Fig. 1) and throughout the cave network (Fig. 2). An entire year of data was collected for the upper portion of the cave and ~six months for the lower portion of the cave, which included the dike. Unfortunately, we did not collect wind data from either inside the cave or near the entrance.

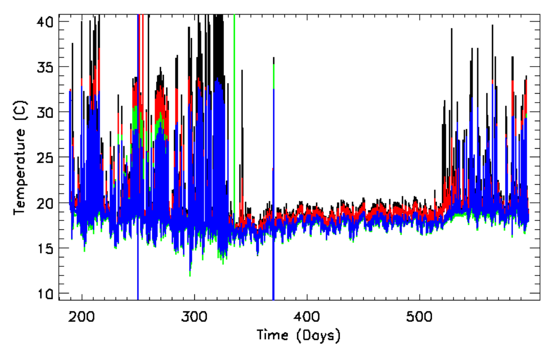

Figure 2: Four surface temperature profile at the bottom of Owl Pit near the cave entrance. The period of low temperature variation occurs when the entrance is completely shadowed from the sun by the pit rim. Each color corresponds to a different sensor.

Data Analysis: We analyzed data collected from Owl Pit cave. During the winter months, the pit wall around the cave entrance (north wall) is in direct sunlight and heat up during the day. During the summer months (Days ~ 350 to 550), the wall around the cave entrance is shadowed by the pit rim and therefore the wall remains at a near-constant temperature. (See Fig 1.)

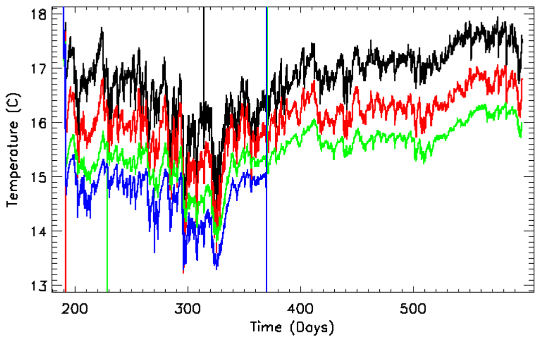

Figure 3: Cave temperatures in descending order: black, red, green and blue.

Over this same period of time, we see two distinct temperature behaviors in the upper part of the cave: (1) During the winter the upper portion of the cave is generally cooling and (2) during the summer this same portion of the cave is slowly warming. While these temperature trends are what one might expect for these seasons at mid-latitudes, this cave is located in the tropics. Also, the change in trends does not occur at a seasonal boundary (transition from winter wet season to summer dry season occurs ~ Day 370 from Figs 2 & 3), but rather when the cave entrance falls into or out of shadow (as indicated by the wall temperatures).

Hypothesis: We suggest that the wintertime cooling is caused by solar heating of the pit wall above the cave entrance. This heating causes convection to occur within the APC, thus causing air to circulate above the cave entrance. This causes a drop in air pressure at the cave entrance, thus drawing air out of the cave. Cooler air deeper in the cave is then drawn into the upper part of the cave, thus cooling it.

The Conceptual Model: A simplified description of the mass airflow from the cave to the pit is as follows. The Bernoulli equation may be used to characterize energy along a given streamline (say, pictured in Fig. 4 within the pit) with velocity V_1, initial pressure P_0 (in this case 101,325 Pa)

$$\frac{1}{2}\rho v_1^2 + \rho g h + P_0 + C = 0 \qquad (1)$$

where C is a constant particular to the given streamline, h is a distance above some datum (e.g. the floor of the pit), ρ is air density (1.225 kg/m^3) and g is gravity. Assume that the air starts at rest somewhere in the floor of the pit (so V_1=0). For a given datum (e.g. h=10m), we may then calculate C= -101445.05.

If we assume a convective updraft velocity of 2 m/s along the warm sidewall and using the previous value of C, we find that the expected pressure drop of $|\Delta P|$ = 233 Pa. Substituting this value into the Darcy-Weisbach equation in order to estimate the mass airflow (Q, in kg s^{-1}) coming from the cave at the foot of Owl Pit: $Q=(|\Delta P|/R)^{½}$, where R is an empirically-determined "aeraulic resistance". Common values of R for rough conduits (such as the cave passageway) are from 0.01 to 0.5 kg^{-1} m^{-1} for 1 m conduits [12]. The cave passageway in Owl Pit is rough-walled with some additional boulders choking the way, hence we estimate the R value to be closer to 0.5 kg^{-1} m^{-1}. The calculated airflow is then Q=22 kg s^{-1}, or 18 m^3 s^{-1}.

The flow rate described here is clearly an upper limit, (especially given that there will be inflow from sources other than the cave passageway) but it indicates that a source of cool cave air (as the temperature within the cave is much cooler than the ambient air at the surface) may be flowing up into the bottom of Owl Pit. We refer to this effect as a "convective cooling effect".

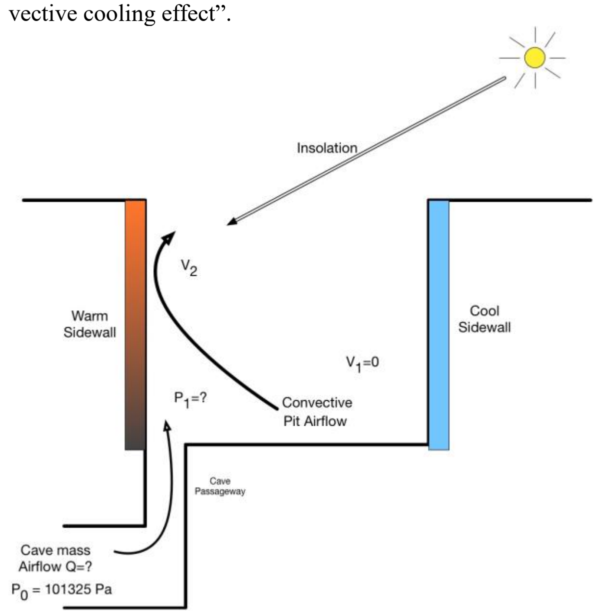

Figure 4: Owl Pit diagram, showing expected airflow patterns due to convection.

Summary: Insolation-induced convective cooling could be an important component for cave breathing where the cave entrance is at the bottom of an APC. One should also note that this affect is of the same order as expected from solar tides[13].

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