# DISCUSSION: "EXTRAORDINARY FEATURES OF LECHUGUILLA CAVE, GUADALUPE MOUNTAINS, NEW MEXICO"

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I would like to address some matters of basic physics and morphology concerning Davis's explanation of rimmed vent formation. He states: "The mechanism of rim formation is not well understood, but they are believed to develop via simultaneous condensation and evaporation across a wall projection. The encrusted sides normally face the surface or the entrance (i.e., a source of cooler, drier air), while the corroded sides face the warmer, moister cave interior. The moisture condensing on the corroded side is assumed to dissolve the substrate there, then move by wicking action to the other side, where evaporation redeposits the material as a rim. In some places, aragonite rims form along walls and ceiling while gypsum rims grow on the floor at the same site, suggesting that slightly drier and therefore denser air tends to follow the floor. (Davis 2000, p.149.)"

Heat flux can only move from a higher temperature to a lower temperature. As Davis observes, this makes the interior, lower areas of a cave warmer than the outer, higher areas. All condensation is the result of decreasing temperature. If warm vapor rising from the cave's interior is in contact long enough with a cold surface for the vapor to be cooled below its dew point, then condensation results. Upon condensing, the vapor transfers the latent heat of condensation, equal to ~600 cal/gm, to the cooling surface, thereby warming the surface unless a heat sink is provided. In the case of a cave roof, the latent heat is probably dispersed throughout the limestone. If this condensation is wicked to a cooler area, then evaporation is impossible. Evaporation requires the addition of 600 cal/gm of water, the latent heat of vaporization, before vapor will enter the air. No source of heat to cause evaporation is available since the rim area (vent exit) is cooler than the vent entrance where condensation occurred, given the direction of heat flow. Dry, or "drier air" may allow evaporation to occur if its vapor pressure is below the vapor pressure of the condensate, but heat is still required.

Physics aside, the morphology of vents and associated rims cannot be explained by a process of condensation, wicking and evaporation, in my opinion. The inside surface of rims appears to be dissolving from the inside out and is always concordant with the bedrock surface of the vent. A physical force, like moving air or water through the vent, must be involved. If air, several obstacles are presented. To overcome surface tension, a velocity of over 40 km/hr is required to drag condensate along the surface. At the same time, for condensation to form, the air must be in contact with a cool surface long enough to reduce its temperature below the dew point, which would not happen unless the velocity was considerably less than 40 km/hr. Consider also, that at these velocities, evaporation is greatly increased, even in 99% RH. How does condensate get blown along a wall for several meters from an entrance to vent without evaporating? Further, the turbulence within the calcite-laden moisture being dragged by air currents would surely cause the loss of $CO_2$, resulting in deposition long before reaching the vent exit.

Vents, rims, and a wide variety of associated forms appear in all stages of development in caves of the Basin and Range, where I have studied them. Many of these occurrences are in physical situations where only the force of moving water would be considered as the likely cause of rims and vents, not condensation corrosion (Green 1997a).

It was a study of vents and rims that led me to the formulation of a totally different theory for deposition of folia than that presented by Davis. He believes them to "…represent a water-table equivalent of shelfstone. Shelfstone maintains a distinct horizontal level controlled by a fixed, perched overflow point. Folia shelves are sloping and overlapping because the calcite accretion attempts to follow the irregular fluctuations of a calcite-saturated water table" (Davis 2000, p.152).

In Goshute Cave, Nevada, two side-by-side passages are at the same elevation. In the west passage, a thick mammillary coating of calcite is mostly dissolved away, exposing bedrock. A rimmed vent connects from the west passage to the east passage, where the mammillary coating is undisturbed and is coated with folia. The lowest folia occurrence is coincident with the lowest part of the vent. If folia are deposited at a fluctuating water table, then why are there no folia in the west passage? My interpretation is that the west-side dissolution, vent scouring, rim and folia deposition, were all occurring at the same time. As the dissolving waters in the west passage emerged from the vent, an out-gassing of $CO_2$ occurred, depositing the rim and creating calcite nuclei, which then form crystallites. It is beyond the scope of this discussion to explain how these crystallites attach to the downward-facing surfaces (folia are only found on downward-facing surfaces), form small ribs, then through accretion, create upside-down cups capable of trapping gas. When studied in detail, folia exhibit very complex forms that, in my opinion, cannot be explained with the fluctuating water table theory but are completely plausible with a subaqueous origin. A more complete discussion of this theory of folia genesis is described in Green (1997b).

Additionally, it is stated in Davis's article that Utah has caves with folia. I believe this is an error.

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# REPLY: "EXTRAORDINARY FEATURES OF LECHUGUILLA CAVE, GUADALUPE MOUNTAINS, NEW MEXICO"

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Condensation-corrosion/evaporation cycles have been shown to be capable of significant influence on cave morphology (Sarbu & Lascu 1997). I know of no quantitative studies specifically on rimmed vents, but my speculative rim model does not violate the physics of evaporation. External warming is not needed to evaporate condensed moisture that has seeped to a cooler, drier spot. If atmospheric humidity is low enough that the condensate's vapor pressure is not in equilibrium with it, evaporation will take place. The air, water, and, to a lesser extent, the substrate will cool further to satisfy the energy budget.

Green devises an alternative subaerial mechanism postulating strong wind blasting the condensate film along the wall, then dismisses it, for good reasons. Having rejected both my idea and his, he concludes, in effect, that a subaerial mechanism for rimmed vents is theoretically impossible, so they must be subaqueous. This reminds me of proverbial theoretical claims that bumblebees can't fly. There is overwhelming evidence, in composition, morphology, and context, that the hundreds of rims in Lechuguilla Cave originated subaerially. Those composed of carbonates are mostly acicular aragonite in the form of frostwork. Frostwork grows in air, typically under evaporative conditions; I am aware of no example of demonstrated subaqueous growth. The many non-carbonate rims in Lechuguilla are gypsum. I know of no plausible mechanism to deposit and preserve gypsum preferentially around underwater orifices; $CO_2$ degassing is irrelevant. Nor do these rims ever show any genetic association with demonstrably subaqueous features.

My suggested model for rimmed vent development may or may not be correct, but the correct one (at least for Lechuguilla Cave) must certainly be subaerial. The process is apparently very slow and subtle, and may have started almost as soon as the water table dropped below the levels where the rims occur, taking up to several million years to translocate a few centimeters of wall rock from one side of a projection to the other. The physical gradients involved may be extremely small.

Green has never been to Lechuguilla Cave, but extrapolates from observations in Great Basin caves. In Goshute Cave, Nevada, he proposes that wall dissolution, creation of a rimmed vent, and folia deposition via $CO_2$ degassing in the next chamber outflow, were simultaneous and subaqueous. I have also visited Goshute Cave, and saw no proof of this assertion. The denuded chamber and rimmed vent appeared consistent with condensation-corrosion. Goshute Cave, like Lechuguilla, is an old cave of hypogenic origin—quite possibly hydrothermal—and could have had a sufficient temperature gradient to drive a corrosion/evaporation cycle before it was entirely drained. If folia had existed in the corroded chamber, they would have been the first layer removed. If they never grew there, it may be because this chamber was closed to air circulation by a sump at the connecting orifice, so $CO_2$ degassing and evaporation could take place only on the outer side of the constriction.

In Green's model, as exemplified by Goshute Cave, the relationship between rimmed vents and folia deposition predicts that folia should occur in the outflow direction from vents. In Lechuguilla Cave, the converse is true. Vents and rims are predominantly in the middle to upper levels, whereas folia are limited to the lower levels, in the inflow direction (assuming rising water) from any scoured and rimmed vents. The Lechuguilla folia are well developed only in two laterally separated areas within ~40 m vertically above the present water table. In all other caves where I have observed folia, they are even more restricted to a narrow vertical range, being limited in the most extreme case to a few-centimeter-high "bathtub ring" in Groaning Cave, Colorado. This seems to me consistent only with a fluctuating-water-level interpretation, not with a fully subaqueous one. The invariable association of calcite rafts with calcite folia also strongly suggests water-level control. Deposits of unquestionably subaqueous origin, such as mammillary crusts, may be associated with rafts but often are not.

Green has made a valuable observation in pointing out that folia can trap gas when they *are* submerged. This is no doubt important in development of folia morphology (restricting most accretion to the top and edge of each inverted cup). This gas may be degassing $CO_2$, or it may be no more than cave atmosphere trapped when water level rises periodically. $CO_2$ degassing, though clearly favorable to carbonate folia growth, is not essential to folia accretion, as the existence of mud folia (Davis 1984) and sulfur folia (Hose *et al*. 2000) shows. Probably the critical requirement is simply a variable water level with a surface scum and/or subsurface suspension of fine particles capable of adhering to growing folia.

I have read Green's prior publications on these matters, but remain unconvinced that rimmed vents develop underwater (though subaqueous features of similar appearance—variants on "geysermites"?—may be possible), or that folia are more than intermittently subaqueous. Continued controversy, however, shows that these phenomena are not understood well enough to remove all doubt. I hope that this will provoke others to contribute new thoughts and observations.

Finally, Green is probably correct in questioning my inclusion of Utah among states known to have folia. I may have been thinking of Indian Burial Cave, which is just inside Nevada.

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