Correlating varnish microlaminations derived climate signals with protalus ramparts formation: Henry Mountains, Utah

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Abstract

This study was conducted to determine the formation history of the protalus ramparts at the base of the Black Mesa Bysmalith, using climate signals from varnish microlaminations (VML). The oldest varnish began to accrete on rocks within the ramparts at approximately 267 ka, during the Pre Bull Lake glaciation. An increased abundance of Mn, as seen by darker layers in the ultra-thin section, indicates a wetter climatic period. Thus, the ramparts likely formed at the time of the oldest VML. The formation of ramparts by a long standing snowbank, upon which eroded rocks slide, roll, bounce, and are deposited at the edge of the snow bank, is the most probable mechanism of formation.

Background

- The Henry Mountains are structured by laccoliths, which is an igneous intrusion that creates a dome shape due to their high viscosity. A bysmalith is a type of laccolith that is bounded by faults and crosscut adjacent sediments.
- The Black Mesa bysmalith is an intrusion of porphyritic diorite, comprised predominantly of Na and Ca plagioclase feldspar, biotite, and hornblende.
- The Black Mesa rockfall formations lie on the NE and SE slopes of the Black Mesa bysmalith, and have been hypothesized to be protalus ramparts (Kenny et al. 2015)
- Protalus ramparts are depositional landforms described as coarse angular rockfall clasts derived from bedrock cliffs with various mechanisms of formation generally considered to be partly mass wasting and partly periglacial. The rampart refers to the up angle opposite to the slope providing the debris as seen in Figure 8.
- Protalus ramparts are closely tied to periglacial processes, which can be defined as cold-climate geomorphic processes. Whether an environment can be described as periglacial depends on the relict features observed, as well as the climatic history of the area.
- The Black Mesa ramparts have been dated to an approximate age of 267 ka, placing its formation prior to the Bull Lake glaciation (Pre-Bull Lake). The study site was investigated for evidence of periglacial processes, with respect to the climatic conditions indicated by the structure of the varnish microlaminations (VML) that have formed on the surface of the rocks.
- VML comprise a mineralization stratigraphy, and are formed by Mn, Fe, Al, Si, Mg, K, Ca, P, Ba and other metals that are precipitated from the rock through acid rain and then cemented biotically to clays that are deposited by aeolian processes. Slow growing bacteria and lithobionts help to oxidize Mn and Fe from the rocks, creating the barrier of movement for Mn. The VML change the mineralogy of the rock and provide a built-in model for local climate and mineralogical changes of the rock. The change in mineral composition is noted by a change in color in the VML ultra-thin section (fig 6) (Dorn, 2009).
- Climate fluctuations change the pattern of microlaminations and they grow differently in wetter and drier climates. While the abundance of Fe in VML stays relatively constant, wetter climate periods are associated with a higher abundance of Mn, noted by dark layers, while drier periods are associated with a lower abundance of Mn, noted by red layers. The VML in our ultra-thin section are also noticeably thicker in cold-climate periods, such as LU - 6 which precipitated during the Bull Lake Glaciation (figs 6 and 7). Thus VML can be utilized as proxies for climate conditions at a particular locality.
- As Galloway (1969) notes, the timberline at the time of formation of the protalus was 1,300 to 1,400 meters lower than the current timberline, and the temperature was 10-11°C colder during the Wisconsinan glacial period.

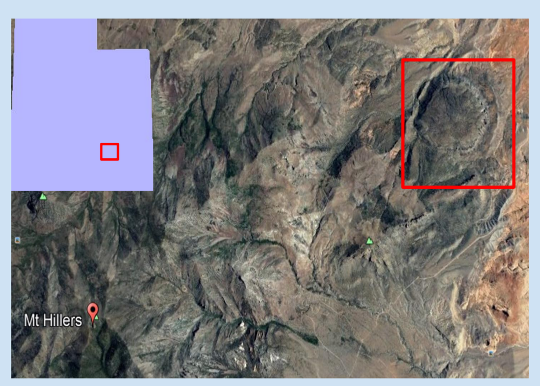

Figure 1. Location of the Black Mesa bysmalith in the Henry Mountains (37° 53'16.36" N 110°37'21.63" W). Bysmalith indicated by red rectangle.

Figure 2. View north showing main talus slope to the west and rampart slope to the east, separated by central depression and loess.

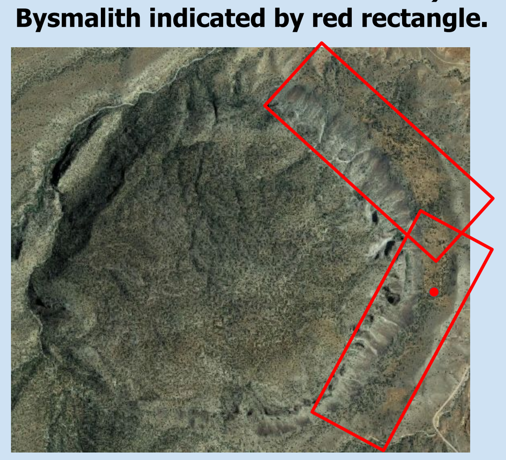

Figure 3. Satellite photo of Black Mesa bysmalith showing protalus ramparts along the Eastern face. Protalus Rampart shown by Red Rectangles. Dot shows location of figure 2

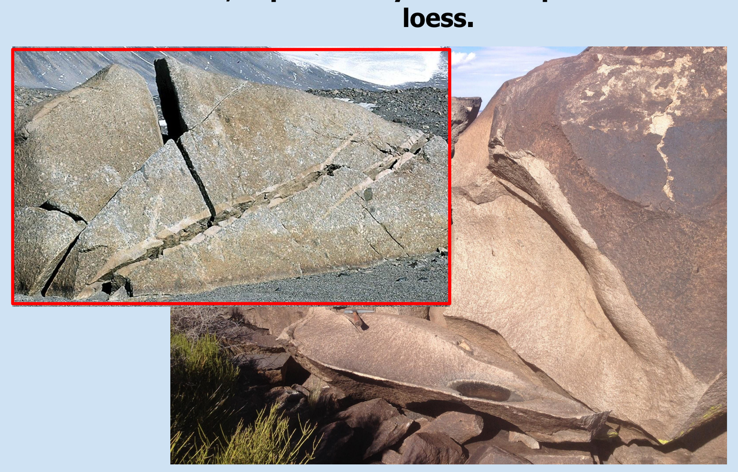

Figure 4. Varnish micro-laminated boulder among ramparts, showing extensive weathering and possible frost fracturing and wedging. Inset shows notable example of frost weathering. From Albion, 2010.

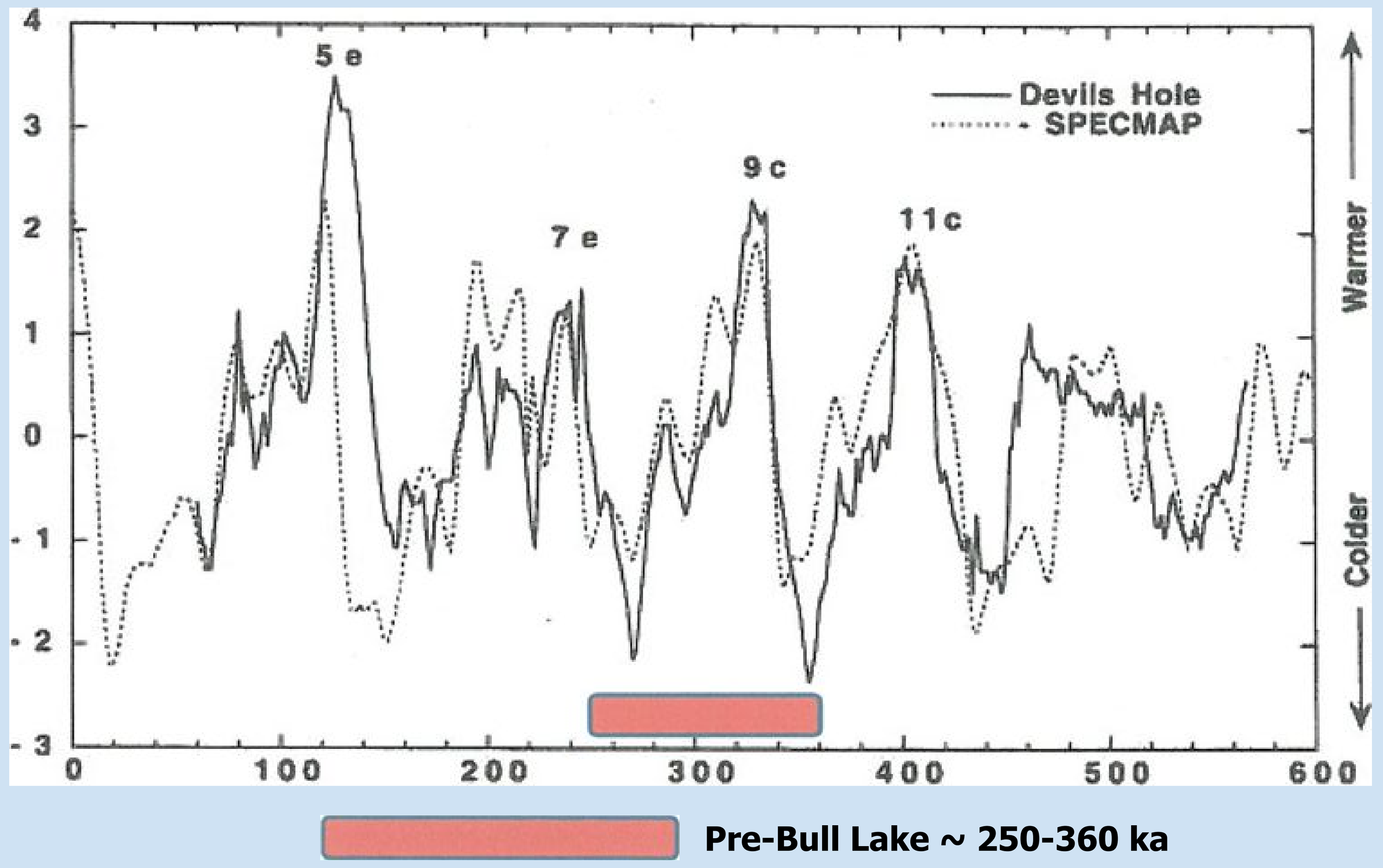

Figure 5. Pre Bull Lake Glaciation Period with Oxygen 18 Isotopes in Standard Deviation Units on the left axis and Colder and Warmer Periods on the right axis. The Black Mesa protalus ramparts have been dated to 267 ka, during Pre-Bull Lake Glaciation period, but just prior to Bull Lake Glacial Period.

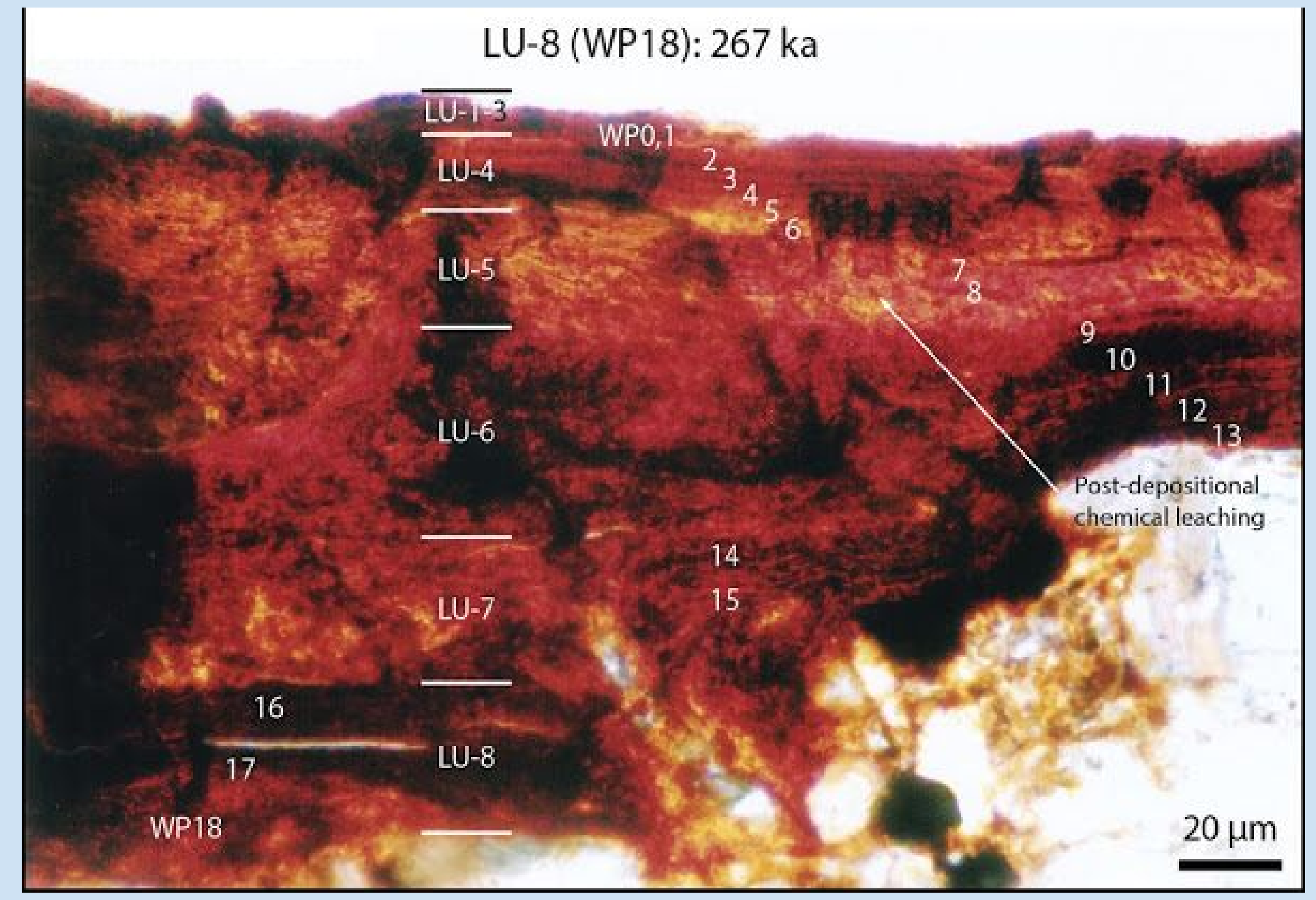

Figure 6. Ultra-thin section (10x thinner than normal) of VML on the protalus rampart at the Black Mesa Bysmalith. LU = layering units, WP = wet phase. VML are the world's slowest accumulating stratigraphic deposit, and laminations can represent on average ~1µm per 1000 years (Dorn, 2009).

Key Results

- Examining the oldest sequence present on the varnish microlamination from the protalus rampart at the Black Mesa Bysmalith, as seen in the ultra-thin section (fig 6), and correlating it to the varnish microstratigraphy (fig 7), we can conclude that the oldest lamination happened at ~267 ka for this specific rock sample.
- Correlating the layering units and layering sequences (fig 6) with the levels of ^{18}O present at the time of deposition (fig 7) shows that the varnish was placed during times of colder climate.
- The elevation levels of periglacial features in the Henry Mountains, as noted by Dr. Ray Kenny, indicate that the lowest elevation at which periglacial features have been observed is 2700 meters (8800 feet), for small sorted nets on NW facing slopes.
- Marker (1990) recorded periglacial features observed at Latitude 37° North in Colorado, including a rock glacier and scree at elevations between 2500 and 3000 meters (8202 to 9843 feet), significantly higher elevations than the Black Mesa bysmalith, which lies to the west at a latitude of N 37°55'40'' (fig 1) at an elevation range of approximately 1682 to 1816 meters (5520 to 5960 feet).
- The slope angle of the distal talus deposits was averaged to 40 degrees, while the slope angle of the rampart was averaged to 8 degrees, over several measurements along the eastern side (fig 4). Ramparts are thought to commonly form slope angles greater than 20 degrees (Shakesby, 1997). However, given the age of the deposits erosion may have reduced this angle significantly.
- Features observed on the talus rampart include frost weathered and shattered boulders and extensive exfoliation on fallen diorite blocks.
- The cliff face of the bysmalith is relatively unweathered in the northeast quadrant, while the southeast face is heavily fractured and jointed.

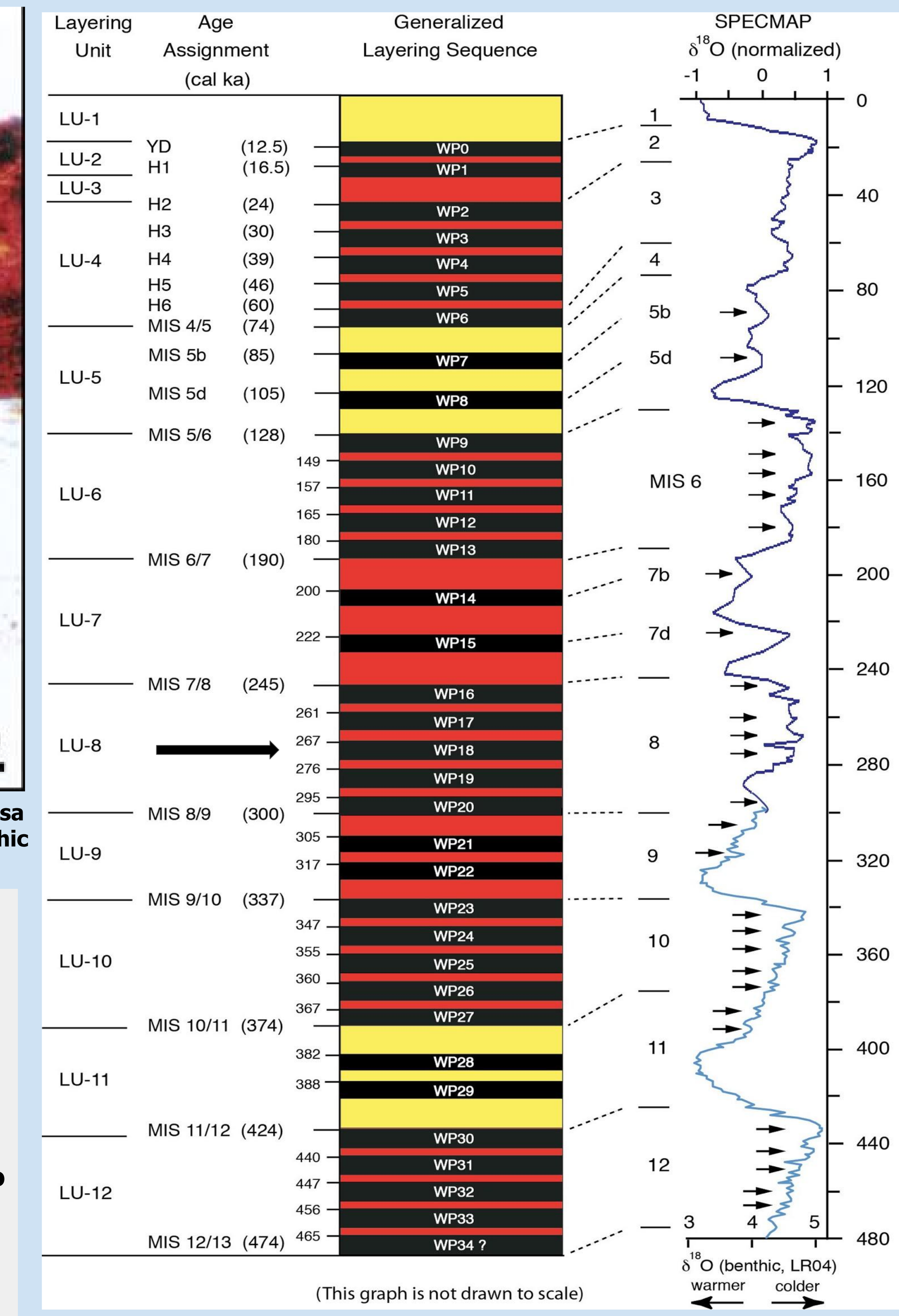

Figure 7. Varnish microstratigraphy
H = Heinrich event, LU = layering unit, MIS = marine isotope stage, WP = wet phase in Pleistocene, and YD = Younger Dryas. Black arrow shows the climate period and year that corresponds to the oldest VML.

Hypotheses

Talus Formation

- The minor evidence for the periglacial weathering and formation of talus by periglacial processes is outweighed by the climatic history of the region, and the minimum altitude of periglacial features noted in the Henry Mountains.
- Thus, a likely source of talus formation is erosional processes, through frost weathering, by wedging, shattering of the exposed diorite in the cliff face, and expansion and contraction of they clays in the diorite.
- Two likely processes for talus formation are frost weathering, which causes rockfall to accumulate at the base of the perennial snowbank, and permafrost creep, which is gravitational creep of permafrost down a talus slope.

Protalus Rampart Formation

- A persistent snow bank does not require periglacial conditions in order to form and is a likely way for protalus rampards to form (fig 8).
- Persistent snow banks often depend on the presence of shaded conditions below the cliff face and talus slope, which would explain why it is more heavily weathered on the southeast face.
- The protalus ramparts observed in this study could have formed pronivially through rolling, bouncing, and sliding down the snow bank, or subnivially as debris flows.

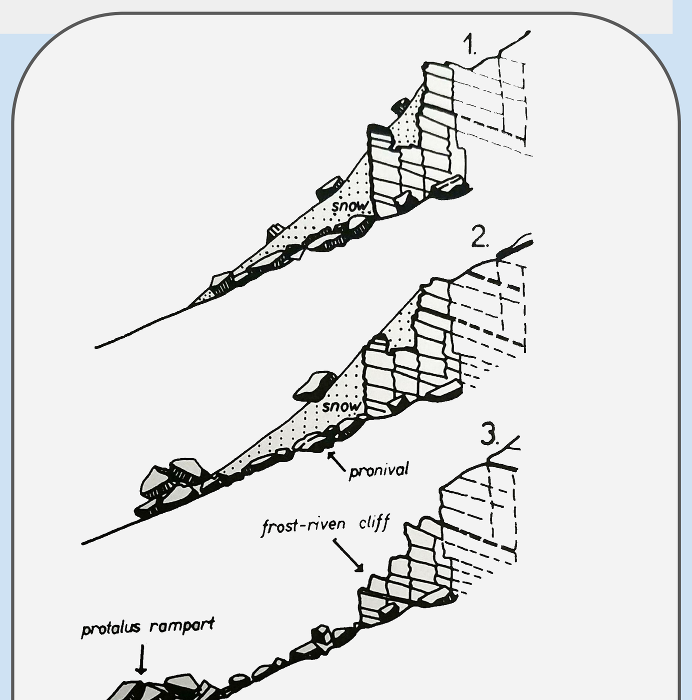

Figure 8. Profiles showing the development of protalus ramparts from a snow bank. Modified from Jemek, 1969.

Figure 9. 3D Graphic of hypothesized snow bank on the terrace below the upper talus slope. In reality the thickness of the snowbank would likely be graded as seen in Figure 10 (to the left).

Discussion

- The weathering features observed in boulders that have fallen from the slope and remained immobile, based on the level of varnish coating, can potentially be explained by frost weathering processes, such as wedging, exfoliation, and shattering, which would accelerate in colder climate periods due to the high daily temperature variation characteristic of this low moisture area. The more extensive weathering on the south extent is perhaps indicative of the solar radiation difference during the day, and subsequent change in rock surface temperature.
- The oldest VML on the ramparts occurred during a cold, glacial and wet climatic period. The moisture provides the high precipitation necessary for a snowbank to form, while the cold temperature allow a snow bank to persist over a period of time that could have lasted months to years.
- The central depression which divides the ramparts from the toe is filled with loose silt characteristic of loess deposits. During cold climate periods, the hypothesized snow bank would have occupied this depression, and acted as a surface upon which the protalus developed. This would have created a slope with eastward extension, forming a bridge that would potentially allow deposits to form along the eastern edge of the terrace, which now comprises the toe. As the snow bank melted during modern warm climate cycle, the base of the protalus slope would have shifted westward, and the slope would have steepened. Thus, the cold-climate toe would have become isolated from the main slope. The depression left by the former snow bank would thus represent new accommodation space upon which the loess deposits formed.
- Frost weathering would be a mechanism possible of shaping the slope on the bysmalith. The cold climate would be capable of frost-riving the edge of the bysmalith and create rock fragments. These fragments formed from the broken edge of the cliff would be collected at the bottom of the snowbank and form the protalus rampart.
- The talus deposits continue to form as evidenced by the modern slides in Figure 4, while the ramparts exist as relicts of past processes, and likely had greater height at the time of their formation. As the ramparts eroded, and blocks fell down the lower terrace, they have likely lost height over time.

Acknowledgments

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