Sedimentary Structures in the Upper Kingston Peak Formation: Implications for Snowball Earth Environments

Jesse Einhorn, Senior, Earth & Space Sciences
Mentor: Darrel Cowan, Earth & Space Sciences

Introduction

The "Snowball Earth" events of the late Neo-Proterozoic Era were global cataclysms, in which most of the Earth was covered by ice for millions of years. Despite the implications for early Earth history, the extent of glaciation and the climate during Snowball Earth remain poorly understood. The duration of the glacial epoch, the condition of the oceans, and the erosive impact on landmasses are all largely unknown.

The Kingston Peak Formation in Death Valley, California, is a thick sequence of Neo-Proterozoic sediment that shows textures characteristic of glacial deposition. By examining the sedimentary structures in the upper-most members of the formation, we infer the local environmental conditions around the ice sheet at the end of Snowball Earth.

Methods

Our field investigation was centered on two little-studied locales to the southeast of Death Valley: the Ibex Hills and the Alexander Hills near the Kinston Range. (**Fig. 1**)

In the Ibex Hills, we drew two measured sections through the formation. We noted changes in lithology and particle composition, and took representative samples for laboratory analysis. In addition, we observed large-scale changes and sedimentary structures along the strike of the outcrop. Although we noted no significant lithologic changes at the Alexander Hills location, we collected another set of samples for analysis.

In the lab, we examined thin section slides from each of our samples under petrologic microscopes. We noted differences in grain size, composition, matrix, and the presence of small-scale structures.

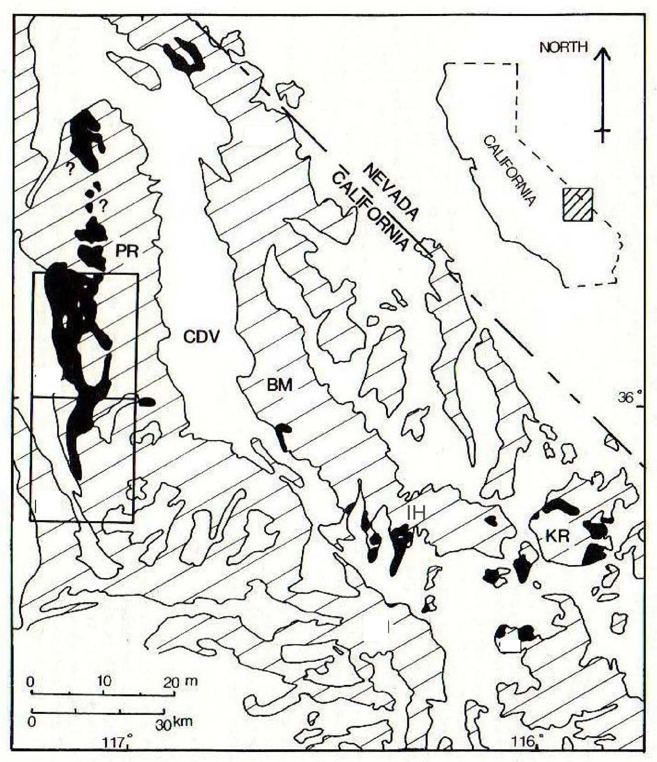

Figure 1. Map of Death Valley region showing Kingston Peak Formation (black), and pre-Quaternary rocks (shaded). Outcrops were separated from the Panamint Range by recent extension. BM = Black Mtns; CDV = Central Death Valley; IH = Ibex Hills; KR = Kingston Range; PR = Panamint Range.

Observations

The stratigraphic section in the Ibex Hills shows two lithologies. At the top and bottom of the section, the outcrop is dominated by laminated silts and thin beds of conglomerate. (**Fig. 2 and 4**) Distinct ripples are absent from the silt layers, suggesting that particles settled from suspension in still water.

Figure 2. Boulder of Kingston Peak Formation in the Ibex Hills. Note the rapid changes between laminated siltstone and a graded conglomerate. These structures were formed in an aqueous environment with a variable sediment input.

In contrast, the clasts in the conglomerate are too large and too well-organized to have been suspended in the water column. The conglomerates show grading by size, from matrix-supported gravels at the bottom to sand and silt at the top. Upward-fining conglomerates are commonly deposited in water-saturated debris flows.

Several meters of rock near the middle of the stratigraphic section are composed entirely of a massive conglomerate, with weakly graded clasts. The maximum clast size in the conglomerate changes dramatically along strike, with individual clasts up to 6 meters long at the west end of the outcrop. These huge boulders are solely composed of the local basement rock, and are too large for transport by water alone; they may have been moved by ice or as a part of a debris flow. This massive conglomerate layer is the most notable feature of the Ibex Hills location. (**Fig. 3**)

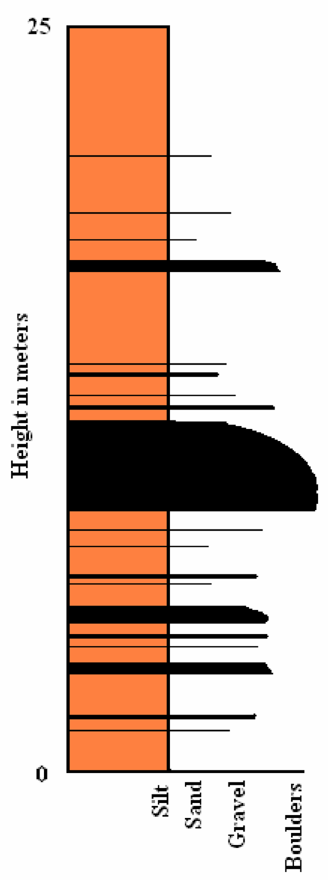

Figure 3. A stratigraphic diagram of the section in the Ibex Hills. Vertical axis is the height of the section in meters from the base to the top; horizontal axis represents dominant grain size. The silt-sized background mode is here colored orange; conglomerate layers are black. Although the massive conglomerate clearly stands apart from the background, it does not necessarily represent a different depositional environment.

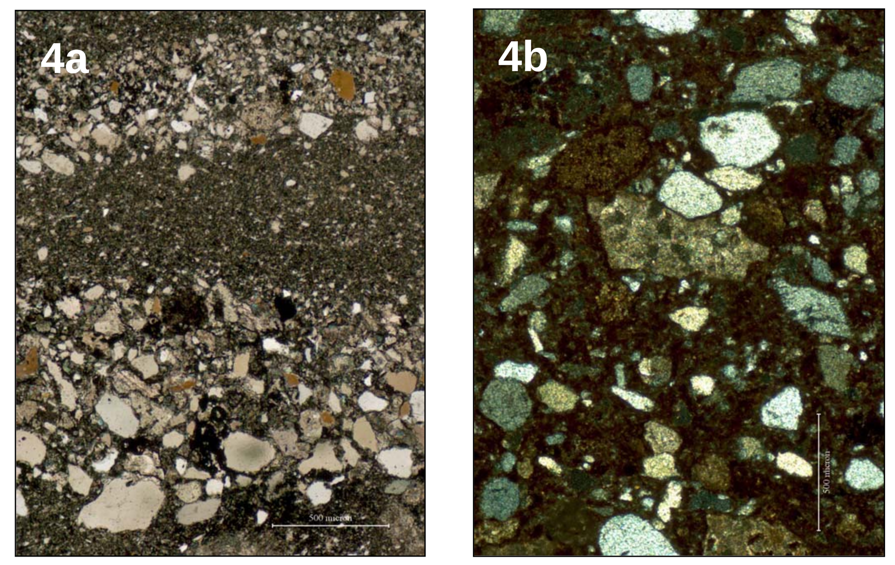

Figure 4. Typical lithologies of the Kingston Peak Formation in the Ibex Hills. **4a** shows regular changes in grain size and organization, typical of a fluvial environment with rapidly changing conditions. The grains in the conglomerate (**4b)** have a random distribution, common in high-density transport environments such as glaciers and mudflows. The proximity of these two rock types indicates that local conditions were quite variable.

Superficially, the Alexander Hills outcrop is similar to the conglomerate in the Ibex Hills, but significant differences become apparent upon close inspection. Microscopic examination reveals a wide diversity of particles (**Fig. 5**), indicating a large and complex source area. In addition, the largest clasts in the Alexander Hills are rarely more than a few tens of centimeters in diameter, and graded beds are rare. This massive, poorly-sorted, and heterogeneous unit has many characteristics of a glacial deposit.

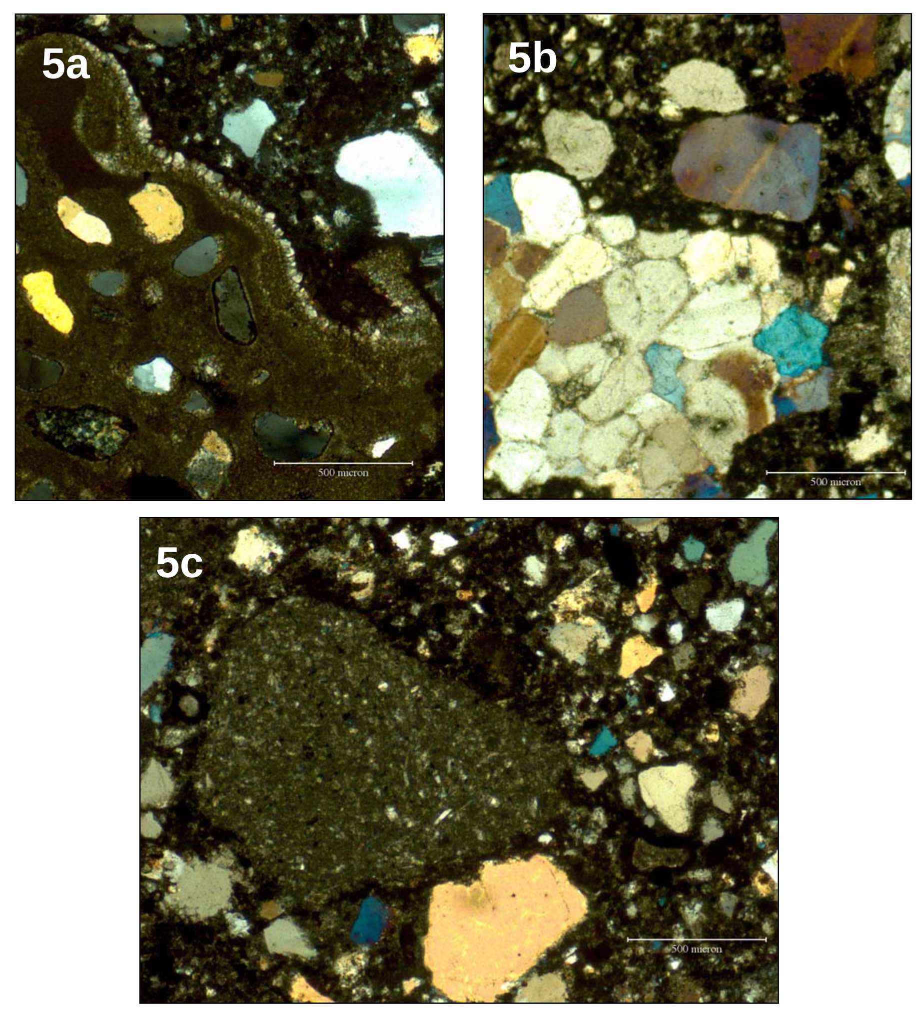

Figure 5. Sediments from the Alexander Hills location. The diversity of detrital grains is strikingly different from the outcrop in the Ibex Hills. **5a** shows a well-preserved carbonate fragment; **5b** shows a polycrystalline assemblage of quartz and feldspar grains; **5c** shows a sub-angular volcanic clast. The diversity of clasts suggests that the sediment was transported from multiple sources spread over a large area.

Conclusions

Although these two outcrops are stratigraphically equivalent, they were formed from different sedimentary materials, moved by different transport mechanisms, and deposited in different environments. Still, we find that both lithologies are consistent with glacial or pro-glacial environments.

In the Ibex Hills, the rapid succession of silt and conglomerate indicates that both depositional processes – particle settling from the water column and subaqueous debris flows – were active at the same time. The large-scale structure of the massive conglomerate suggests to us that it is simply the largest of the submarine debris flows in the outcrop, and does not represent a change in the depositional environment, such as a glacial advance or change in water depth. Our contention is supported by the similarity of sedimentary materials in both coarse and fine layers.

The diversity of sediment sources in the Alexander Hills, and the apparent lack of sorting or structure in a very thick bed is consistent with the accumulation of glacial till, transported over relatively long distances. The Ibex Hill sediments are consistent with rapid glacial erosion and fluvial transport, but show only local transport and deposition in shallow water. With respect to the Snowball Earth scenario, we draw two conclusions: First, erosion by terrestrial glaciers was significant, and therefore the hydrologic cycle was not fully interrupted by the ice. Second, areas of shallow water must have remained unfrozen near the ice sheet, allowing interactions between the ocean and the atmosphere We look forward to future work testing these hypotheses.

Acknowledgments

We thank Joanne Bourgeois and the sedimentology group for support and constructive criticism, without which this project would have been much more flawed; Charlotte Schreiber for encouragement and invaluable assistance with petrographic interpretation; Bruce Nelson and Joy Laydbak in the isotope geochemistry lab; and Robert Winglee and the Earth & Space Science Department for travel funding. This project has been supported by a Mary Gates Research Scholarship.

For further information

Please contact *jce@u.washington.edu*. More information on this and related projects can be obtained at:

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