Soft-sediment Deformation and Dune Collapse in the Navajo Sandstone, Utah

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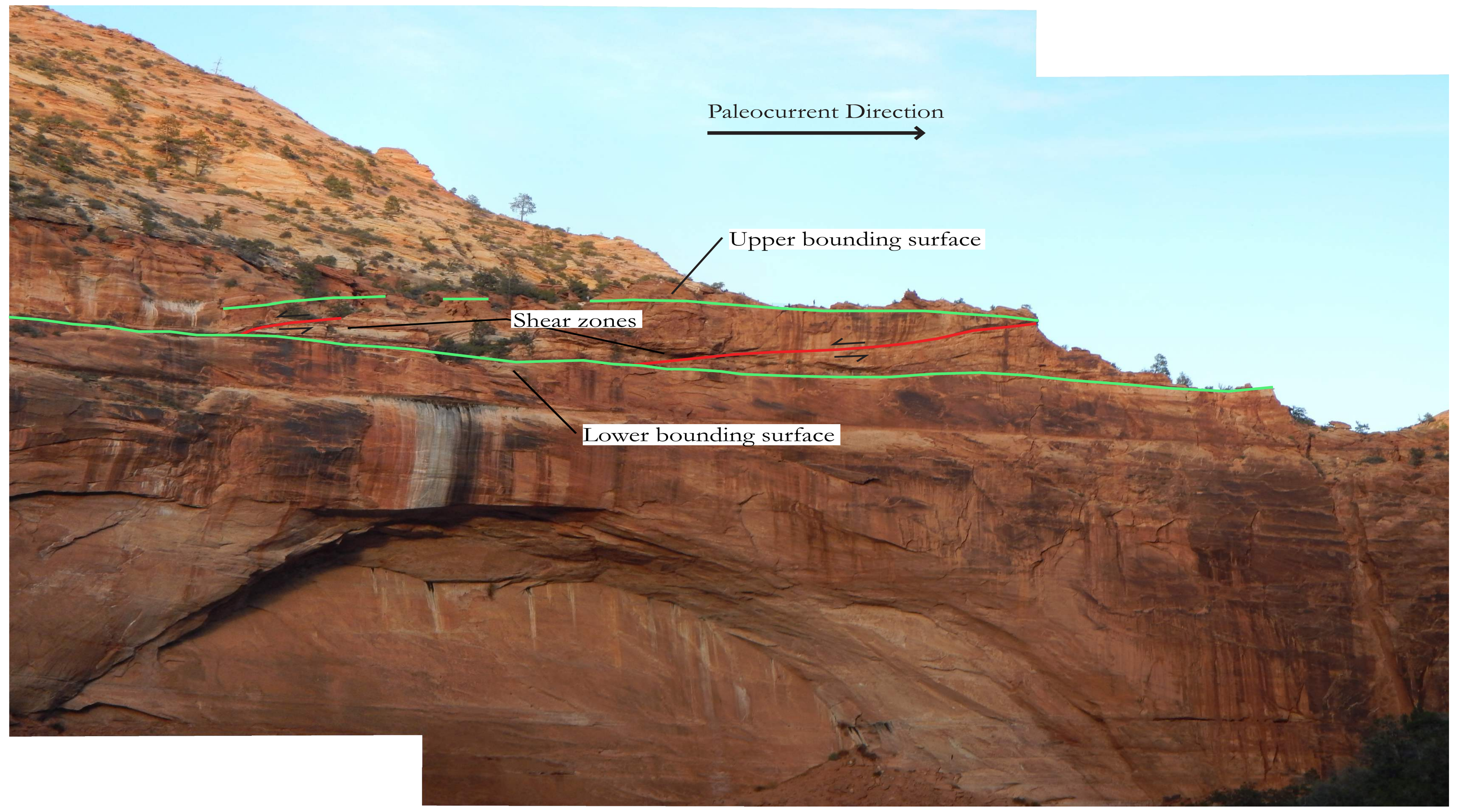
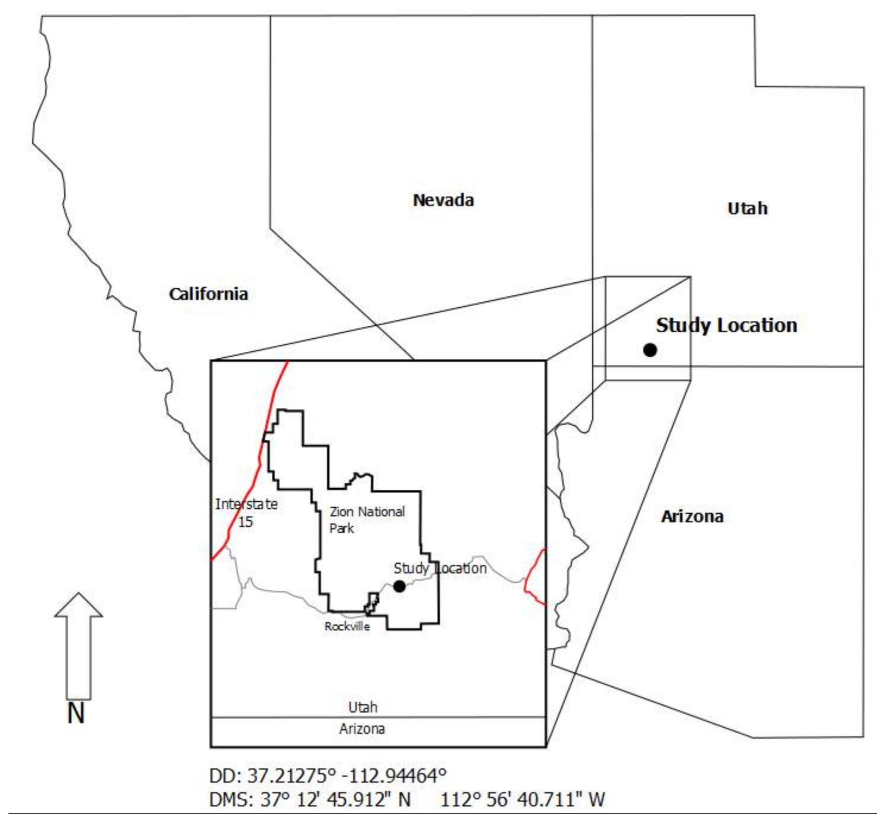
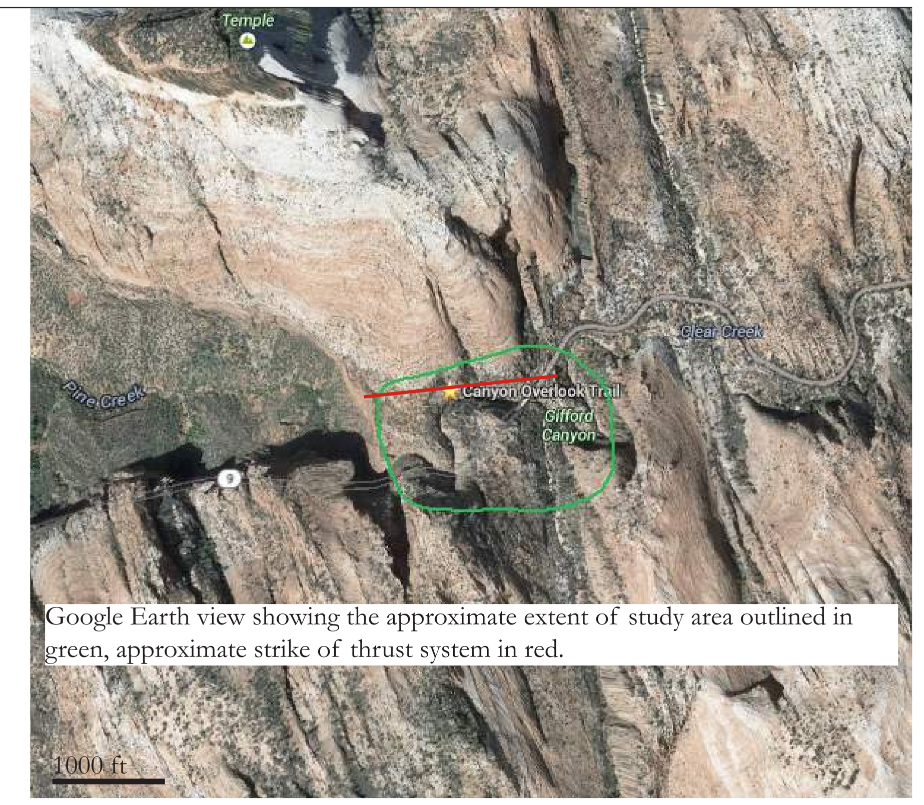





Google Earth view showing the approximate extent of study area outlined in green, approximate strike of thrust system in red.

Abstract

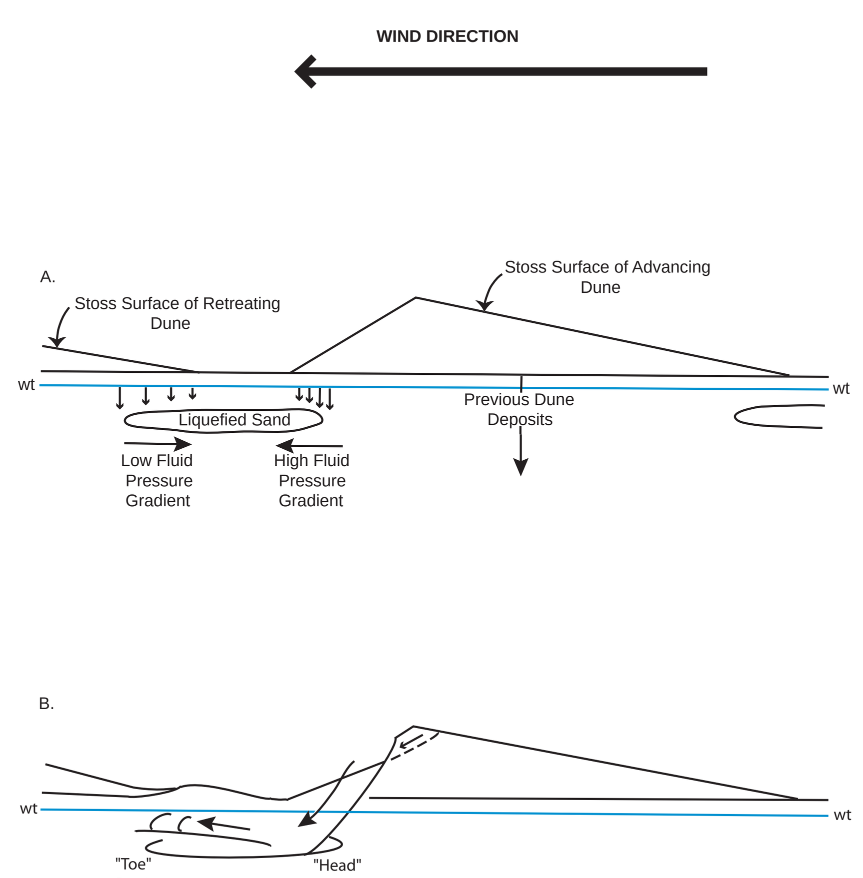
In 1982, Daniel Horowitz suggested a model for the generation of large-scale soft-sediment deformation in eolian formations. This was among the first models suggested for such features, and Horowitz intended it as a general explanation. More recent research by Bryant and others, however, has revealed features which do not fit a dune collapse model, such as deformation features which attenuate upward, and others which likely took place during an aggradational phase of erg development. While not all outcrops can be attributed to the dune collapse model suggested by Horowitz, it is well developed and makes several testable predictions. This report will apply these predictions to the outcrop on the Canyon Overlook Trail in Zion National Park in Southern Utah, which displays more distinct physical features and can therefore be used to suggest more robust criteria for the identification of the dune collapse process.

One of the main predictions that Horowitz makes is that material will be shifted in a downwind direction, as the steeper lee face of a large dune founders into the liquefied interdune deposit. He based his model on contorted fabrics in outcrops in Red Rock Canyon, Nevada, and off Highway 89 West of Kanab, Utah. Our outcrop in Zion, however, includes interdune carbonate muds, which added some support to the original deposit while lubricating shear planes, leading to distinct thrust faulted structures. These thrust faults have their strike perpendicular to the local paleo-wind direction, and they dip upwind, as predicted by the dune collapse model. Furthermore, deformation is clearly constrained to a single large cross-bed set, and the upper contact is truncational. Interdune carbonate mud layers were pushed to the surface in several locations, and were more resistant to erosion, leading to an irregular topography which is clearly preserved in the outcrop.

The outcrop in Zion is dissected by modern erosion in a way which reveals a great deal of the three-dimensional architecture. Therefore, by incorporating 3D modeling into traditional mapping techniques, this report will suggest more robust physical criteria for recognizing dune collapse.

Horowitz dune collapse model

- The water table is closer to the surface at interdune deposits, increasing the risk of liquefaction.
- The steeper lee face of the upwind dune exerts greater load than the shallow stoss slope of the downwind dune.
- Any liquefaction in the interdune will encourage movement of material in the downwind direction.
- The loss of support leads to collapse of the lee face of the upwind dune.
- The original model also called for subsequent deflation to a horizontal water table, producing a horizontal upper bounding surface.



Methods: creating the 3D model

- Take up to 70 photos of the subject from as many angles as possible.
- To create this model, the camera was mounted on a telescoping pole.
- Upload the photos to Autodesk's free 123D Catch service.
- 123D Catch calculates the parallax between photos, creating a wireframe model.
- The service also stitches the photos together to skin the model
- Photos may be edited before analysis, such as the green line following the surface of truncation in the example on the display.

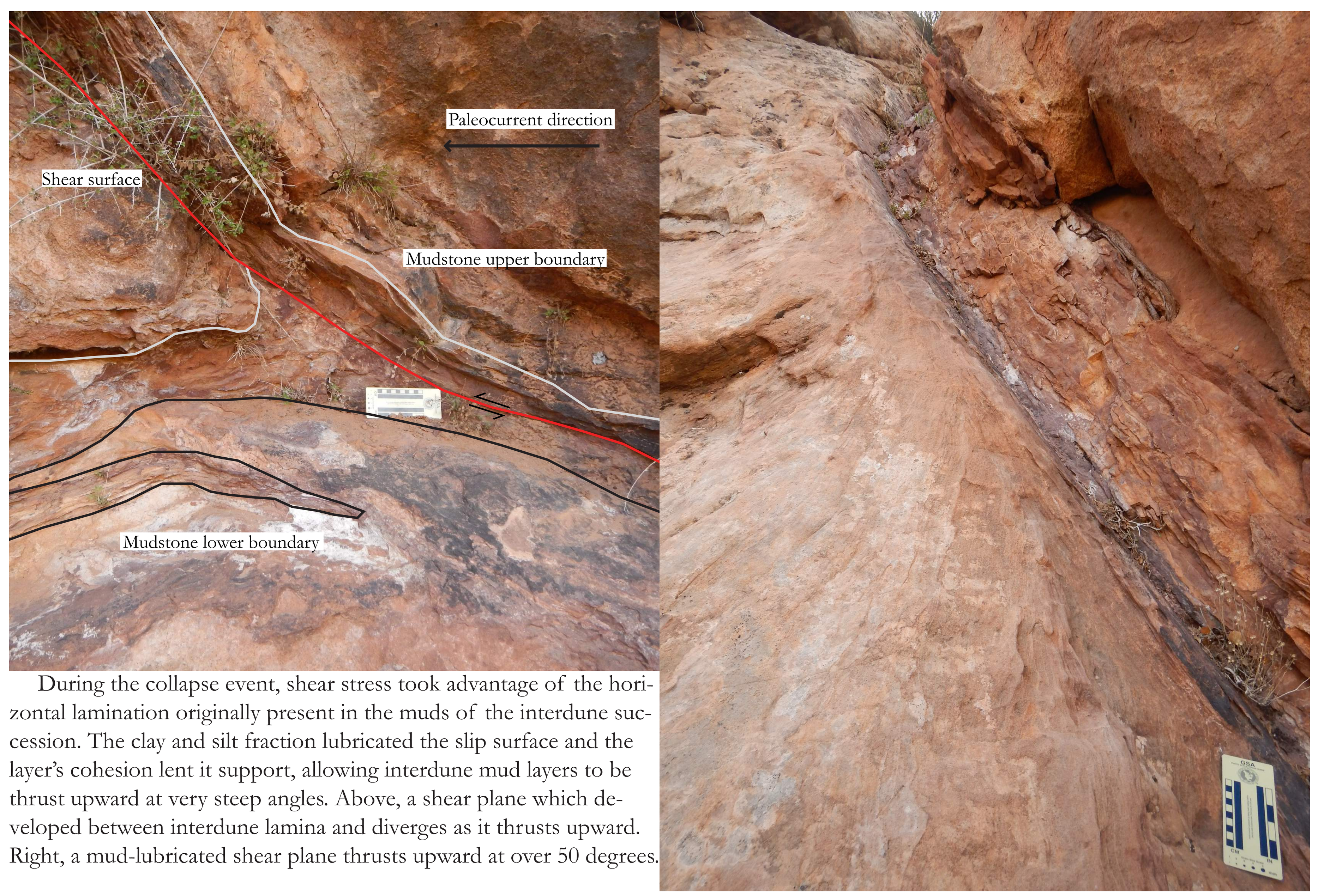
Results

Following are several sets of annotated photos which illustrate features that are predicted by the original dune collapse model, and also features that indicate the necessary refinements to the model. In addition, the three-dimensional model on the screen accompanying this poster shows the complex shape of the deformed interval's upper boundary, a feature not predicted by the original model.

Lines of evidence predicted by the Horowitz model include:
- Presence of shear features with strike approximately perpendicular to paleocurrent direction
- Indicators of rapid deformation and fluidization

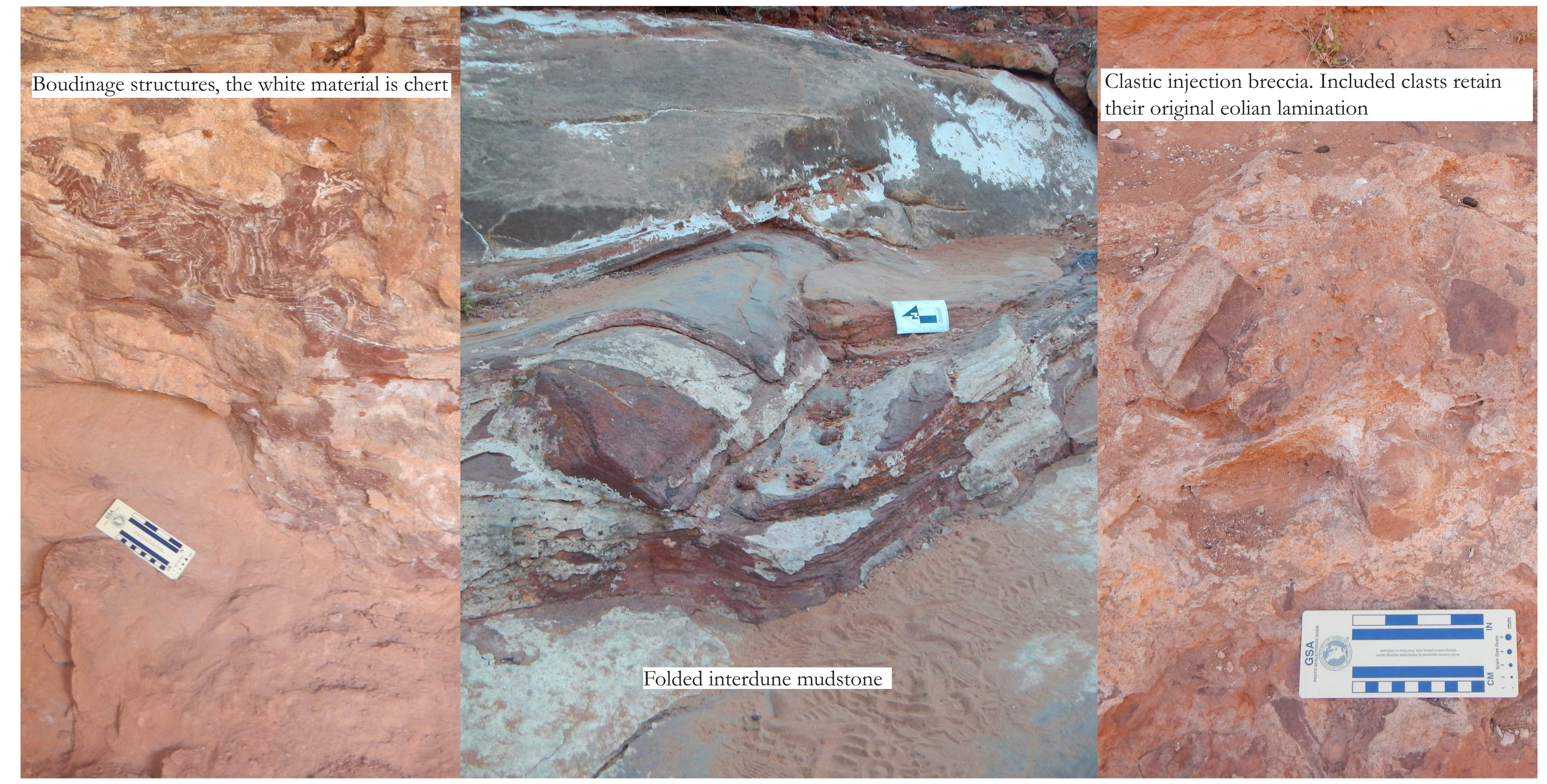
Not predicted by the original dune collapse model:
- Irregular topography created by the deformation is preserved

Shear planes



During the collapse event, shear stress took advantage of the horizontal lamination originally present in the muds of the interdune succession. The clay and silt fraction lubricated the slip surface and the layer's cohesion lent it support, allowing interdune mud layers to be thrust upward at very steep angles. Above, a shear plane which developed between interdune lamina and diverges as it thrusts upward. Right, a mud-lubricated shear plane thrusts upward at over 50 degrees.

Other stress indicators


Boudinage structures, the white material is chert

Folded interdune mudstone

Clastic injection breccia. Included clasts retain their original eolian lamination

Discussion

The collapse of dune lee faces into liquefied interdunes is unquestionably the most resilient and predictively powerful aspect of Horowitz's model. The presence of a well-developed interdune succession in the Zion National Park outcrop, and the preservation of major soft-sediment thrust faults fits the model's predictions.

The unique nature of the outcrop in Zion, however, suggests important refinements to the original dune collapse model. Because the model is dependant on the presence of a liquefiable, wet interdune, it can be inferred that the relatively resistant interdune complex present in Zion would be a common element of dune collapse features. Therefore, the unique assemblage of folding, shearing, and fluidization presented in this poster, all of which are closely associated with the interdune mud, can be used as additional diagnostic criteria when recognizing this species of soft-sediment deformation.

In addition to providing new diagnostic criteria, this outcrop addresses a particularly problematic aspect of the original dune collapse model. Work by Kocurek (1981), Bryant (2011) and others has suggested that deflation of the deposit to the water table only takes place when the deposit is undergoing degradation. The stratigraphic relationship evident at the deformed zone's upper boundary shows that the deposit did not necessarily erode to the level of the water table as Horowitz's model predicted. The cross-bedding above this "structural bounding surface" is complex but only lightly deformed, if at all. This suggests that the portion of the bedform which did not collapse, probably along with much of the deformed material, migrated over the complex topography created by the slump. This allows the dune collapse model to be applied to eolian deposits during aggradational conditions.

References

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Horowitz, D. H. (1982). Geometry and origin of large-scale deformation structures in some ancient wind-blown sand deposits. Sedimentology, 29(2), 155-180.
Kocurek, G. (1981). Significance of interdune deposits and bounding surfaces in aeolian dune sands. Sedimentology(28), 753-780.

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