Lower–Middle Ordovician Paleokarst Architecture:

A New Outcrop Analog from the Nopah Range, California, USA

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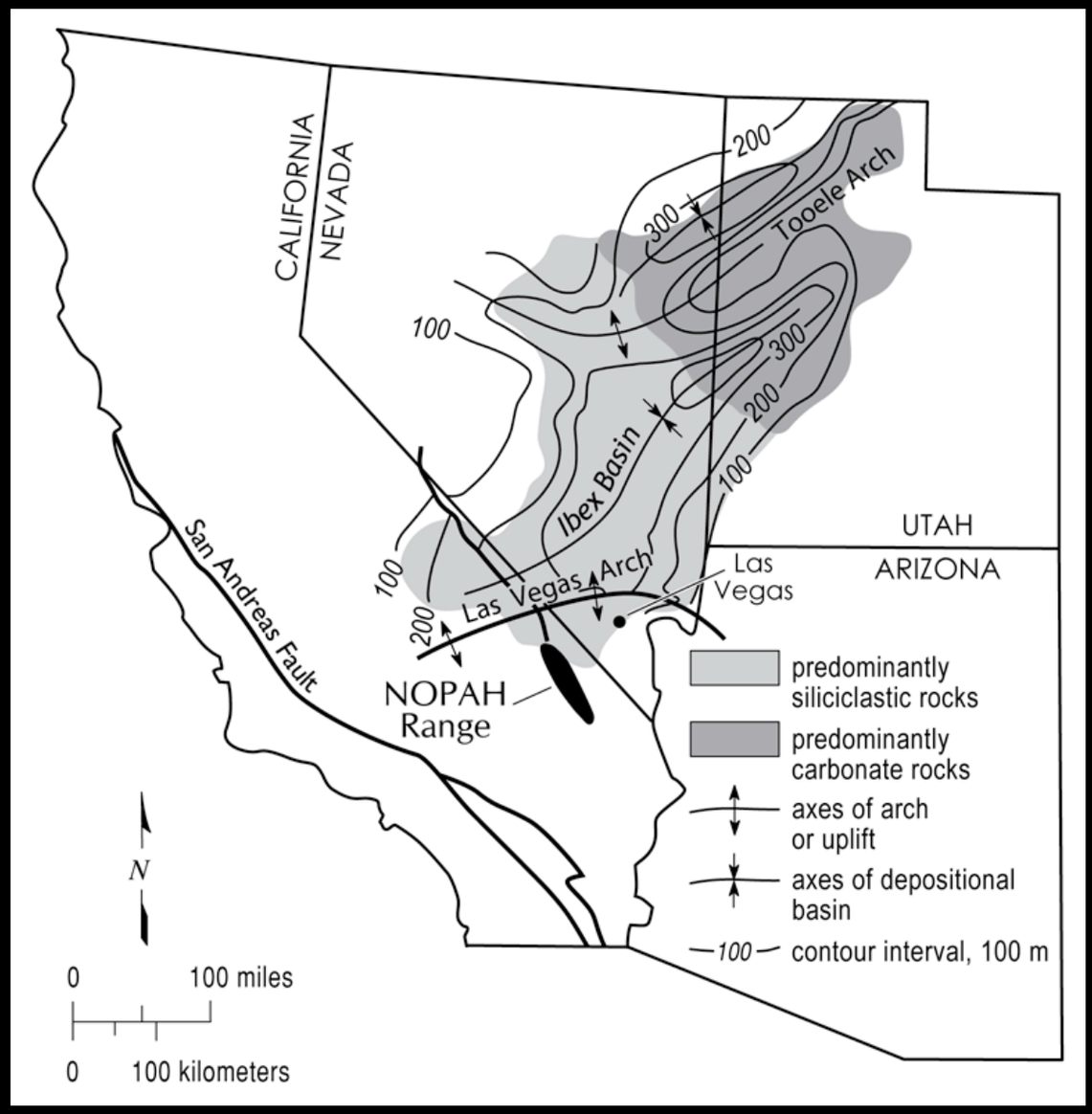
I'll be presenting initial results from recent field activities in the Nopah Range along the California-Nevada border. This shot was taken from a Cessna looking southeast near the northern tip of the Nopahs. The range consists of steeply dipping strata ranging in age from Cambrian to Devonian. Our intent is to learn more about Ordovician paleokarst from these excellent exposures.

Goals

- LiDAR- & GPS-based facies maps to constrain paleokarst architecture
  - *Brother Bob Loucks* "large outcropping paleokarst systems are rarely adequately documented" (AAPG, 1999)
- Identify paleo-fracture system
    - narrow (<1-m) vertical shafts
  - reflect precursor fracture sets
- Constrain paleokarst evolution/fill
  - stratigraphic/structural principles
  - conodont ID of breccia clasts
  - cathodoluminescence
  - fluid inclusions
  - paleomagnetics
- Build 3D numerical geologic models



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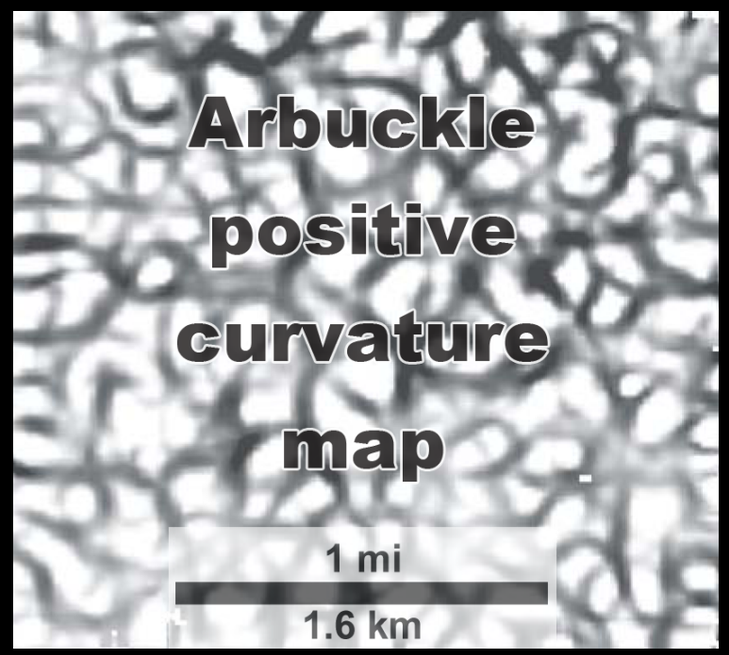
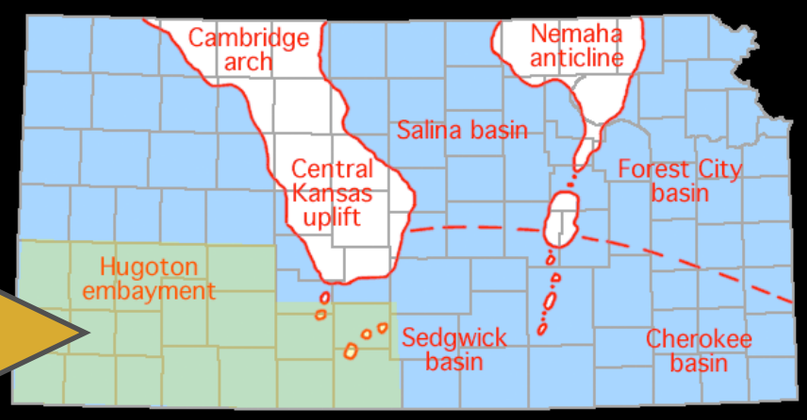
Project goals are to develop...(see slide).
The timing of karst events still needs refinement. Does it record one massive lowstand? Might some caves have a transgressive record as it is a near the platform margin? This would be similar to Abo coastal paleokarst in the Sierra Diablos of Texas.

Driving Force

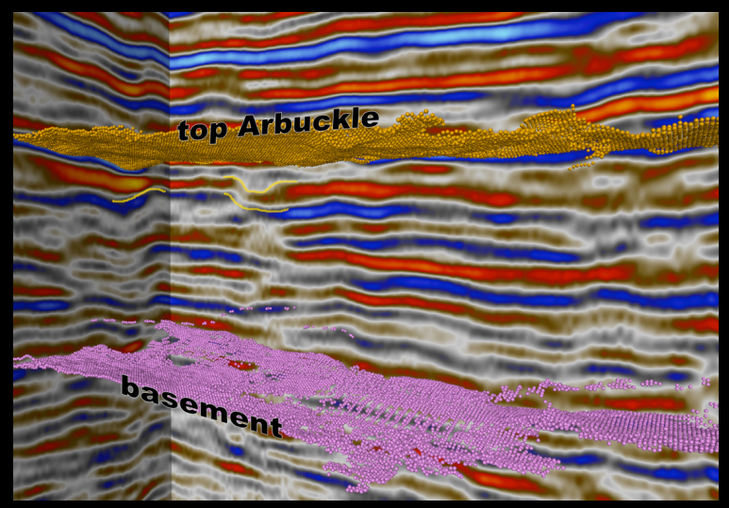
DOE CO_2 sequestration funding ($12 million)

- potential of Arbuckle saline aquifer (SW Kansas)
- seismic volumetric curvature for paleokarst & leakage pathways





sequestration study area



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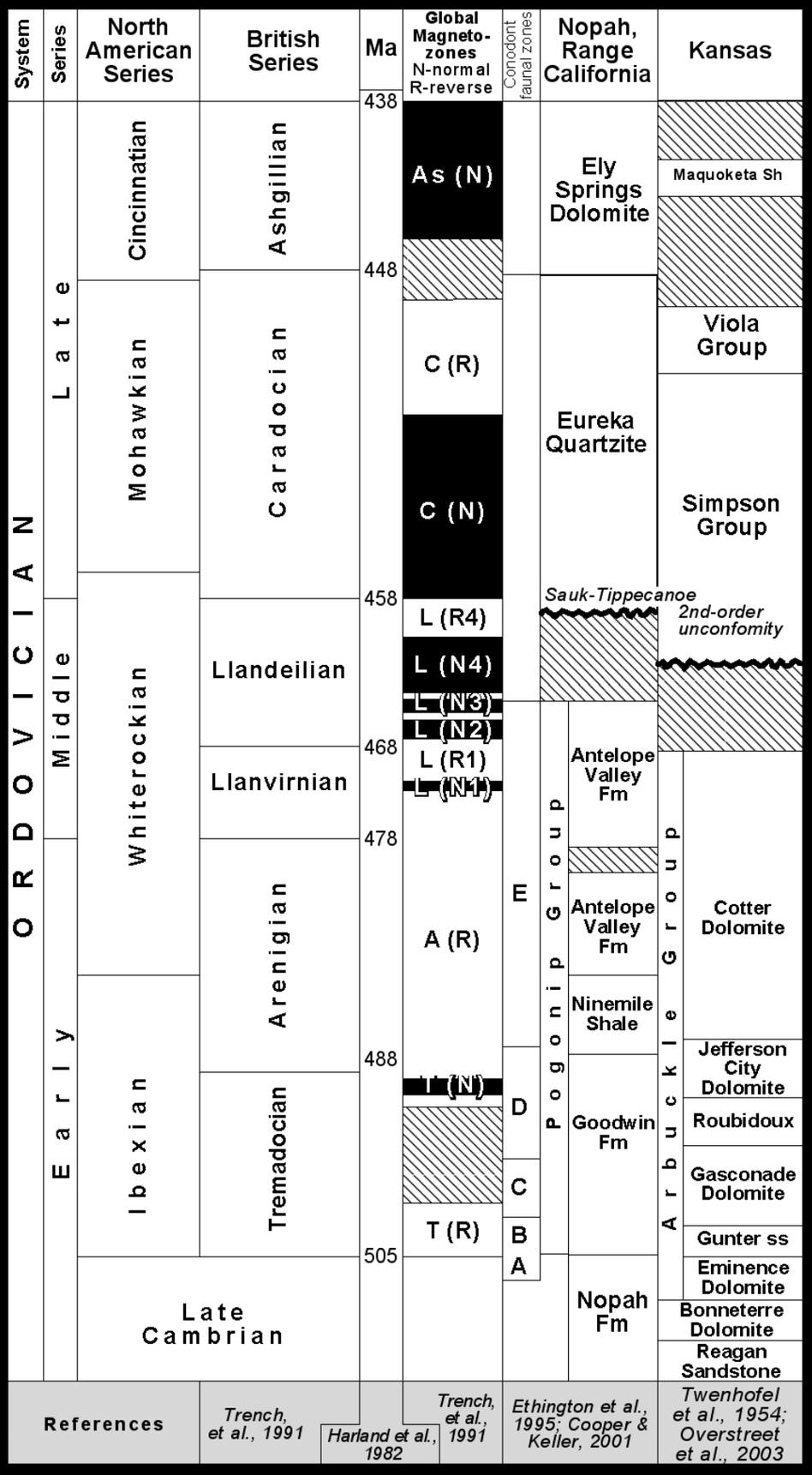
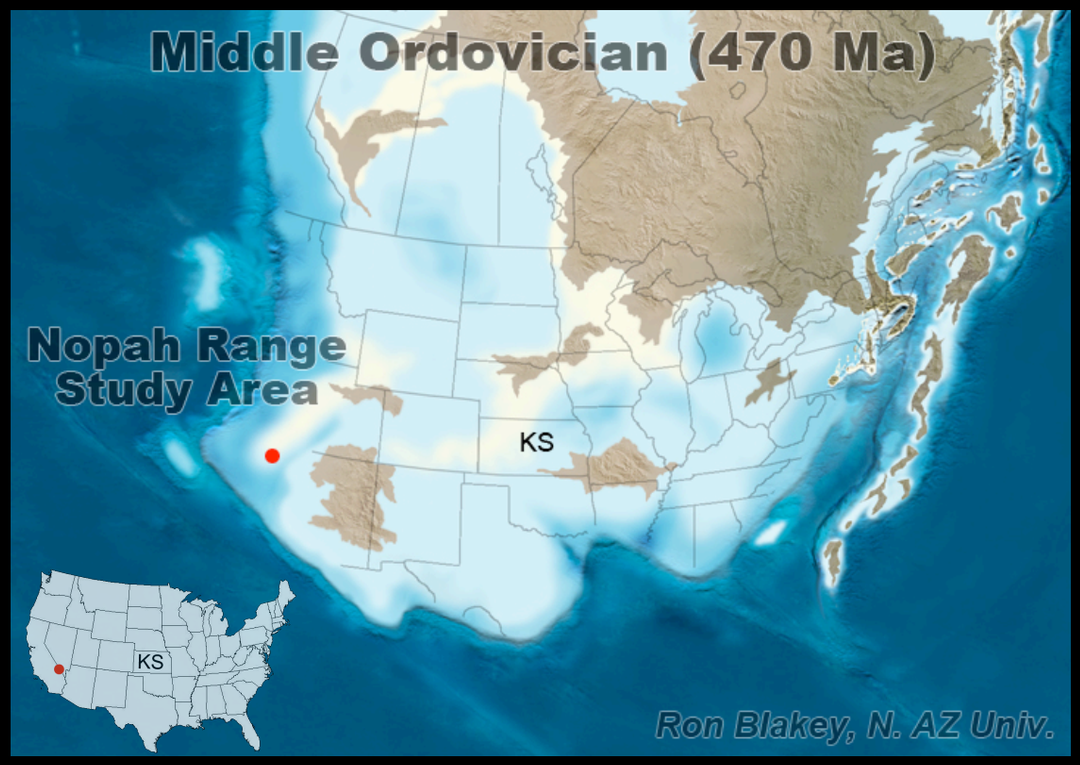
The driving force behind this field-oriented study are DOE-funded assessments of sequestration potential
(1) within karsted Arbuckle Groups strata in southwestern Kansas (POINT).
(2) The KGS is also investigating the utility of seismic-based volumetric curvature for identifying paleokarst heterogeneity at depth (POINT).
Both of these DOE-funded studies are fundamentally reservoir characterization and modeling projects. As such, the aim is to build a realistic stratigraphic-structural model that can be populated with petrophysical properties. For the Arbuckle, we also need to include a realistic paleokarst overprint. Because of a regional water drive only a few oil and gas wells penetrate more than the uppermost 50-ft of the Arbuckle. Little is known regarding the 3D-distribution of paleokarst. As such, an extensive outcrop analog is greatly needed to constrain modeling algorithms.

Ordovician Chronostratigraphy Nopah Range–Kansas

- Strata: Ibexian–Mohawkian
- Sauk–Tippecanoe
- Peritidal setting
- Nopah records minimal karst depth





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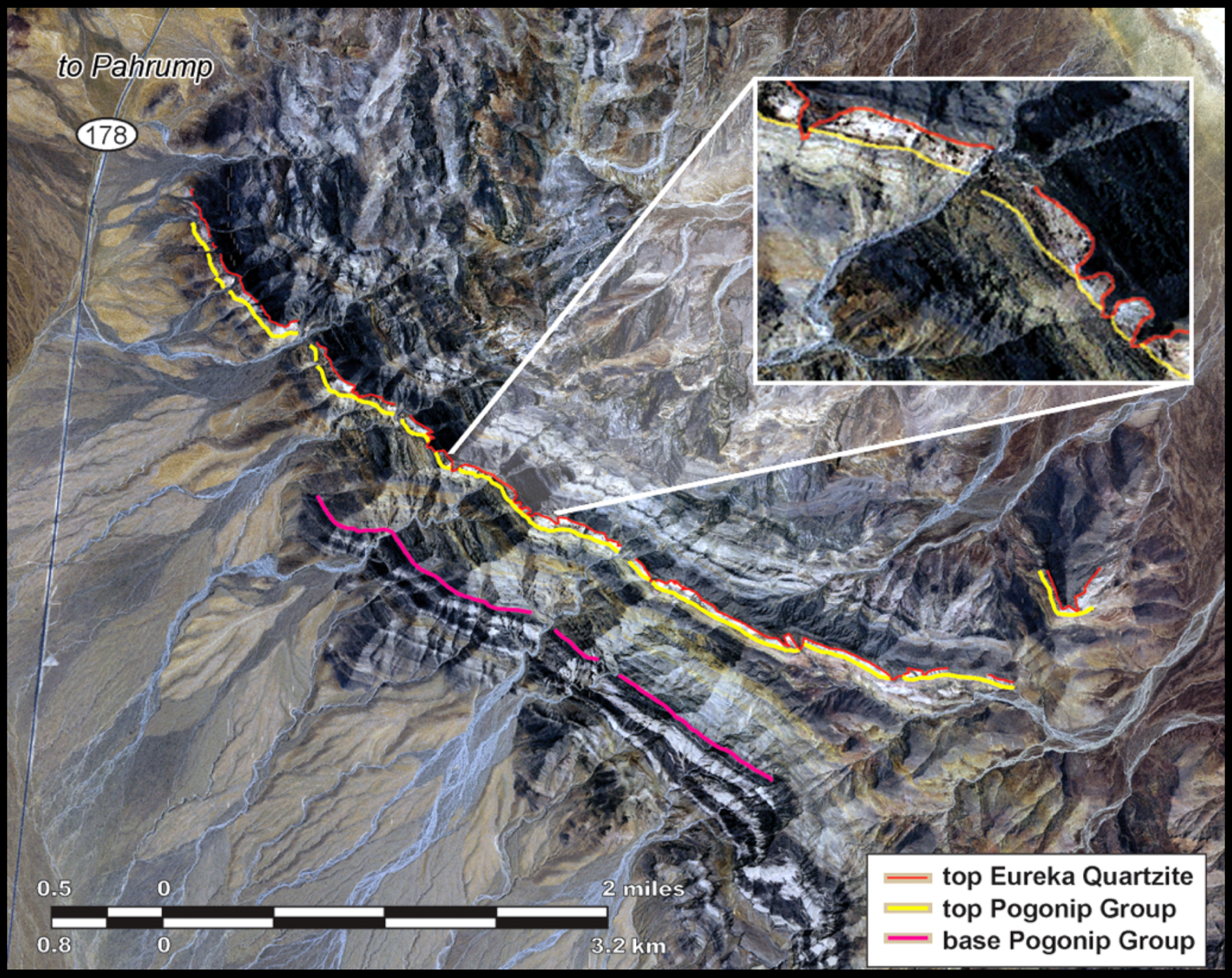
The basinward Arbuckle sequestration target in southwest Kansas (POINT) was impacted by the Sauk-Tippecanoe unconformity and not the pre-Pennsylvanian unconformity that ultimately removed the remaining Arbuckle over much of the Central Kansas Uplift. As much as 1200-ft of the Cambro-Ordovician Arbuckle section remains in southwest Kansas, which is coincident with the Paleozoic Hugoton embayment. Both sections are dominantly peritidal carbonates. The prevailing thought is that the depth of karsting recorded in the Nopahs reflects a minimal depth--when compared to the midcontinent--as it was situated at the platform margin. Stated differently, any karst events recorded at the margin would most certainly have been recorded in the interior, but not vice-versa.

Nopah Range, California



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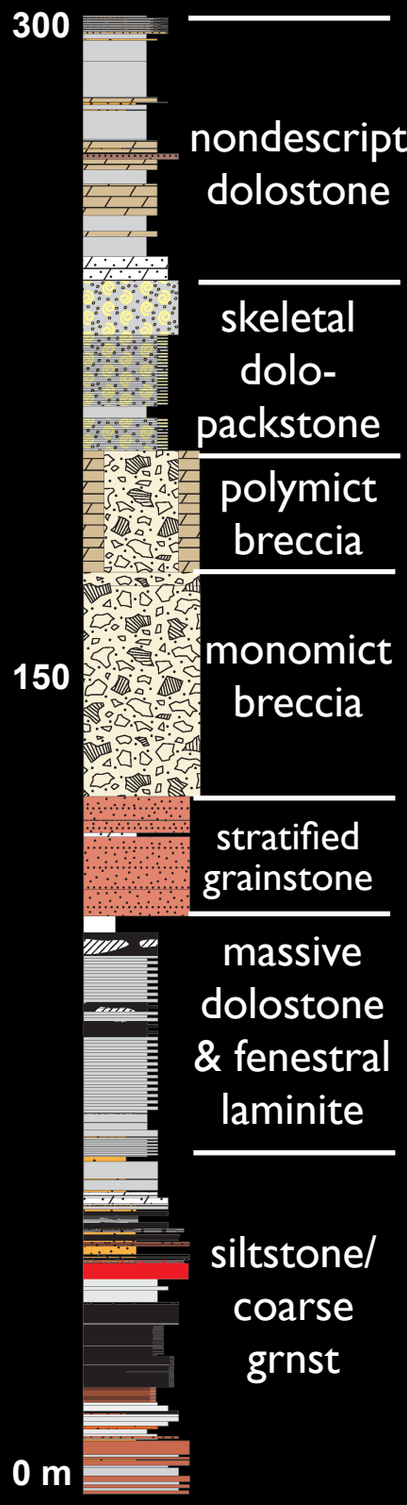
On this orthophoto, I have mapped the top Cambrian Nopah Formation (POINT), the top Pogonip Group, and the top Eureka Quartzite, which shows doline-shaped features (POINT). Some dolines pass downward into narrow shafts within the uppermost Pogonip before opening into paleocaverns. Strata dip about 65º ENE, which complicates mapping and projections across high ridges. Ultimately, we want to acquire an airborne LiDAR survey to aid correlations between canyons.

Cooper & Keller's 2001 article in Sedimentology was the first to document paleokarst within Pogonip strata. Prior to their publication, these breccias were interpreted as tectonic breccias and scree.

Upper Pogonip Group Depositional Facies

Antelope Valley Fm



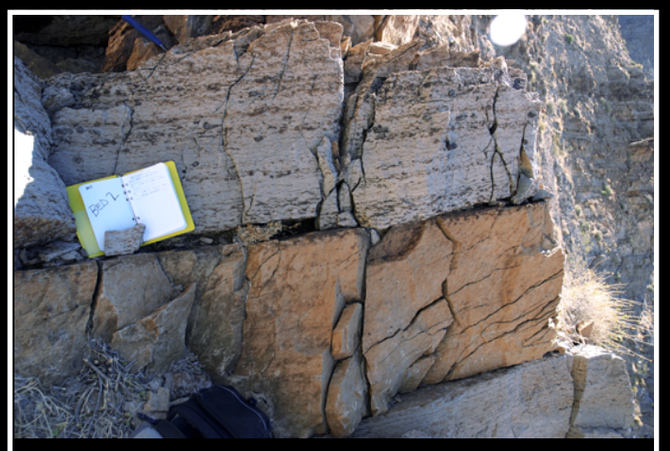
current-stratified dolo-grainstone

siltstone & carbonate lenses with rip-up clasts

algal laminite

mottled, subtidal, gastropod dolo-packstone

Thallasinoides ichnofacies



nondescript dolo-grainstone

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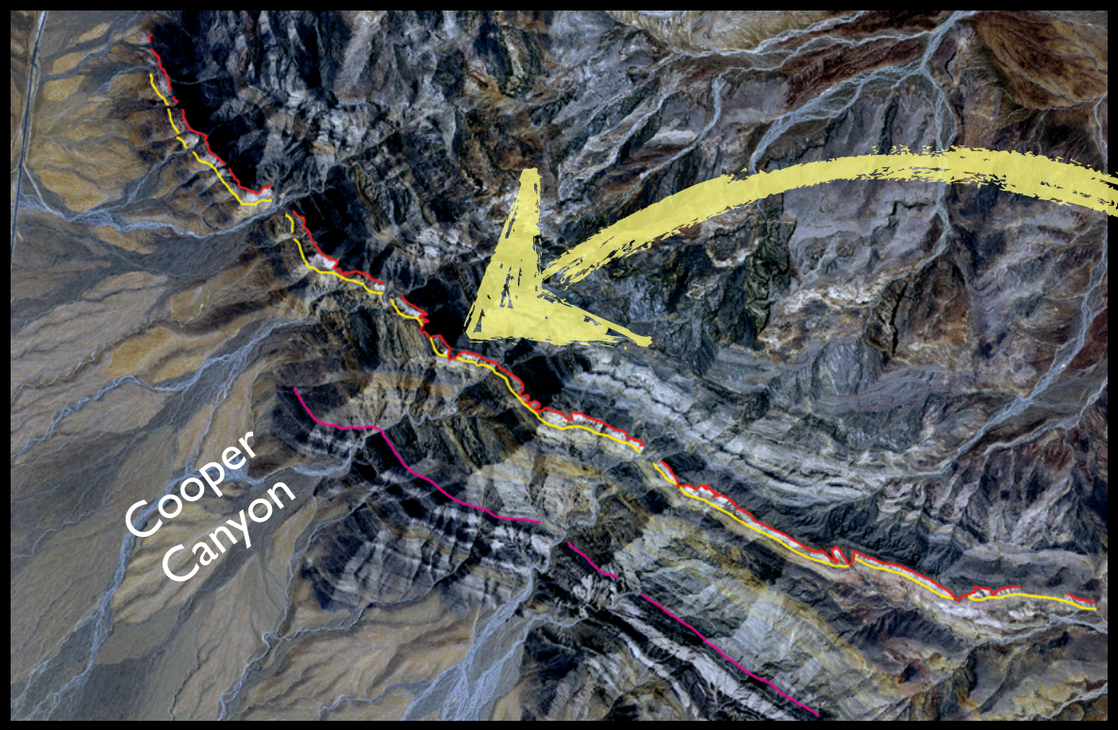
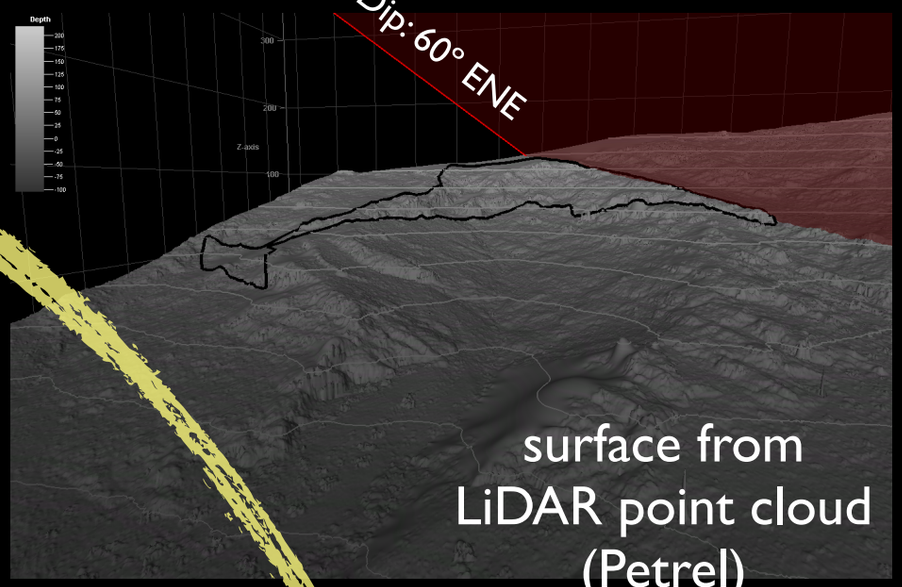
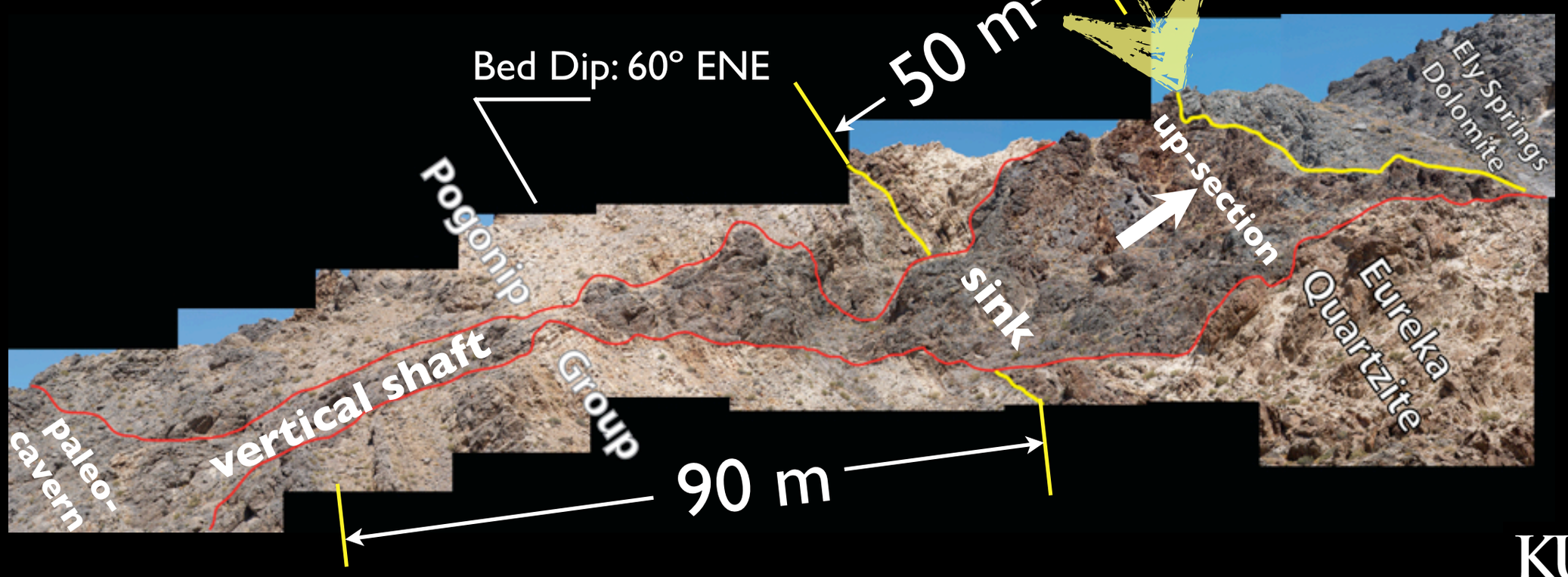
On the right is a simplified measured section from heretofore un-named canyon. We call it Cooper Canyon in honor of John Cooper. On the right are typical Antelope Valley depositional facies. DESCRIBE & POINT.

Paleokarst Architecture

Cooper Canyon – northwest wall







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Shown here is one of the more accessible exposures. The upper right shows a 3D-model with strike and dip projected into the outcrop. Sink/dolines developed in the Eureka Quartzite. The lower interpreted photomosaic shows a complete surface to cavern transect consisting of... describe sink, shaft, cavern, and their dimensions.

Paleokarst Architecture

Cooper Canyon – northwest wall

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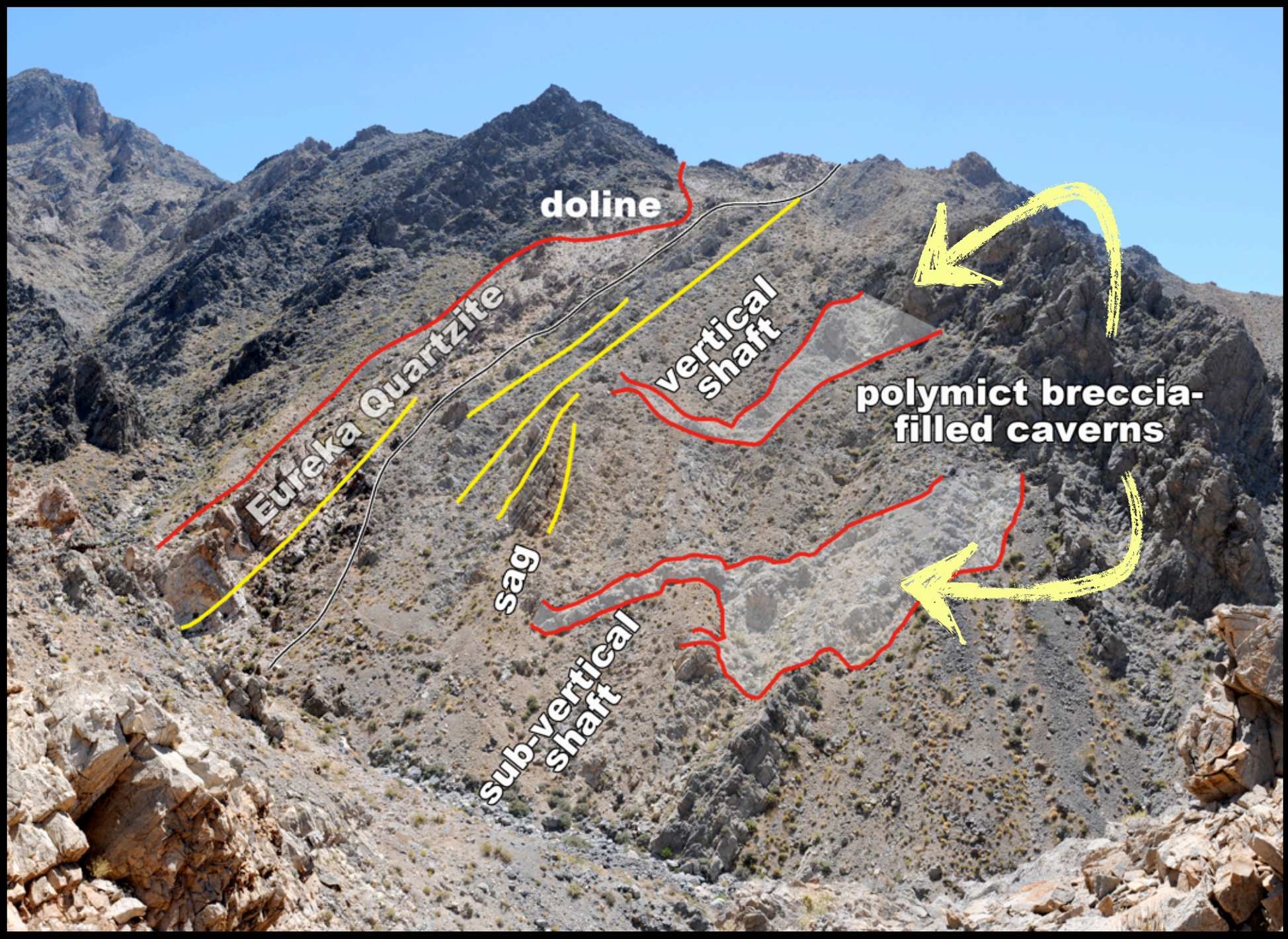
Shown here is a closeup of the lower shaft and uppermost paleocavern. Notice the clasts and exceedingly sharp margins.

Paleokarst Architecture

Cooper Canyon – southeast wall



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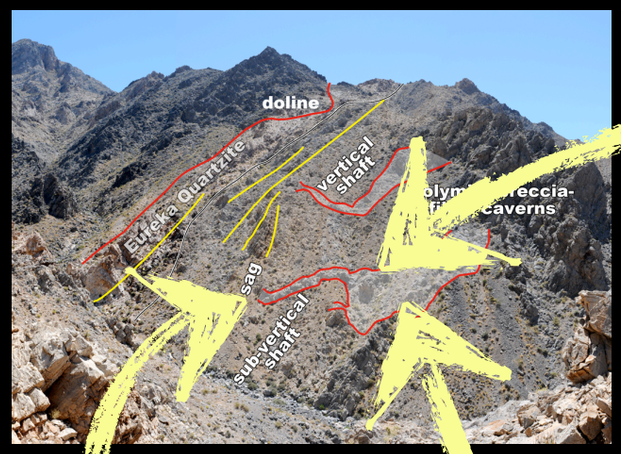
Describe photo then interpretations. Multi-storied caves? Same age? Sag may indicate earlier lowstand.

Paleokarst Architecture

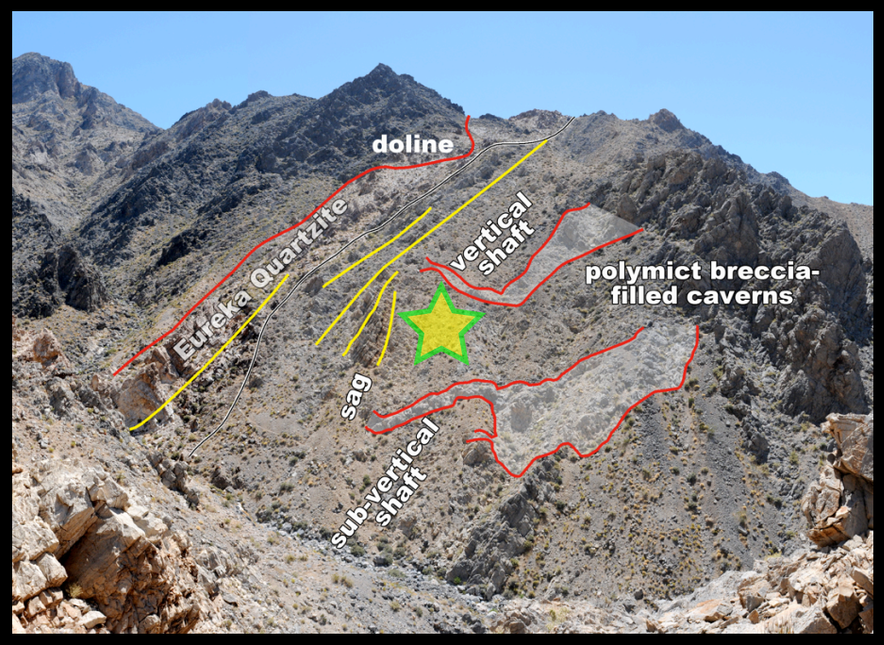
Cooper Canyon – southeast wall



Shown here are features along the southeast wall. Lower left is a another vertical shaft that ultimately opens into a paleocavern. Upper right photo shows polymict breccia that is interpreted as proximal cavern infill. Lower left is a monomict breccia that might record gravitational failure of the roof.

Paleokarst Facies

Cooper Canyon – southeast wall



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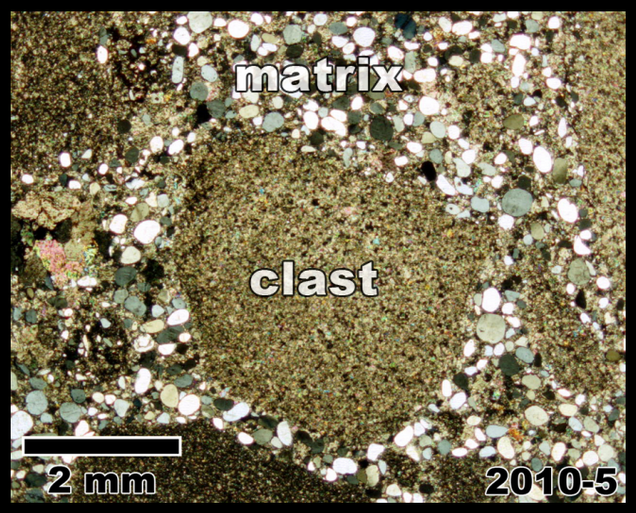
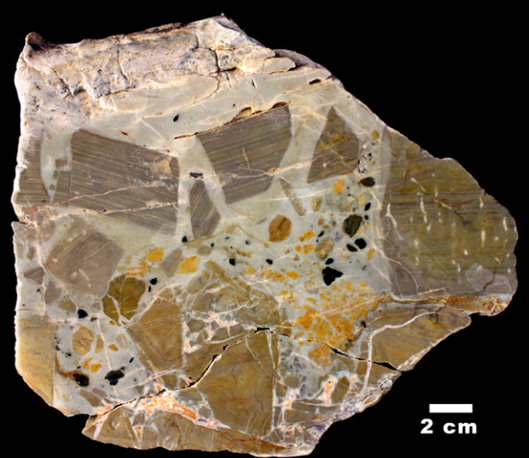
Paleokarst Breccia – matrix

siliciclastic sand

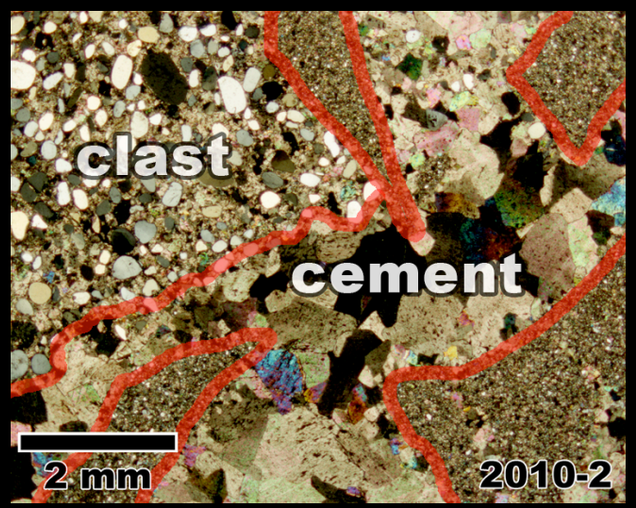
vertical shaft fill

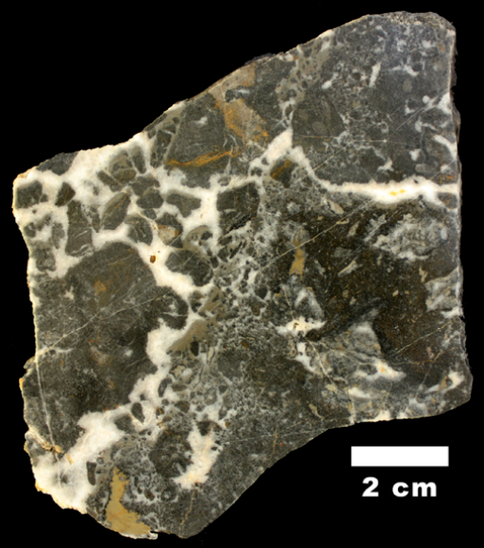




carbonate cement
(dolomite)

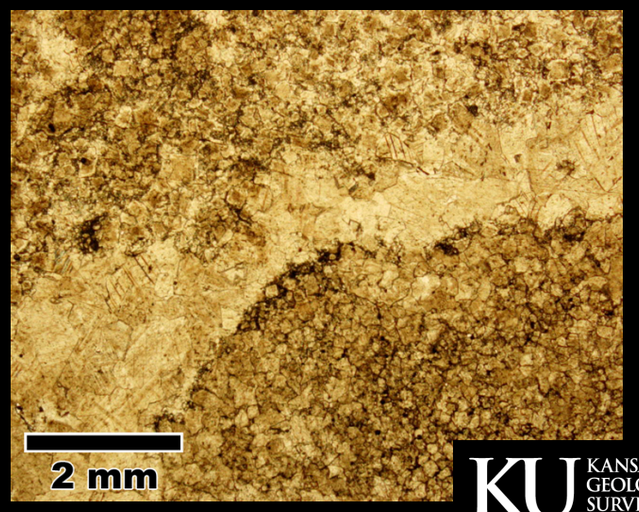
paleocavern fill





dolomite cement
rhombs show zoning

crackle breccia?
roof?



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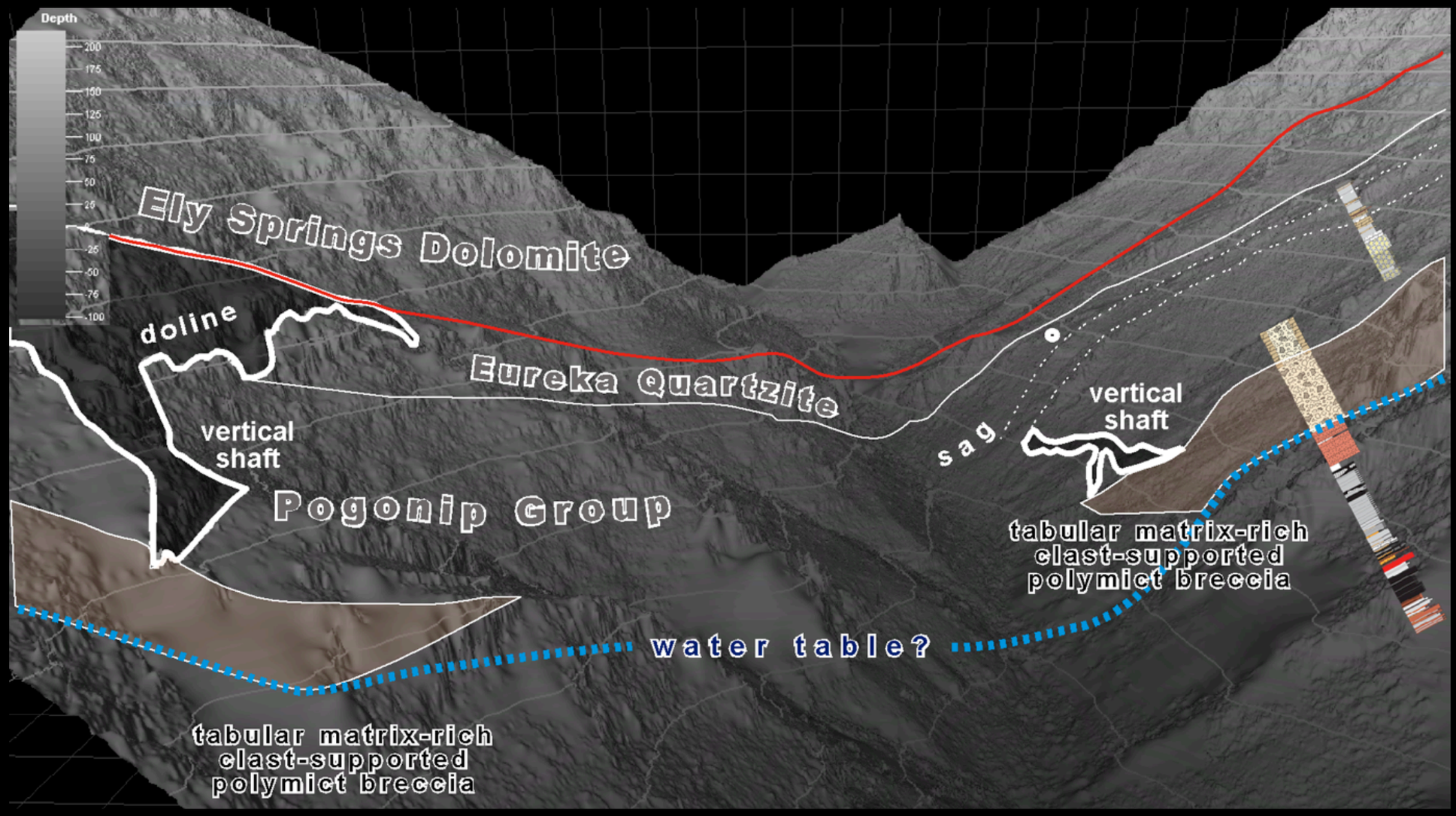
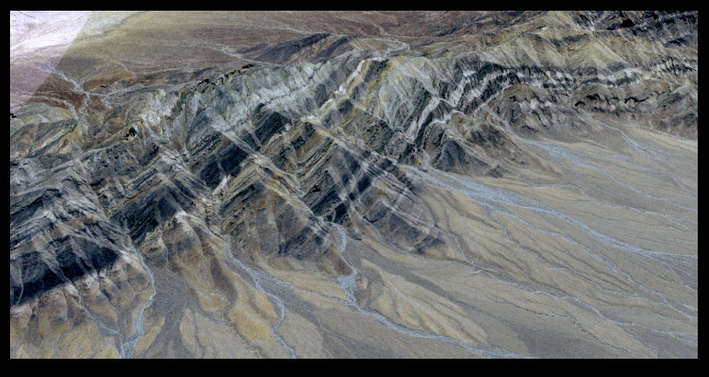
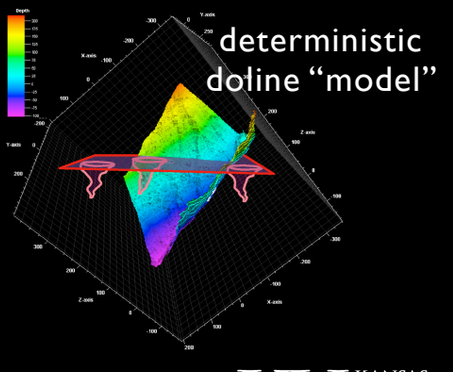
Final Goal: spatially constrained geocellular models







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Shown at top is a surface derived from two LiDAR ground-based surveys. This shot shows much of the data presented earlier, but illustrates the amount of additional 3D control that can be honored during the modeling process. Once the paleokarst is mapped across the entire range and modeled, we will have an ideal data set to analyze karst evolution and constrain similar reservoir models.

Conclusions

- Geometries & sediments reflect arid karst system
- Common paleocavern position may record aquifer
- Nopah's offer a new & promising Ordovician paleokarst analog
    - particularly well-suited for airborne LiDAR survey
- *Fortunately, a substantial amount of fieldwork is needed*

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