A Digital Outcrop Analog for Upper Paleozoic Carbonate Slope Reservoirs*

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Abstract

Production from Upper Paleozoic isolated carbonate platforms is prolific, including several super-giant fields in the Pricaspian Basin that have produced many hundreds of millions of barrels. As these reservoirs mature, well locations commonly shift from the relatively homogeneous platform facies into the slope portions of the buildups. The heterogeneity of slopes, where deposits are variable mixtures of margin-derived breccias and platform-derived grainy to muddy sediment transported through an irregular margin, leads to a spectrum of deposit types, complex pore structures, and variable reservoir quality.

To better constrain slope styles and shelf-to-basin depositional models, a detailed examination of superbly exposed Permian margin, slope, and basinal outcrops (Capitan and Bell Canyon formations) was conducted along a portion of the southern Guadalupe Mountains using a combination of airborne lidar, spectral analysis of ASTER data, and conventional field work. This locality offers world-class exposures of Upper Permian mixed carbonate and siliciclastic shelf to basin deposits that are well preserved and with minimal structural deformation. The interval focused on was the Seven Rivers and Yates formations-equivalent slope and basin deposits of the Capitan and Bell Canyon formations.

The preliminary results from this work show vertical stacking patterns of siliciclastic siltstone and very fine-grained sandstones that are overlain by platform-derived packstones to grainstones followed by platform- and margin-derived breccia clasts. The current model suggests that incision and clastic sediment are related to shelf bypass during lowstand, whereas the carbonate platform grains and margin debris were transported during sea-level transgression to highstand, respectively. Identification of these features on airborne lidar data made it possible to define slope-channel paleoorientation and geometry. Channel orientation and geometry combined with relative proportions of clastic and carbonate infill were used to define position along depositional dip as a proxy for along-strike variability of the platform margin.

Selected References

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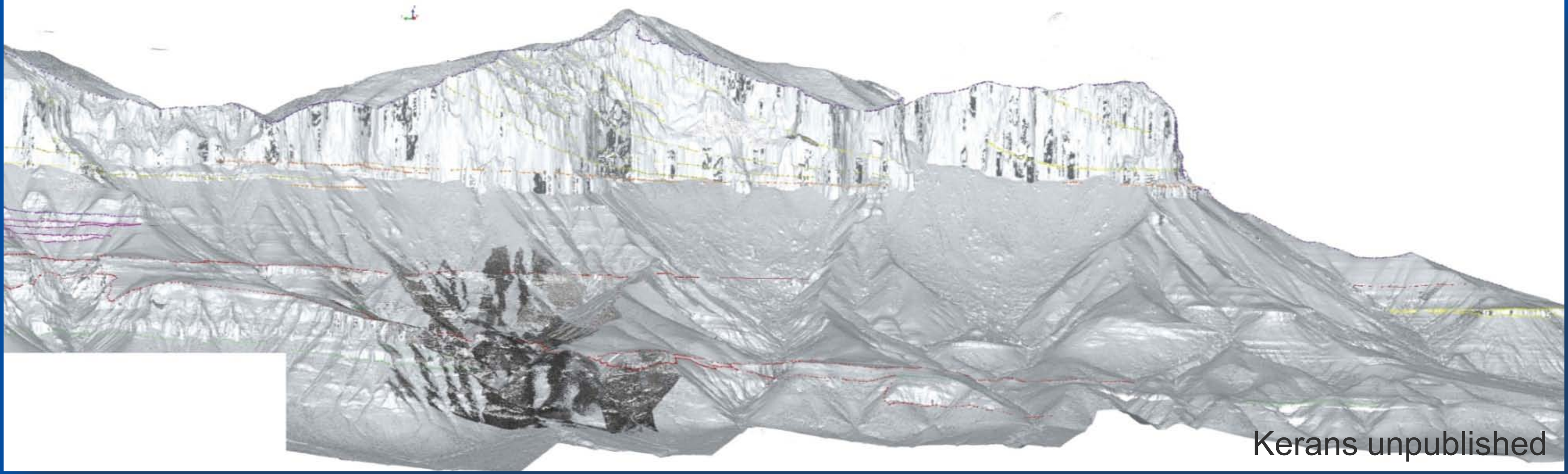
Presentation Outline:
A Study of Slope Heterogeneity

- Rationale for this study
- Lidar and 3-D GIS adding value
- Channel forms and Rader Breccia
- Discussion and Conclusions

Summary

- This talk is a review of work in progress toward better carbonate slope reservoir characterization.
- Airborne lidar in conjunction with spectral image data, previously published maps, high-resolution aerial photography, and field mapping were combined into a 3-D GIS to make multi-scale observations.
- Channels were observed in the Capitan lower slope and appear to show interfingering between “classic” deep-water channels and carbonate slope debrites.
- Obliquity of preliminary channel axes to regional dip hints towards margin heterogeneity which is not directly exposed in outcrop.

Project Rationale
Sub-seismic Reservoir Heterogeneity



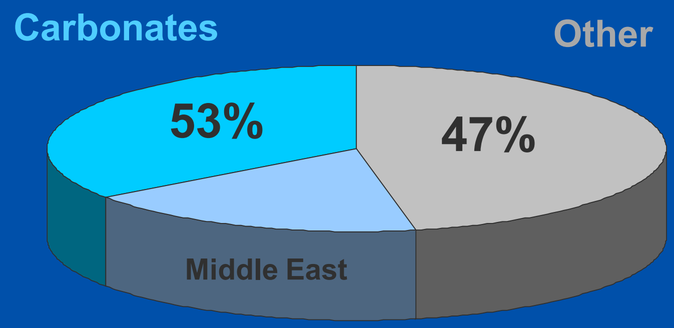
Outcrops, such as those of the Capitan Reef of the Guadalupe Mountains of west Texas, offer outstanding multi-scale, 3-D exposures of a mixed siliciclastic and carbonate shelf/slope with:

- a deep-microbial-boundstone reef system
- a debris-dominated slope/toe of slope
- deep-water siliciclastic channel/fan system

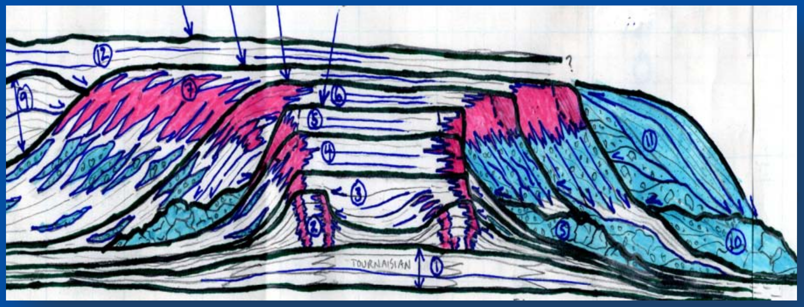
Project Rationale

Chevron has Significant Carbonate Holdings

Over 50% of the world's remaining oil reserves are in carbonates. Moreover, Chevron's largest carbonate assets are in isolated platforms (e.g., Tengiz, Karachaganak).



As platform depletion matures production steps-out into geologically complex **slope** environments leading to a need to better understand controls on slope heterogeneity and how it will impact production.



Playton unpublished bar napkin sketch

Project Rationale

We simply need to know more about carbonate-slope-reservoir geometry and continuity.

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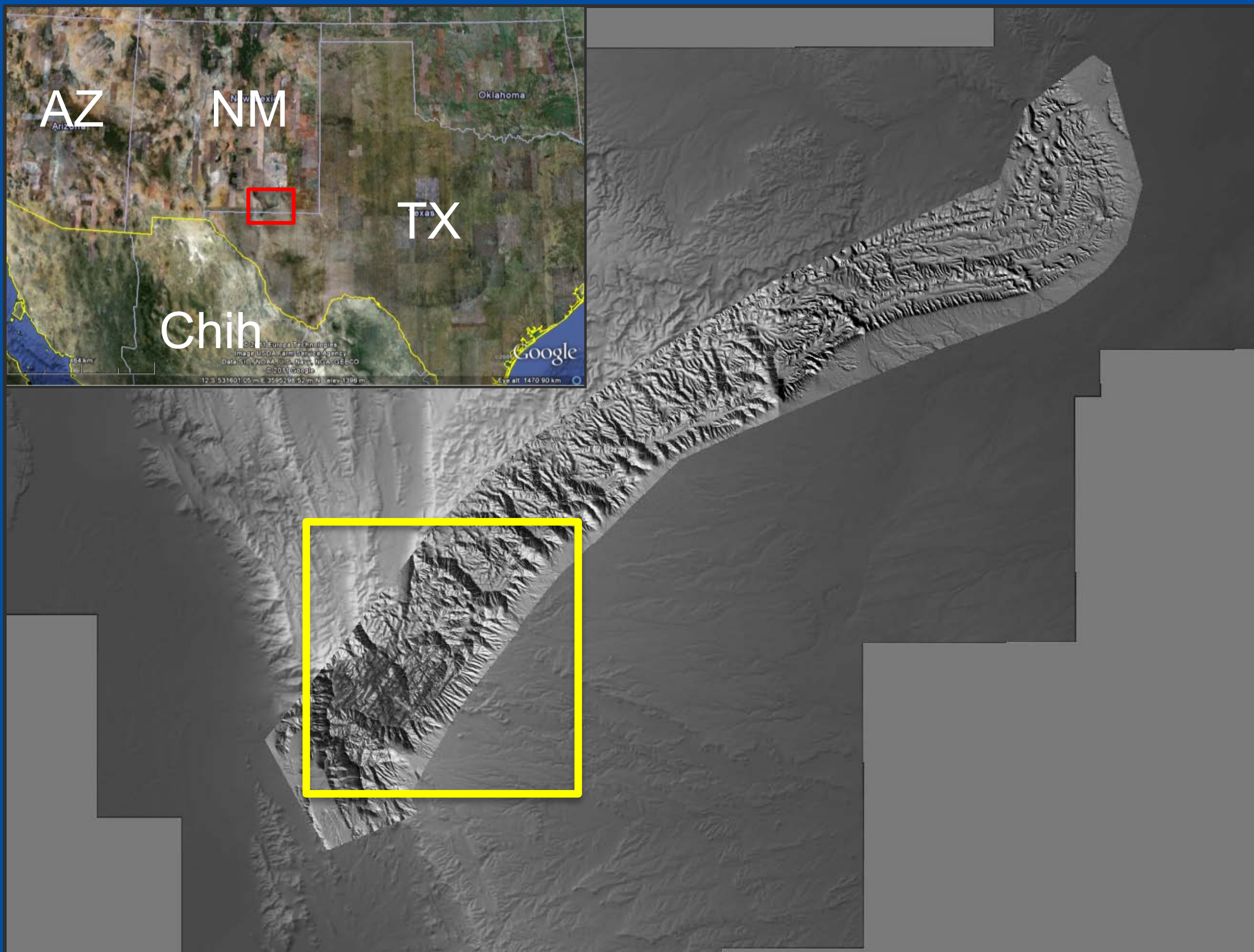
Study Area

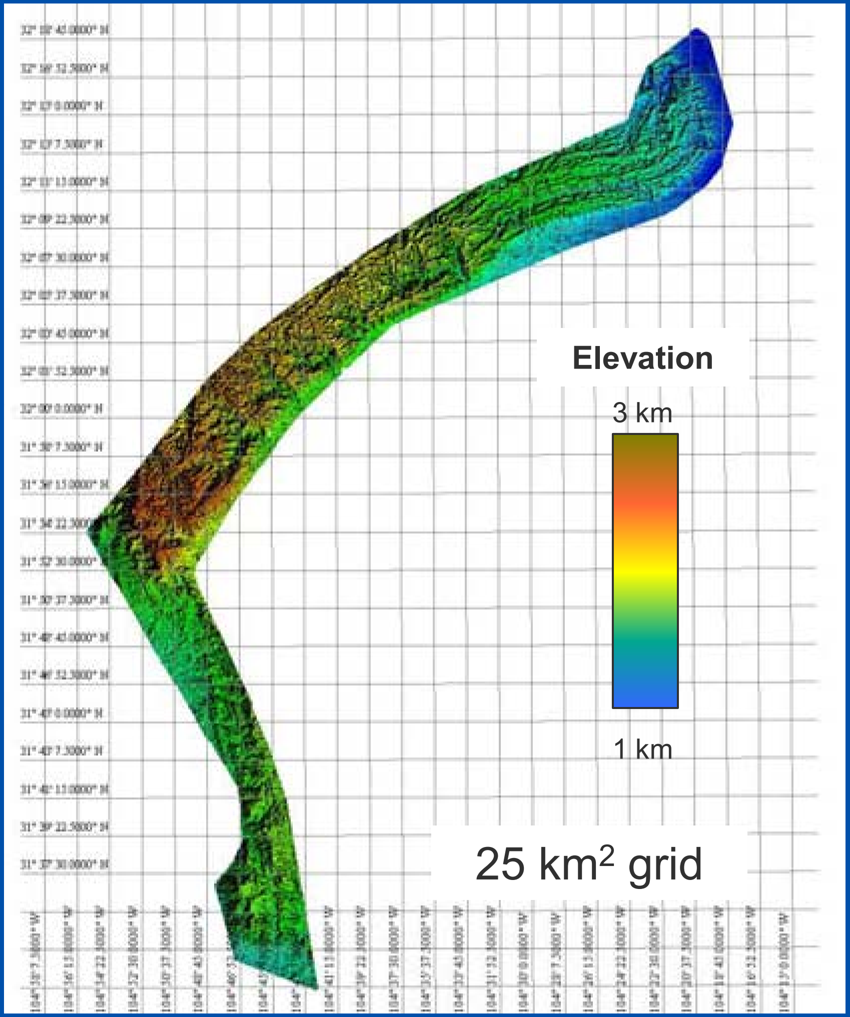


Shelf:
Tansill Fm.
Yates Fm.
Seven Rivers Fm

Margin:
Captian Fm.

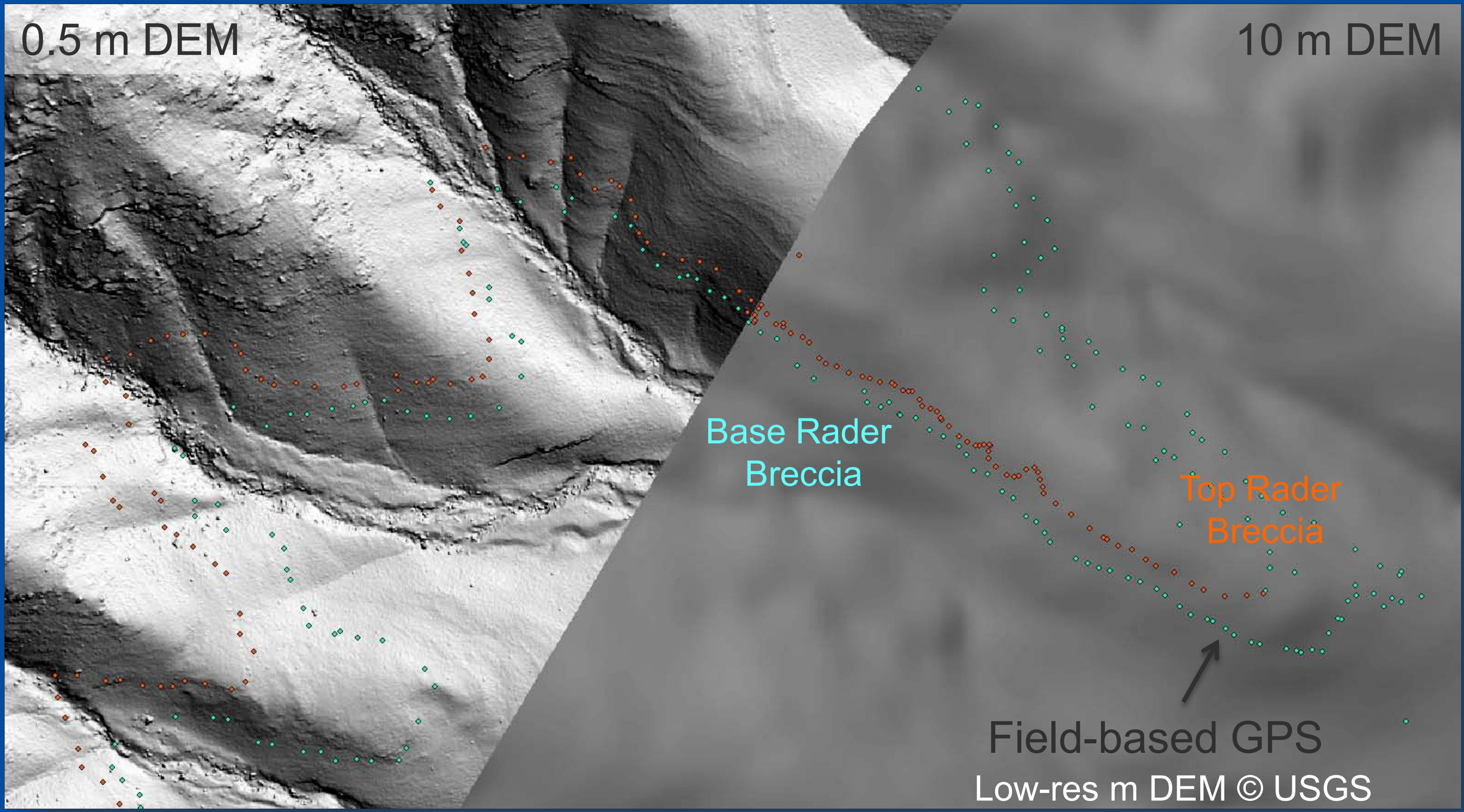
Basin:
Bell Canyon Fm.
- Lamar
- McCombs
- Rader
- Pinery
- Hegler

Guadalupe & Delaware Mountains Airborne Lidar Project



- Partnership includes CVX, COP, STO, UT Austin, and XOM.
- 5 Terabytes of data presents a significant computing challenge.
- Non-routine remote sensing project (largest high-resolution data set known).
- Lidar offers exceptional spatial correlation tool for structure and stratigraphy.
- Collaboration with the partners reduced the cost of data acquisition and increases the quality of our carbonate field analog portfolio.

Lidar Does Help in Stratigraphic Interpretation but it is not a Silver Bullet



All You Ever Wanted to know about Lidar…

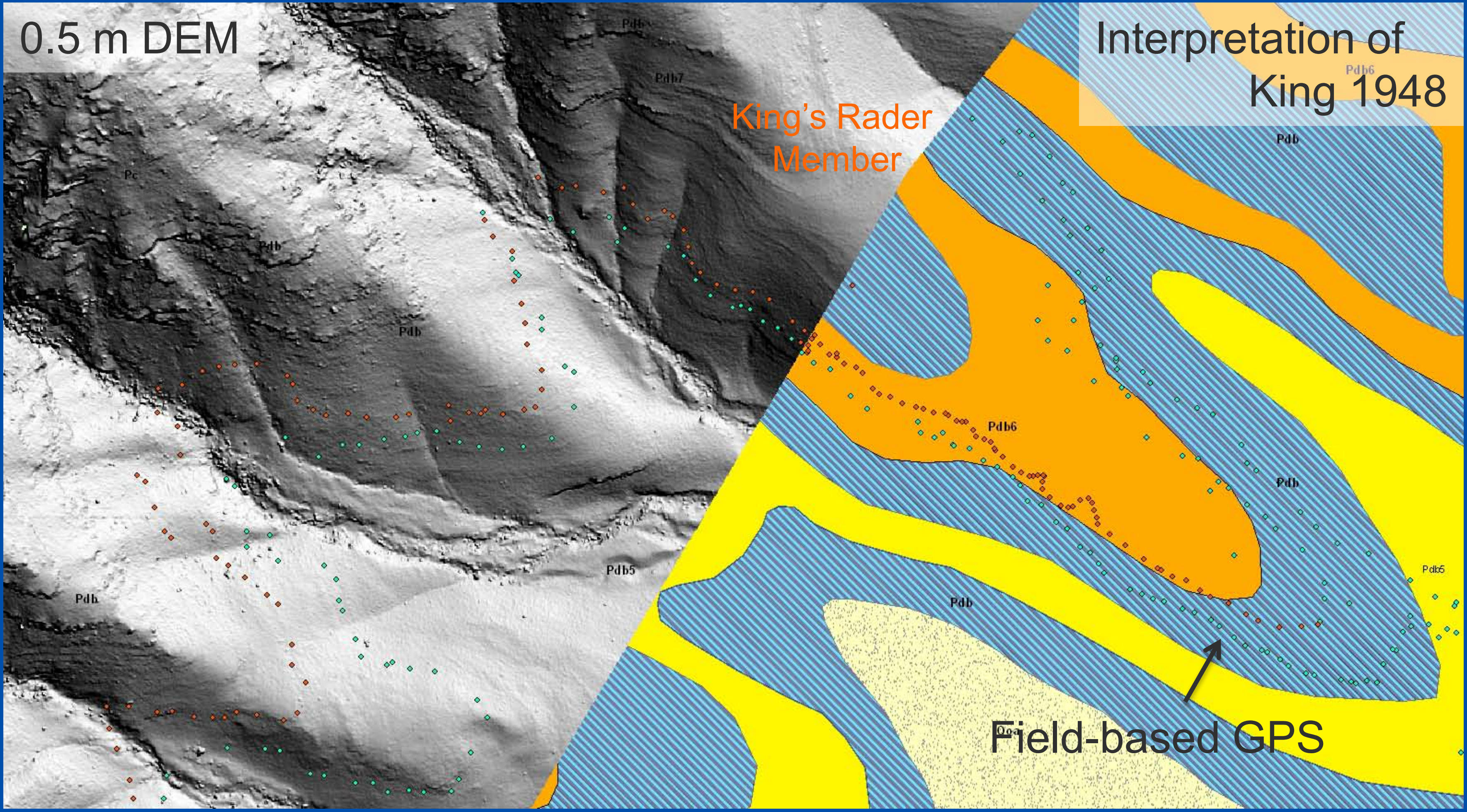
Lidar does:

- provide data for high-resolution 3-D surface models.
- enable the interpreter to project through/across large areas and compare geometric data from anywhere to anywhere.
- force the interpreter to intensely interrogate stratigraphic correlations.
- streamline field time by pinpointing areas of least confidence.

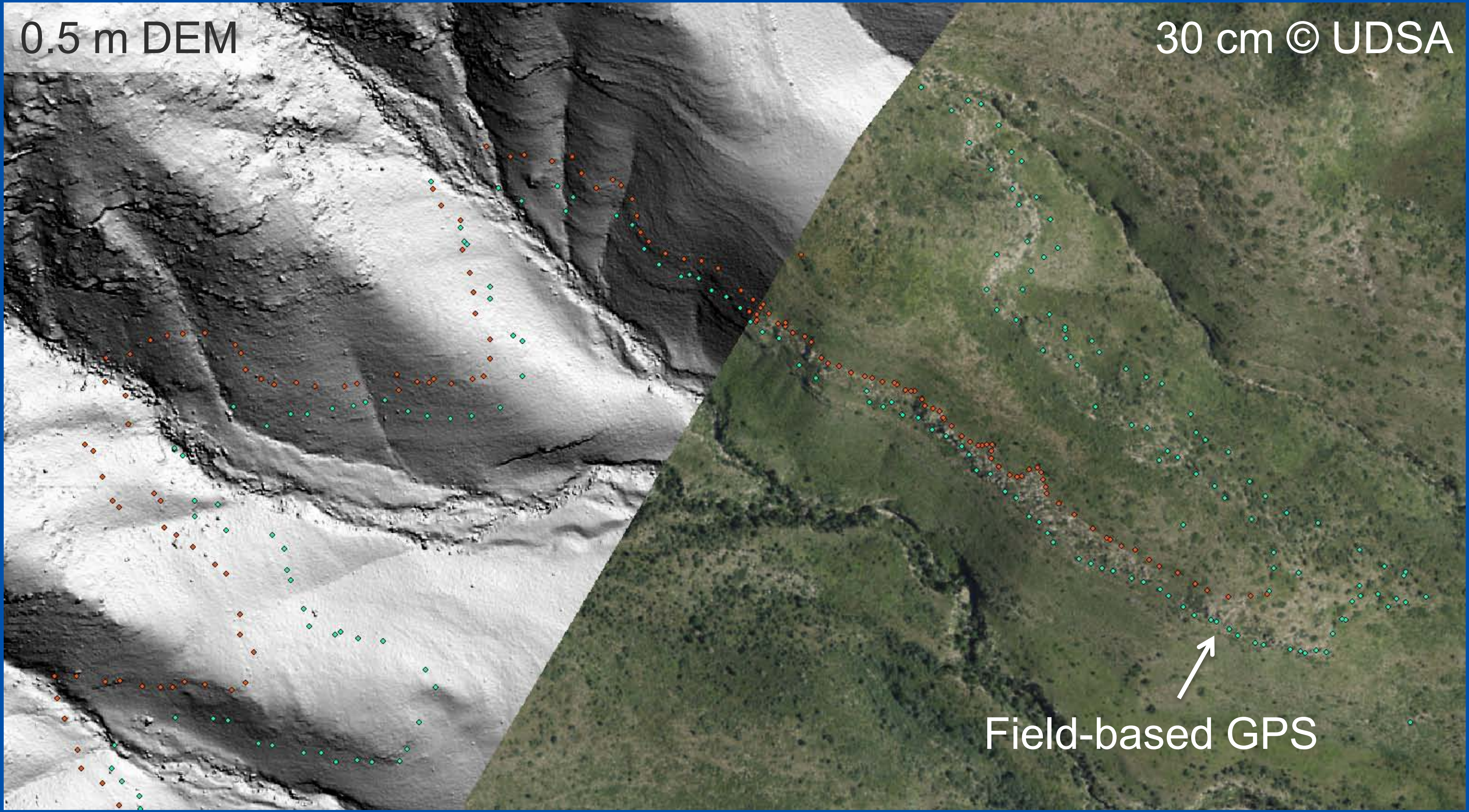
Lidar does not:

- cost as much money as you may think (anymore).
- take the place of doing field work.
- penetrate into the outcrop but is absolutely 3D.
- interpret itself, get you coffee, or help you out-hike Kerans.

Lidar in Combination with other Data Such as Field GPS and Maps…



…and Imagery
Adds more Tools to your Tool Box!

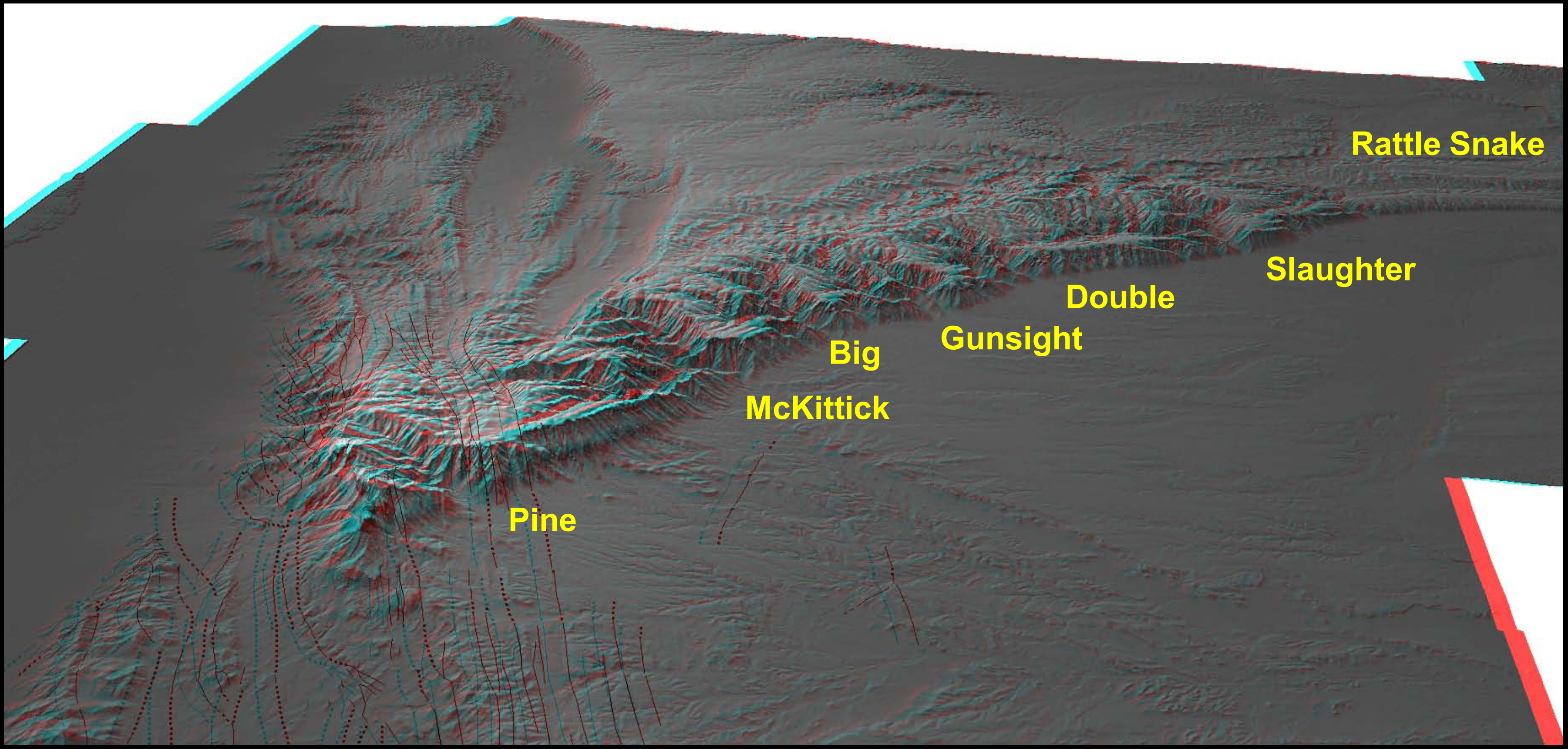


Combine these Data in a Regional 3-D GIS

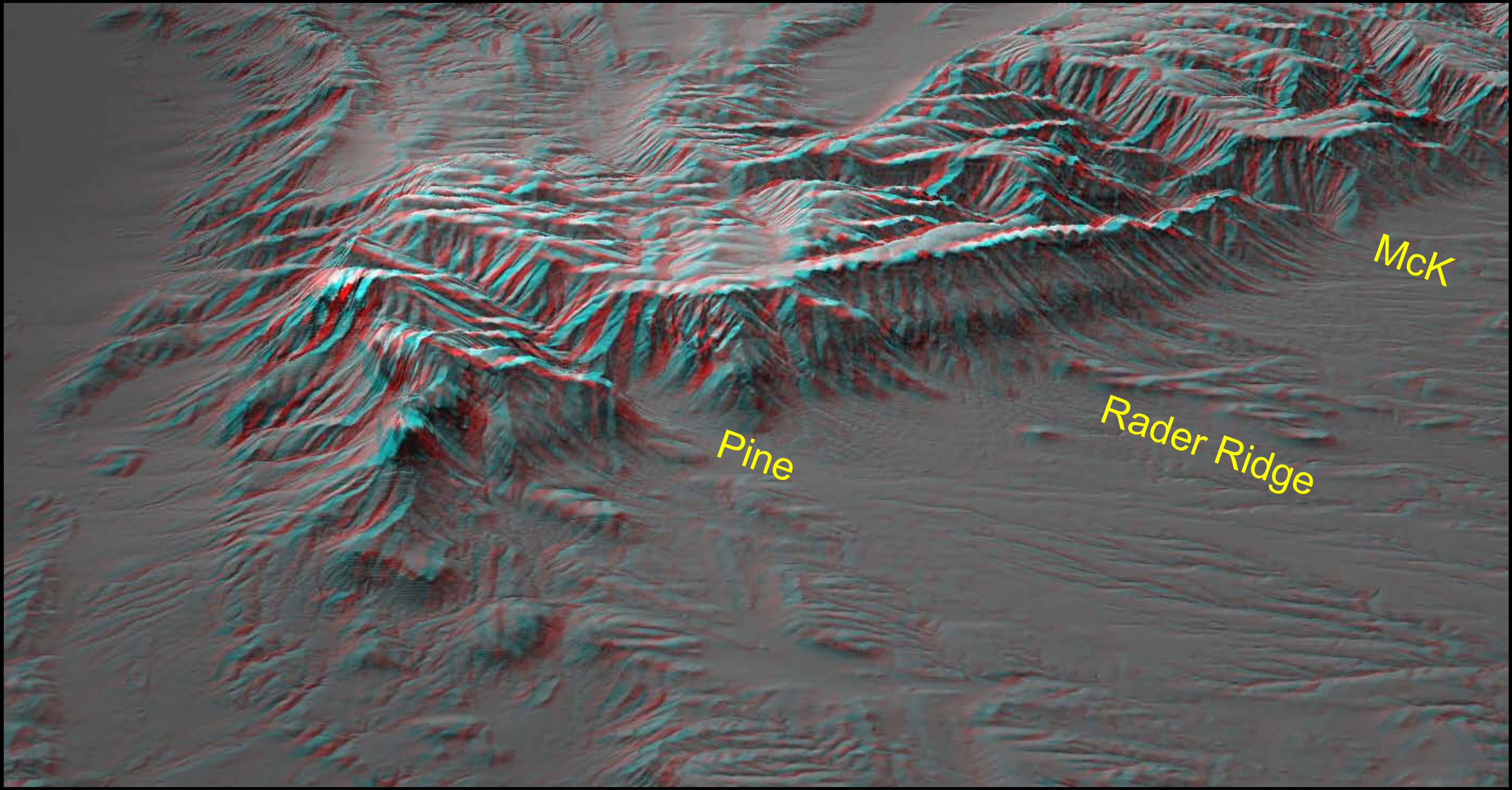
- LIDAR/SRTM DEM
- Field Observations
- Regional Geology
  - King 1948
  - GAT (BEG)
- Literature, e.g.
  - PRGT Guide
  - Playton 2008
  - Tinker 1998….
- Satellite/Airborne
  - ASTER and TM
  - 30 cm USDA

3-D GIS

Anaglyph of Major Canyons in the Region

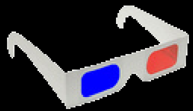


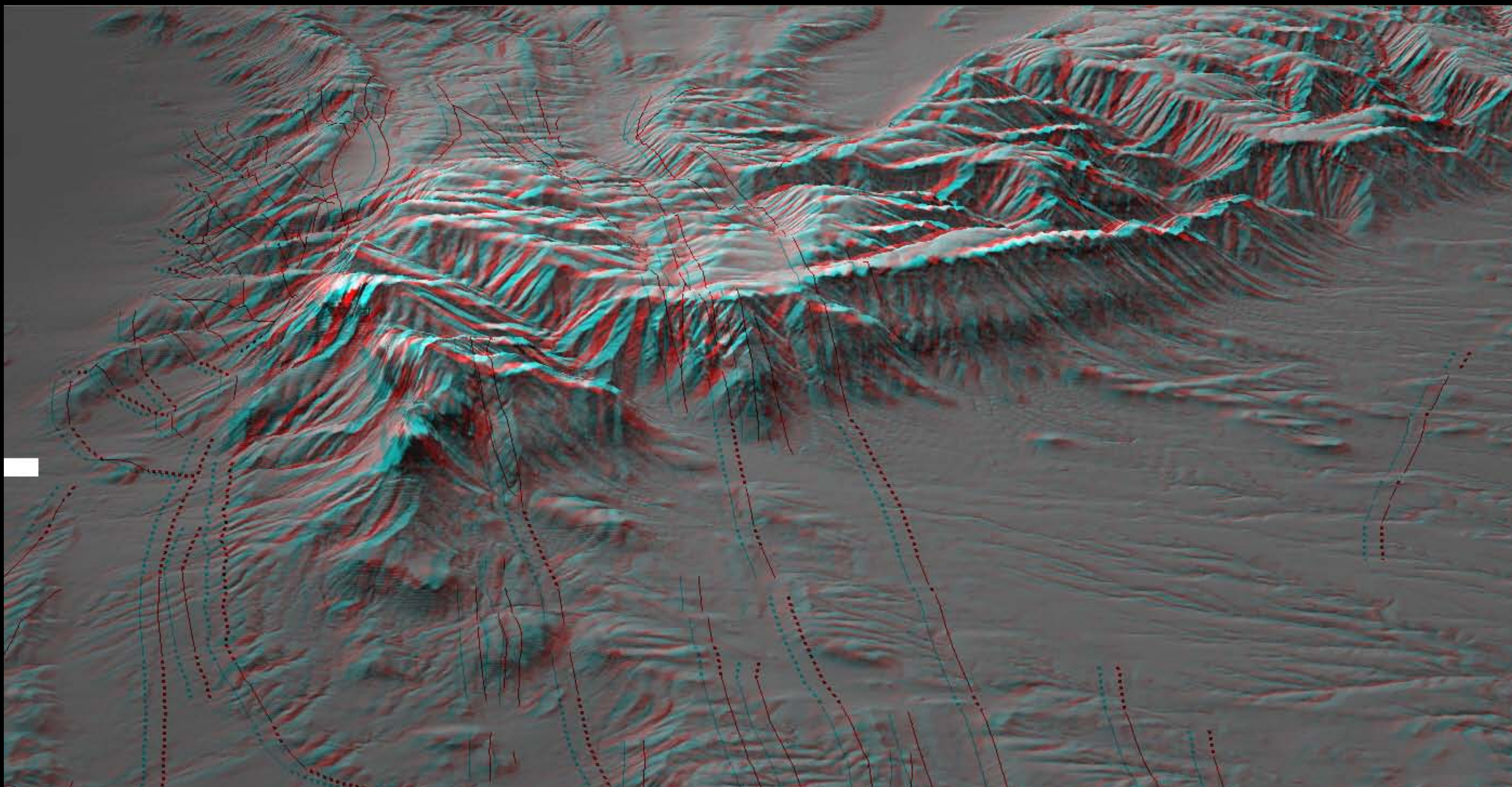
3-D GIS
Area of Interest



3-D GIS

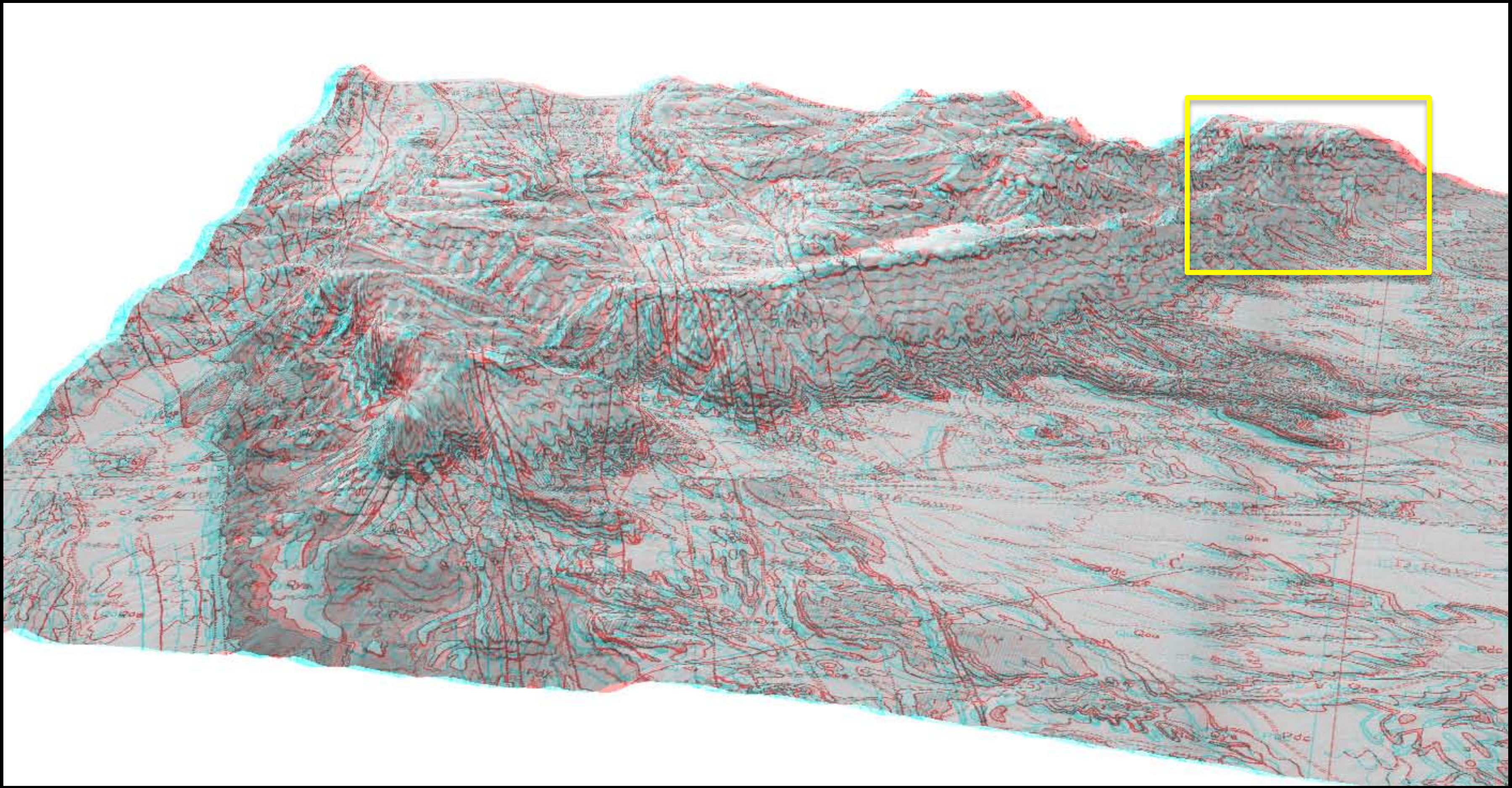
Regional Faults – Modified from King 1948





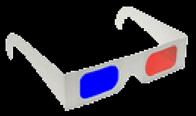
3-D GIS

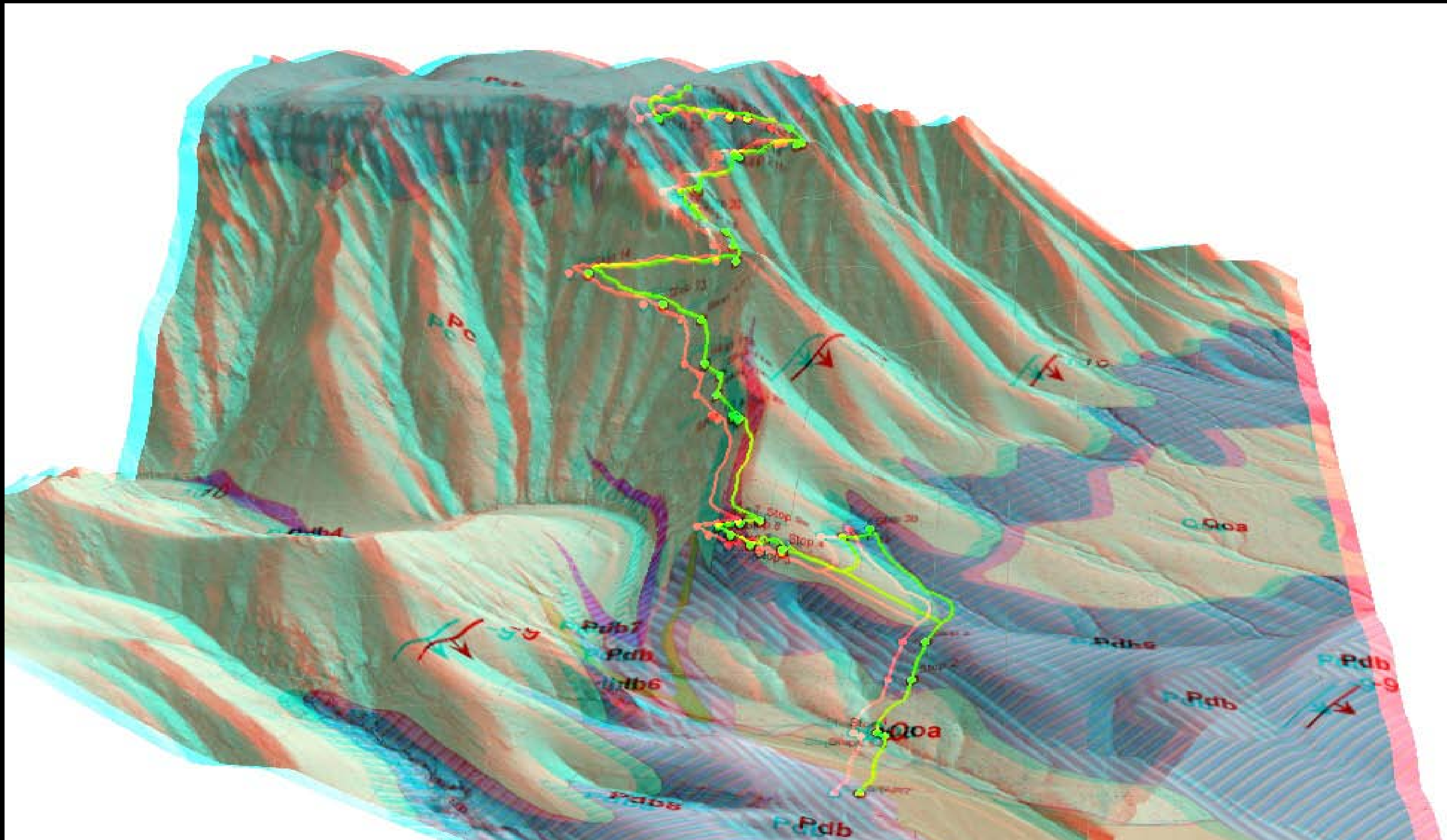
Regional Geology – Modified from King 1948



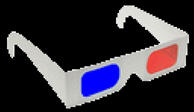
3-D GIS

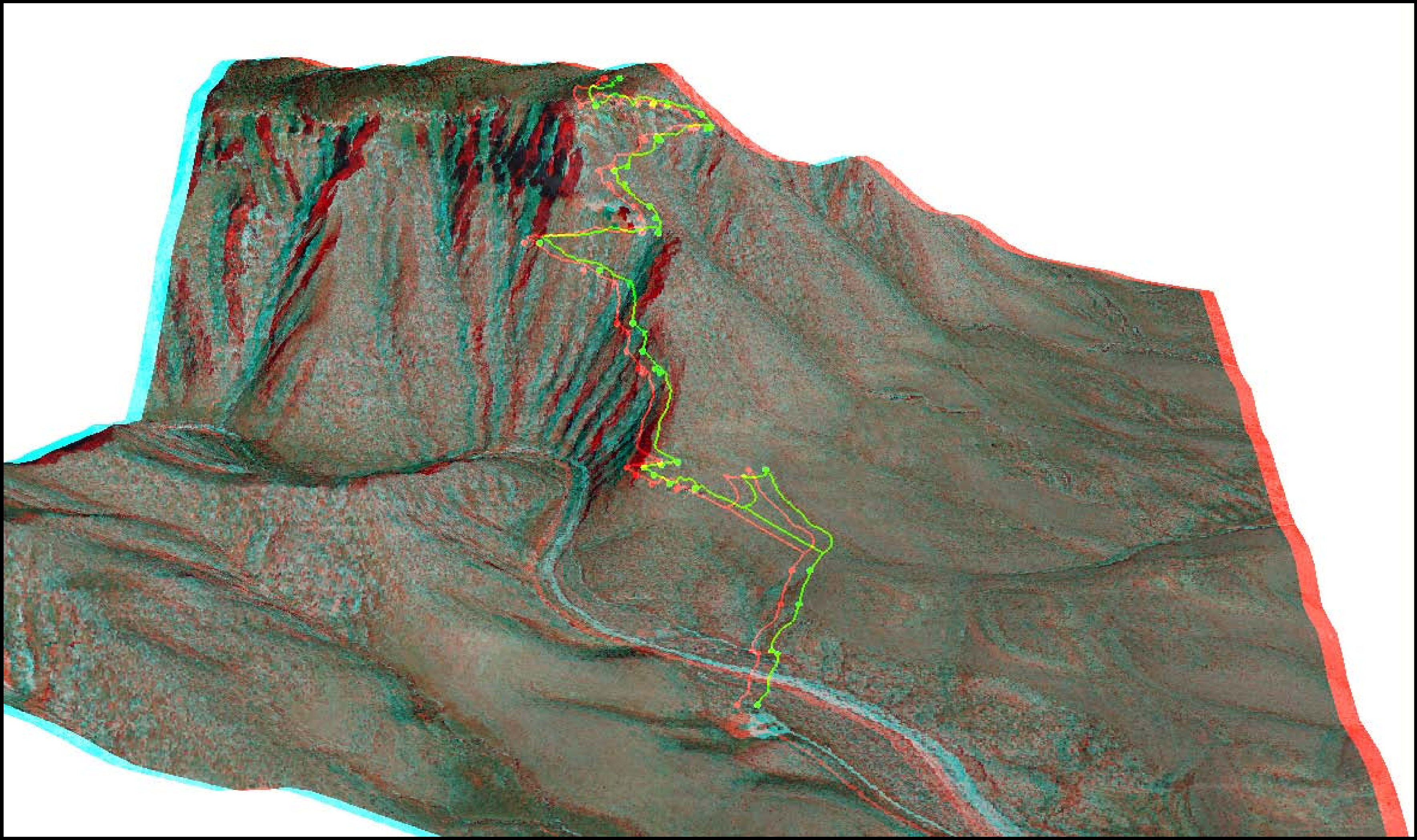
McKittrick Canyon Permian Reef Trail with King '48





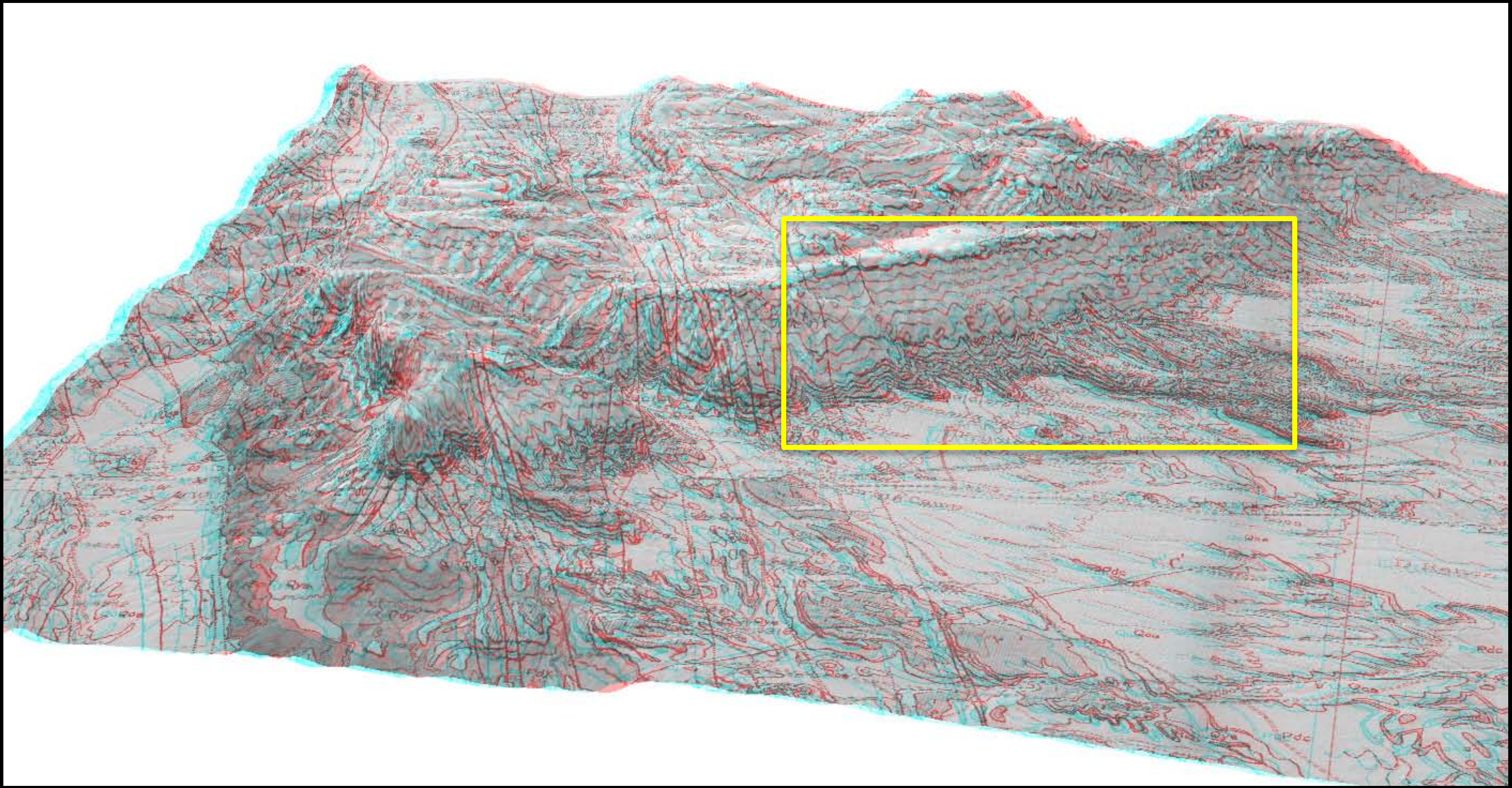
3-D GIS
McKittrick Canyon Permian Reef Trail



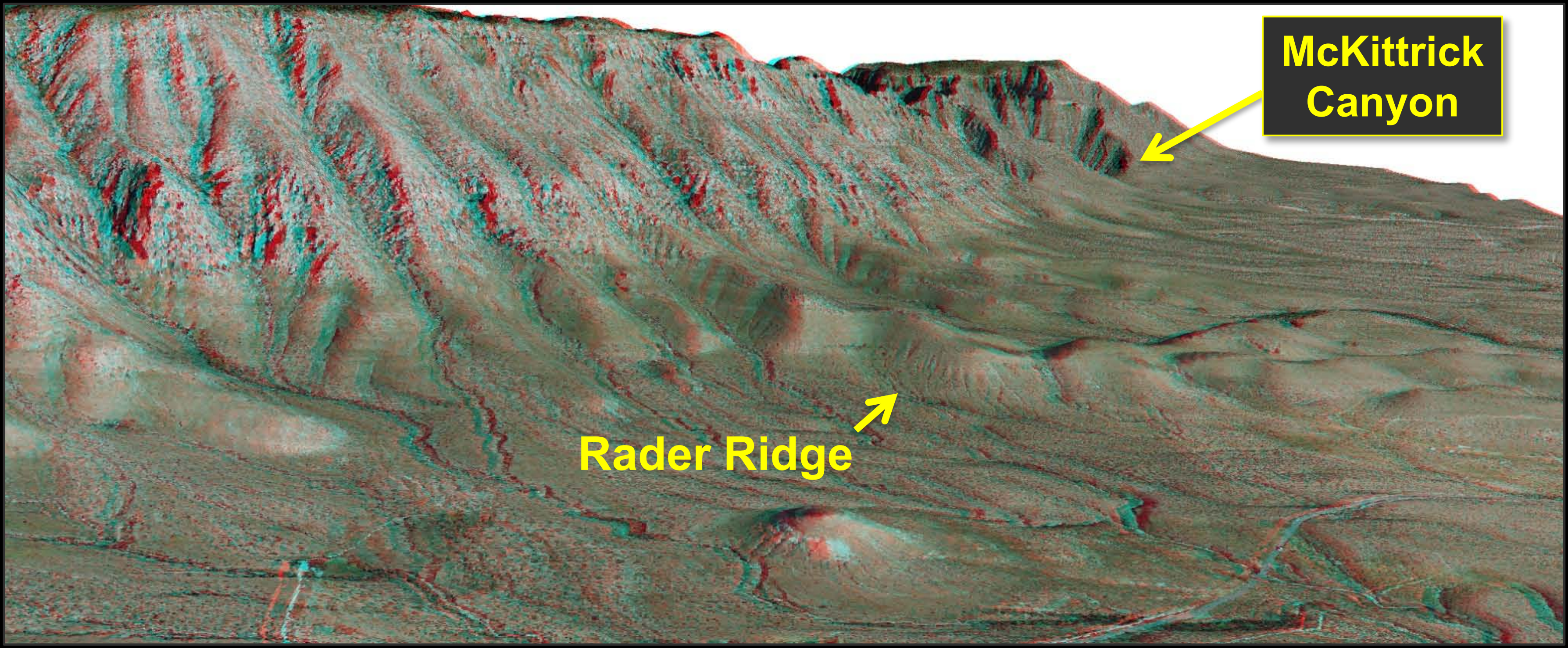


3-D GIS

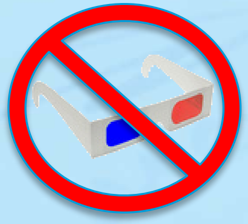
Regional Geology – modified from King 1948



3-D GIS
Bell Canyon and Rader Ridge Area



3-D GIS Summary



- In much the same way as interpreting seismic on different angle stacks, or using various log suites to better characterize lithologies drilled through, 3-D GIS combines multiple data types to better understand the rocks in order to better predict their distribution.

- The utilization of 3-D GIS helps us observe stratigraphy, mineralogy, weathering patterns, and spatial relationships of geobodies. These observations help us tie what we see into what we think.

- Hopefully this was demonstrated in the last few slides for those of you who are less familiar with the Guadalupe Mountains (or were before this session).

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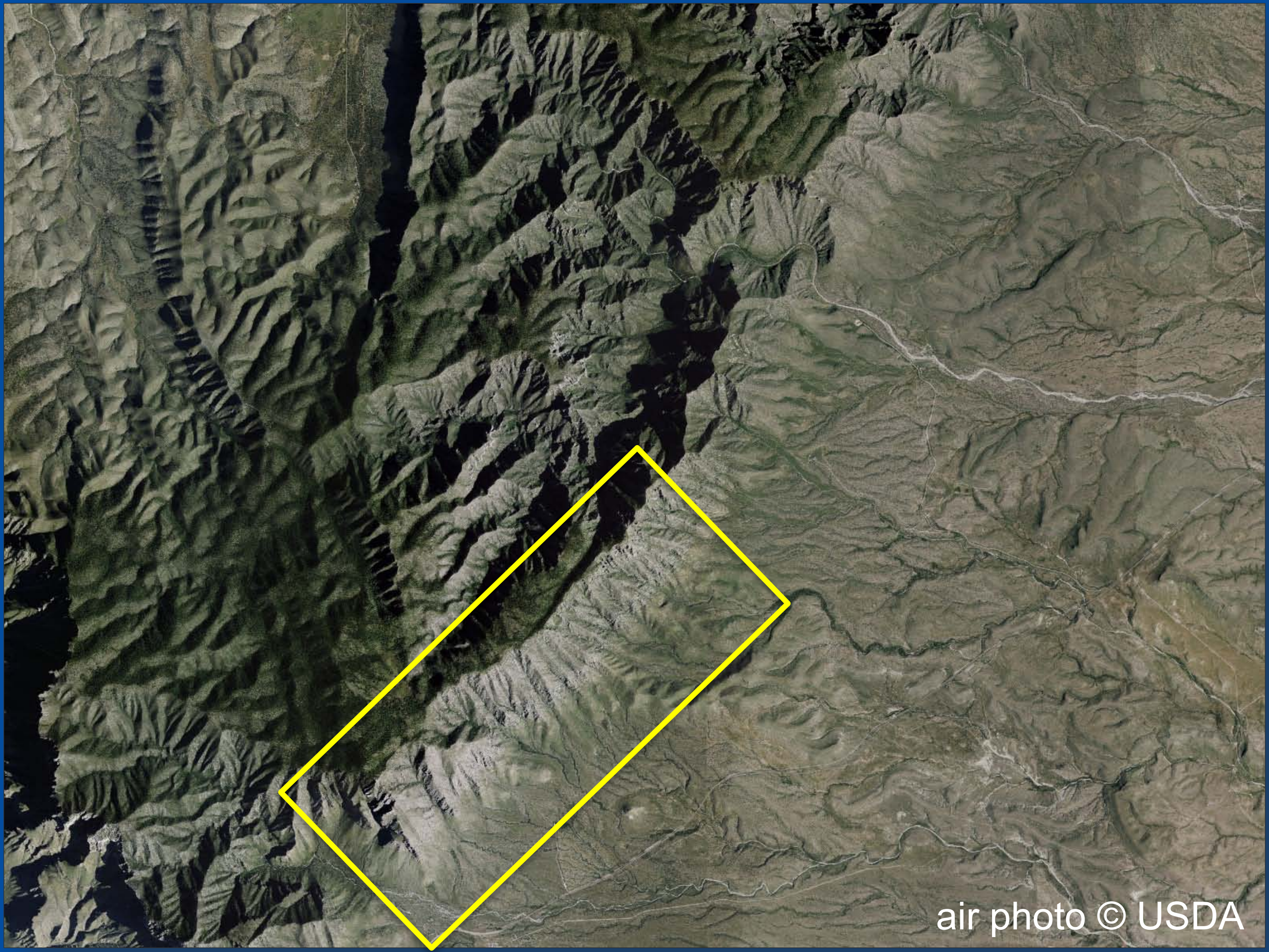
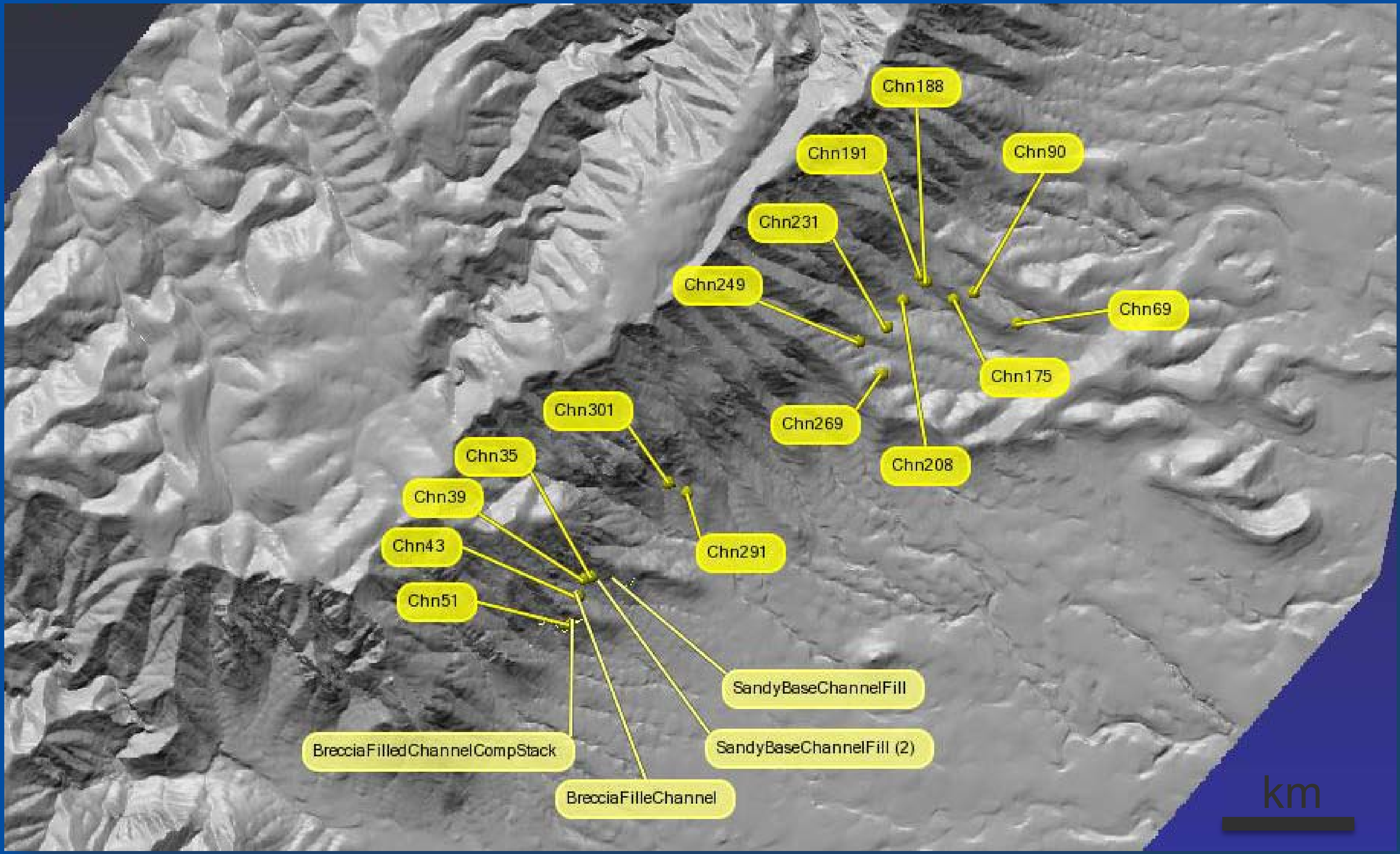
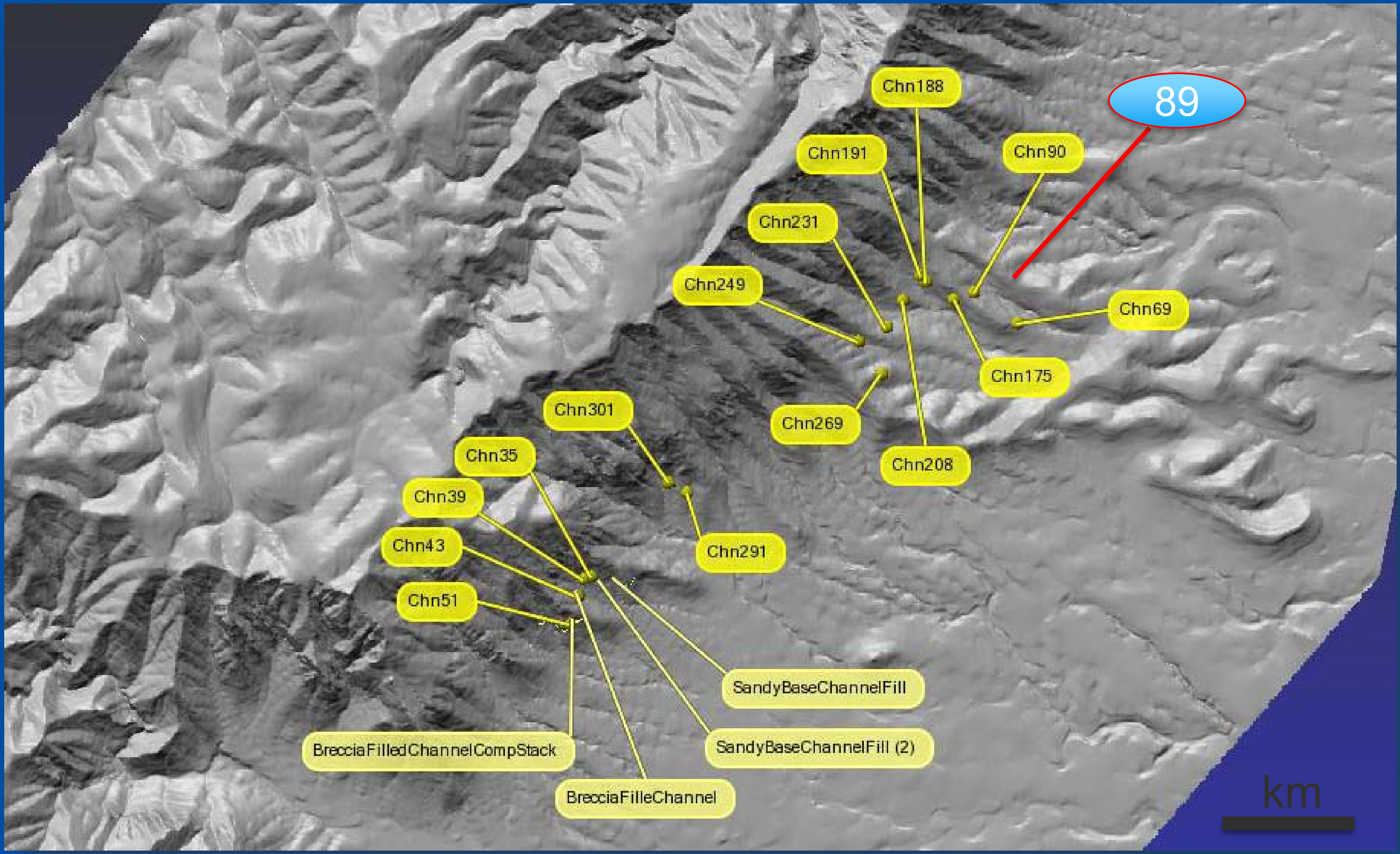
Area of Investigation



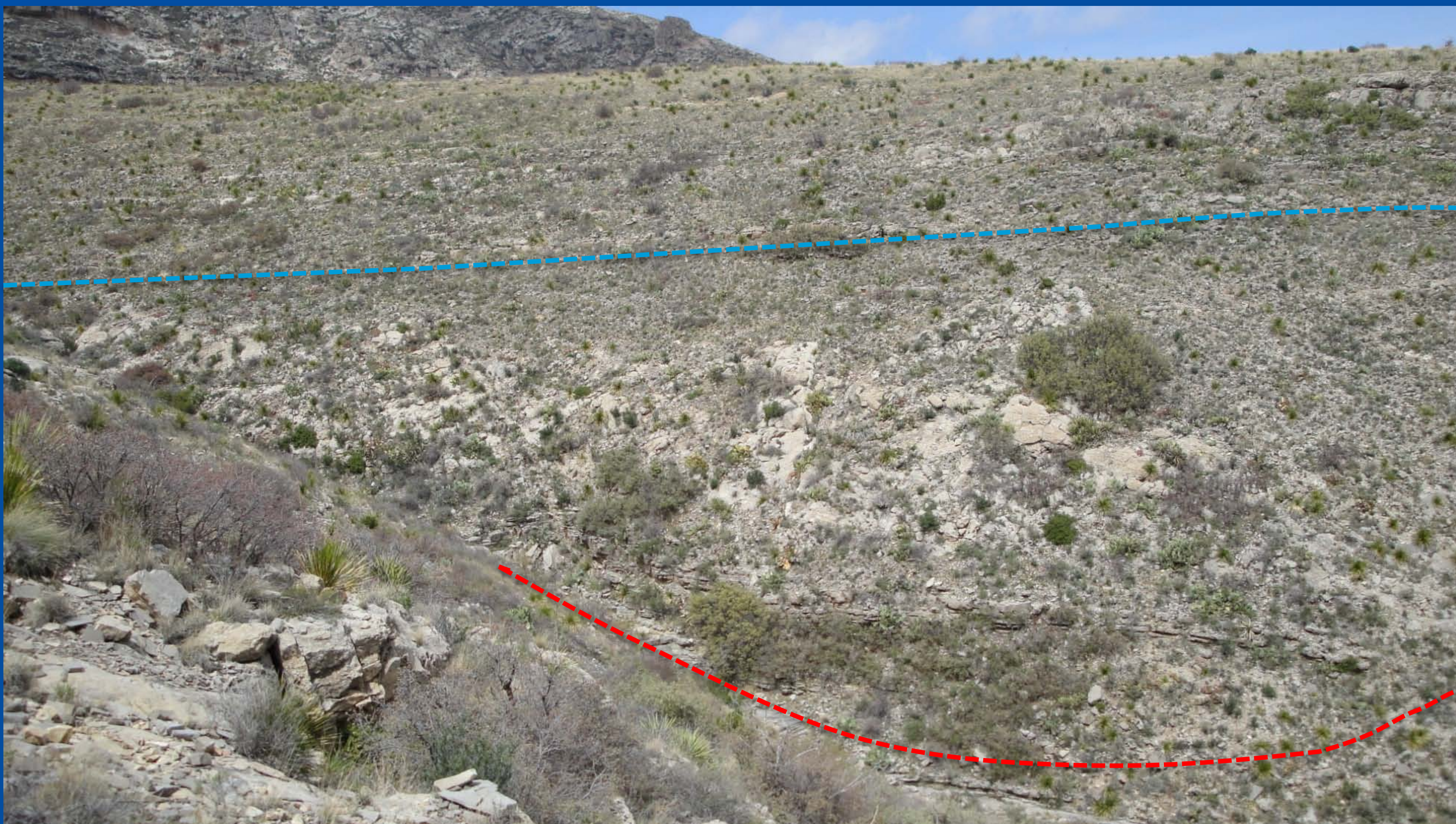
Area of Investigation
Field-Mapped Evidence for Channels



Area of Investigation
Field-Mapped Evidence for Channels



Lower-Slope Channel Fill
Large (10 m) Slab in Breccia Fill



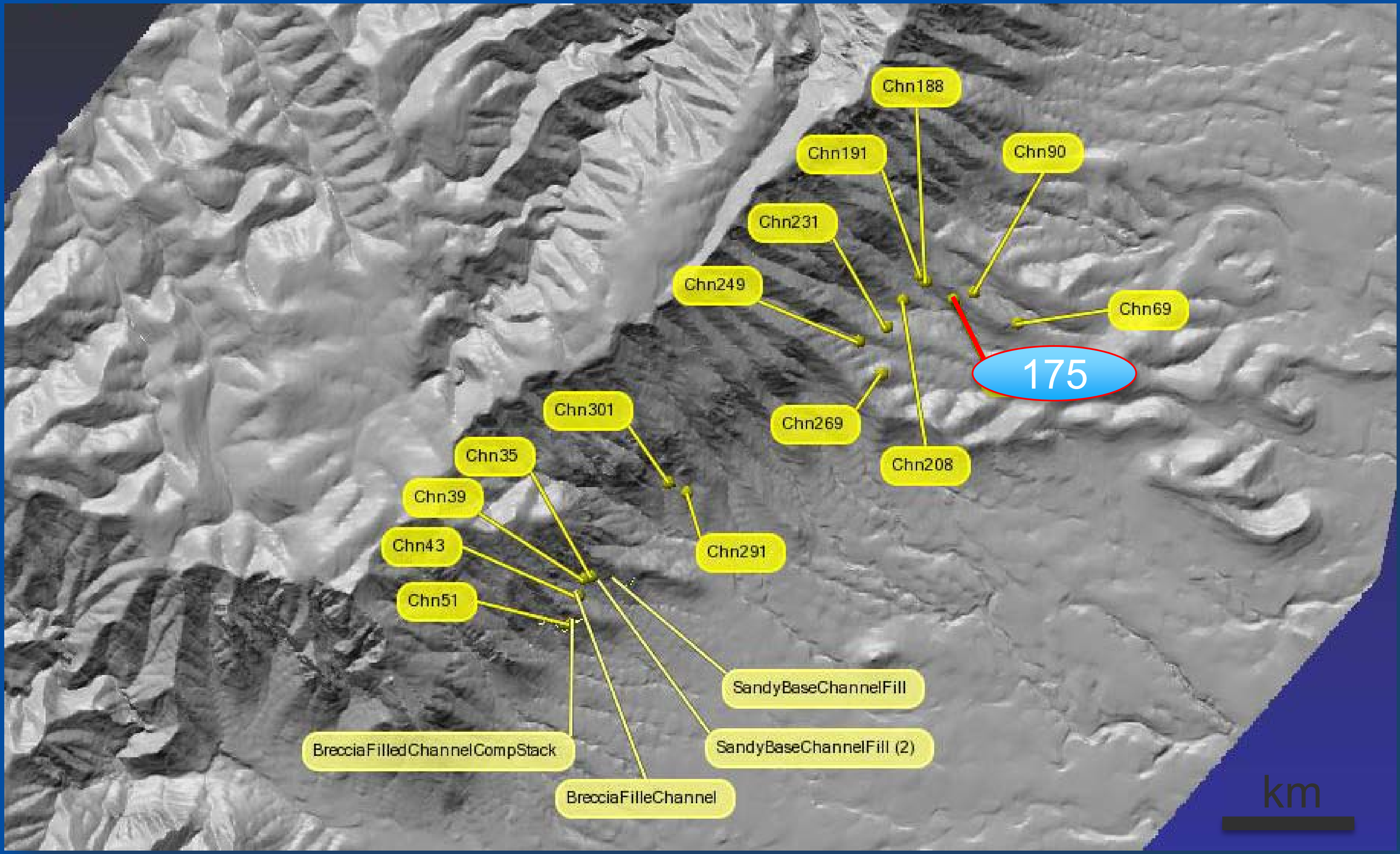
Lower-Slope Channel Fill
Large (10 m) Slab in Breccia Fill

Margin-derived reef blocks

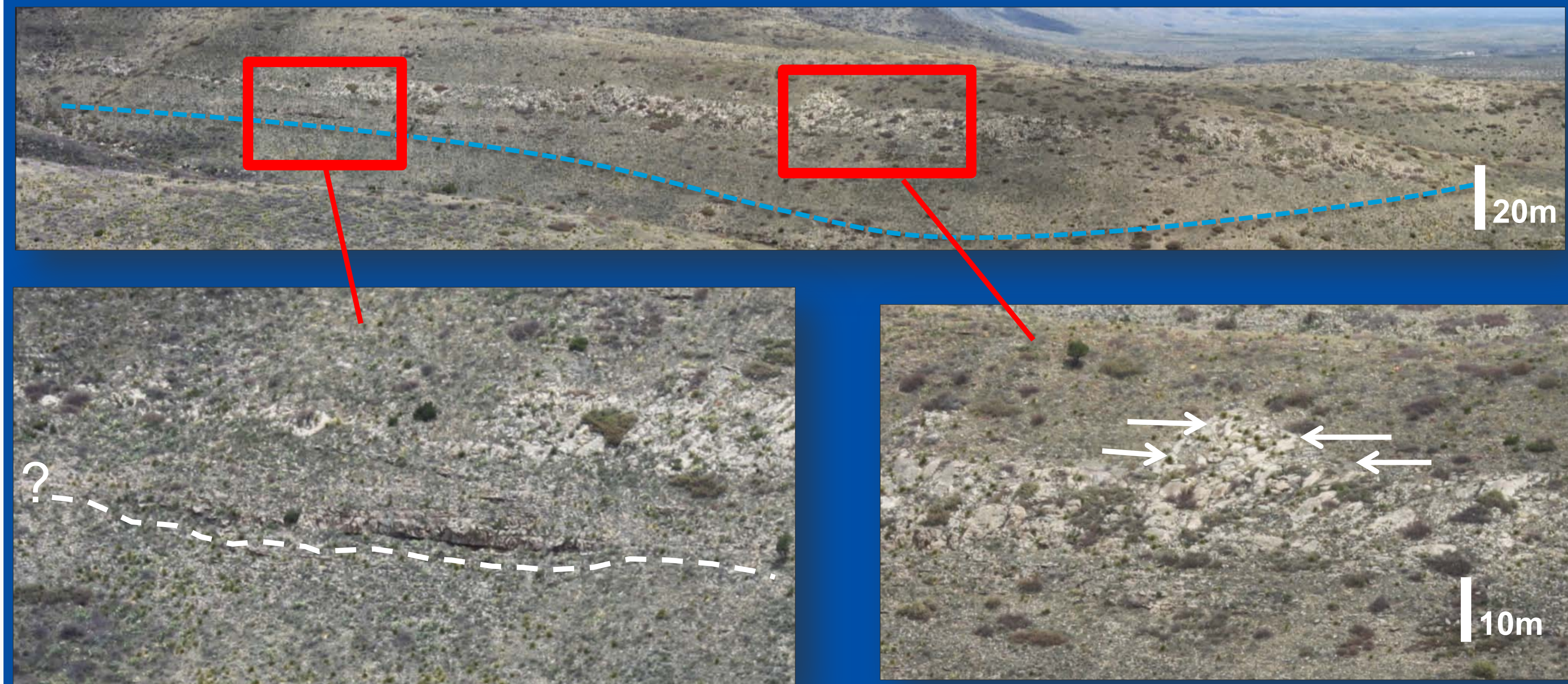
Silt-matrix polymictic breccia

Interbedded silts and wacke-packstones

Area of Investigation
Field-Mapped Evidence for Channels

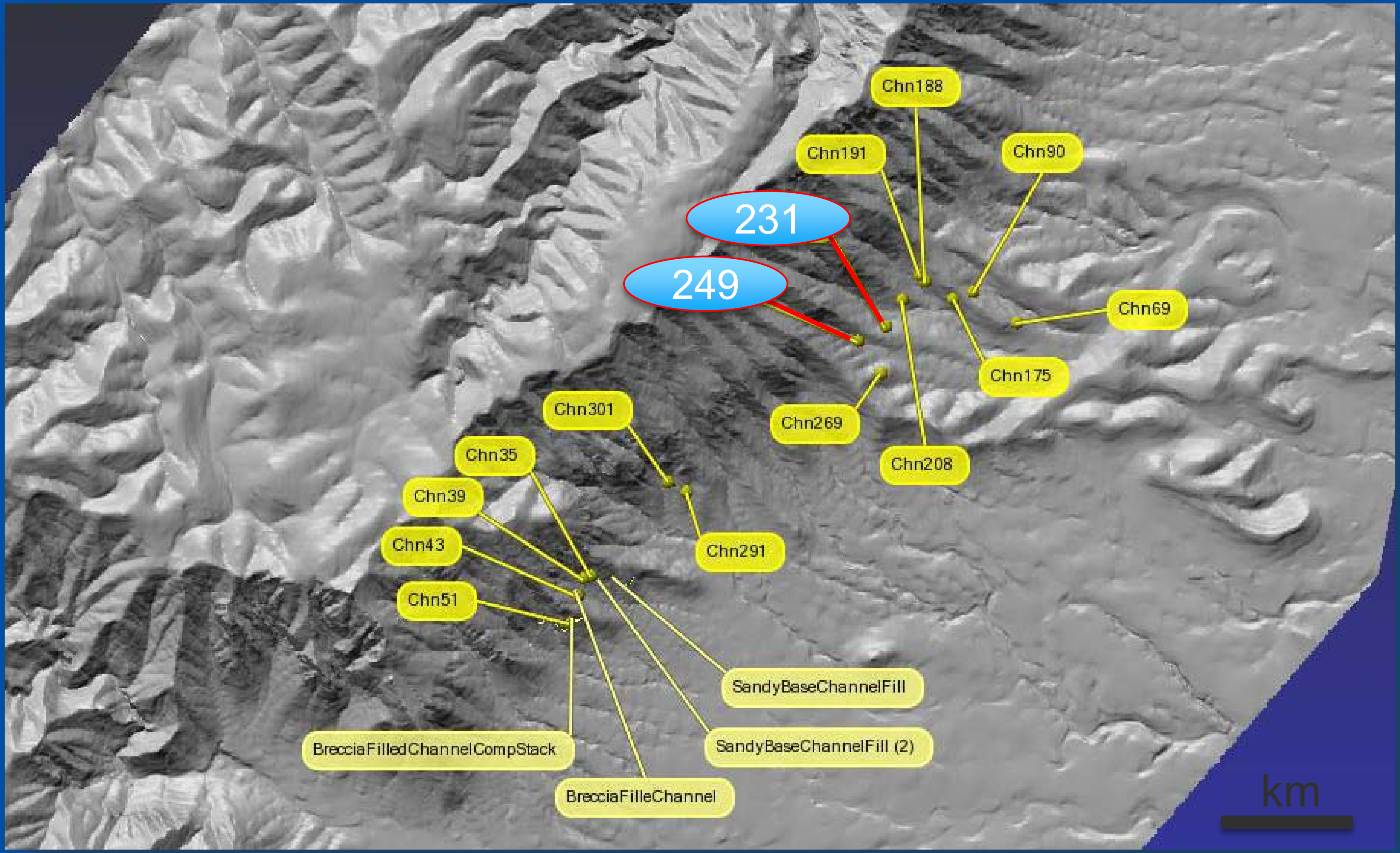


Lower-Slope Channel Fill
Complex Cut-Fill and Compaction History

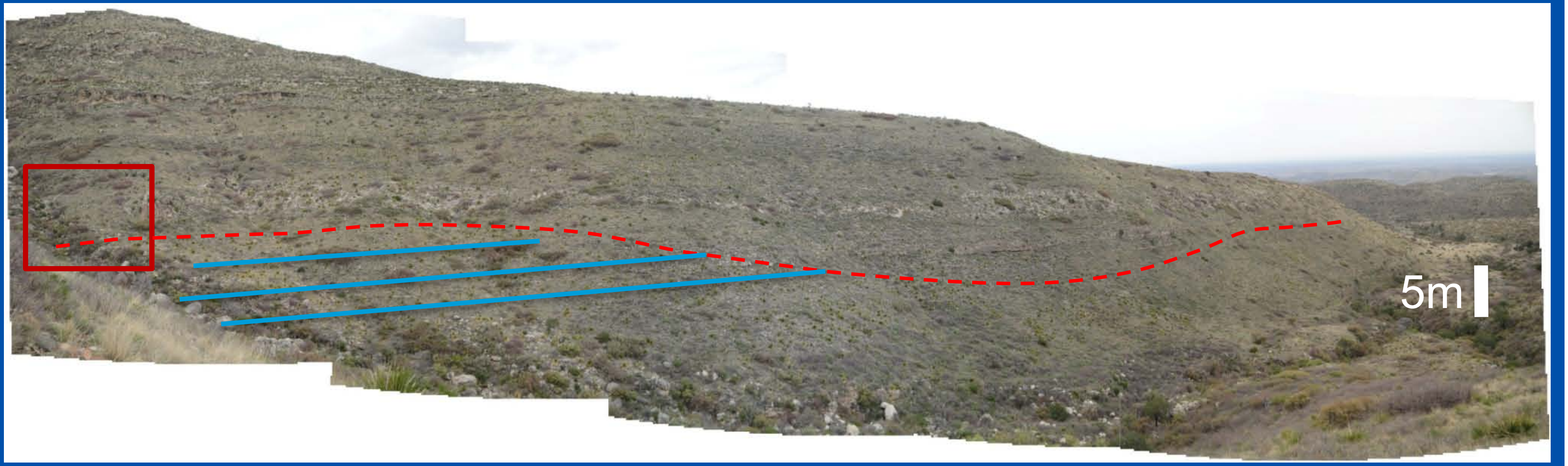


- Toe-of-slope/lower-slope breccias observed
- Potential slope-channel system with complex cut and fill
- Relief enhanced by differential compaction

Area of Investigation
Field-Mapped Evidence for Channels

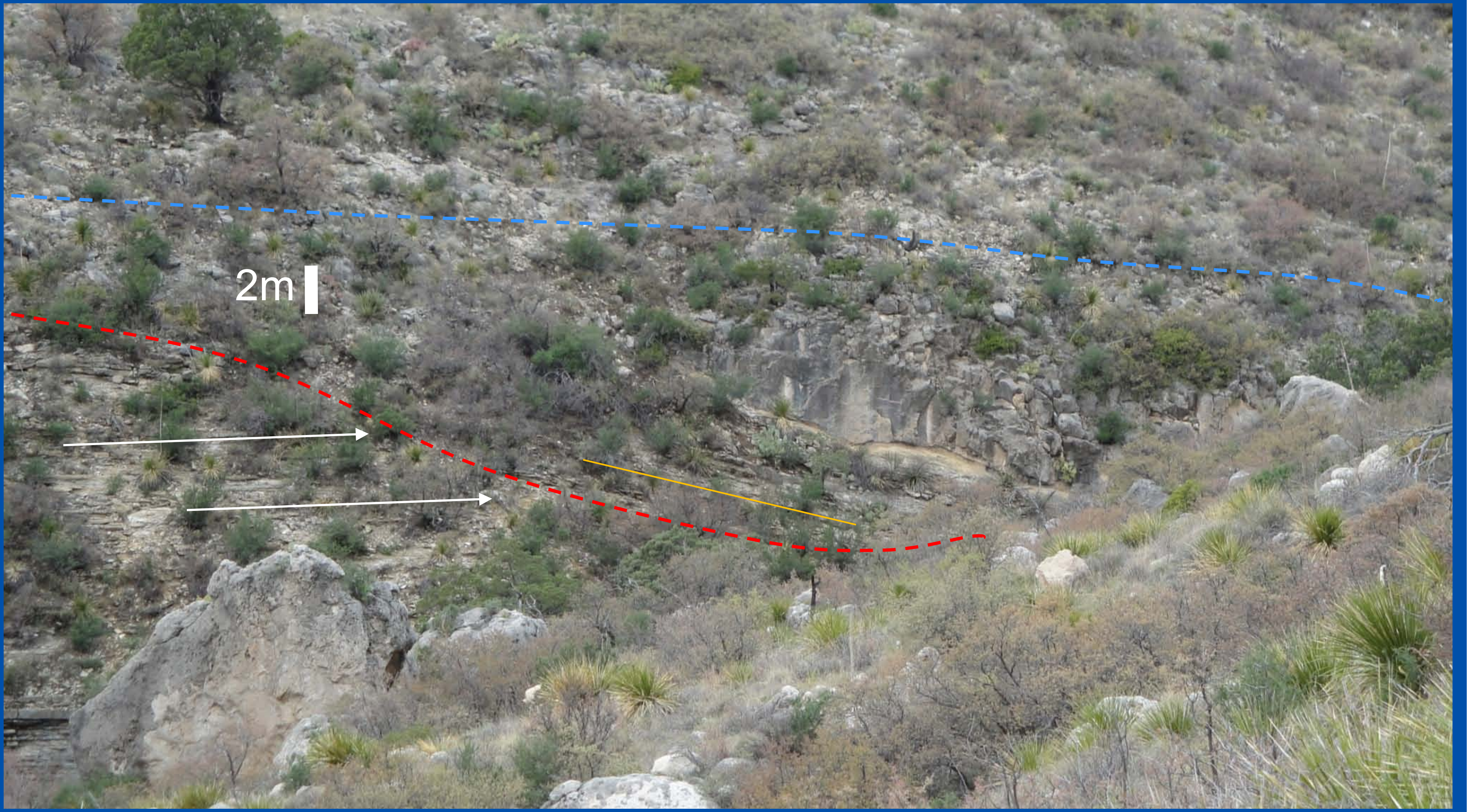


Master Erosional Surface & Bypass *Sands & Silts*



- Slope carbonates are incised and filled with clastic-rich sediments
- Carbonate breccias overlie clastic-dominated channel succession
- Red box (left) in next slide-

Siltstone/Wackestone-Draped Erosion Surface
Platform-Derived Breccia Backfilling



Incision, Siltstone/Wackestone Drape, Breccia Fill

Lower-slope wackestones
(rock hammer for scale)

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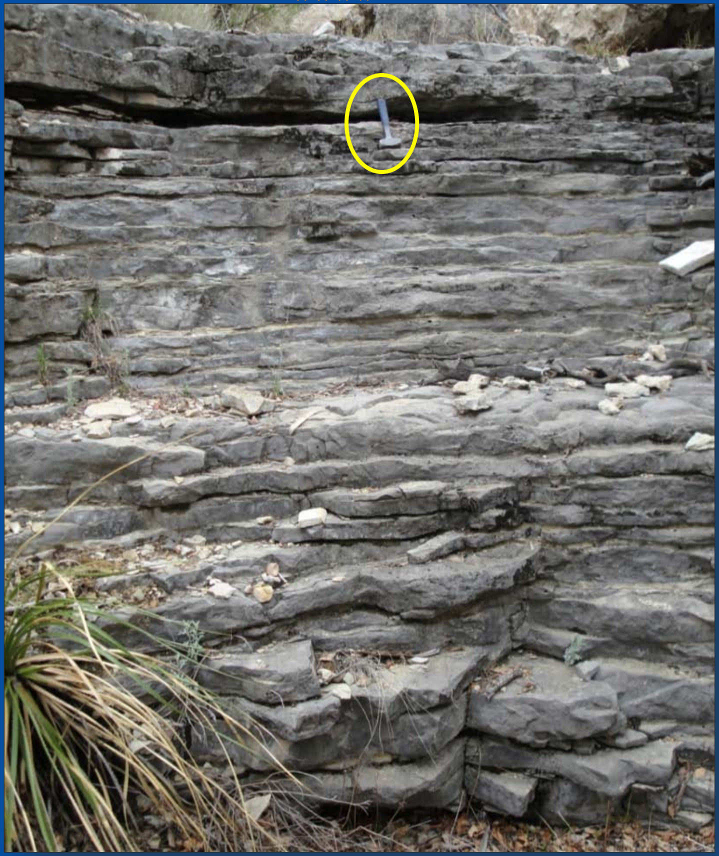

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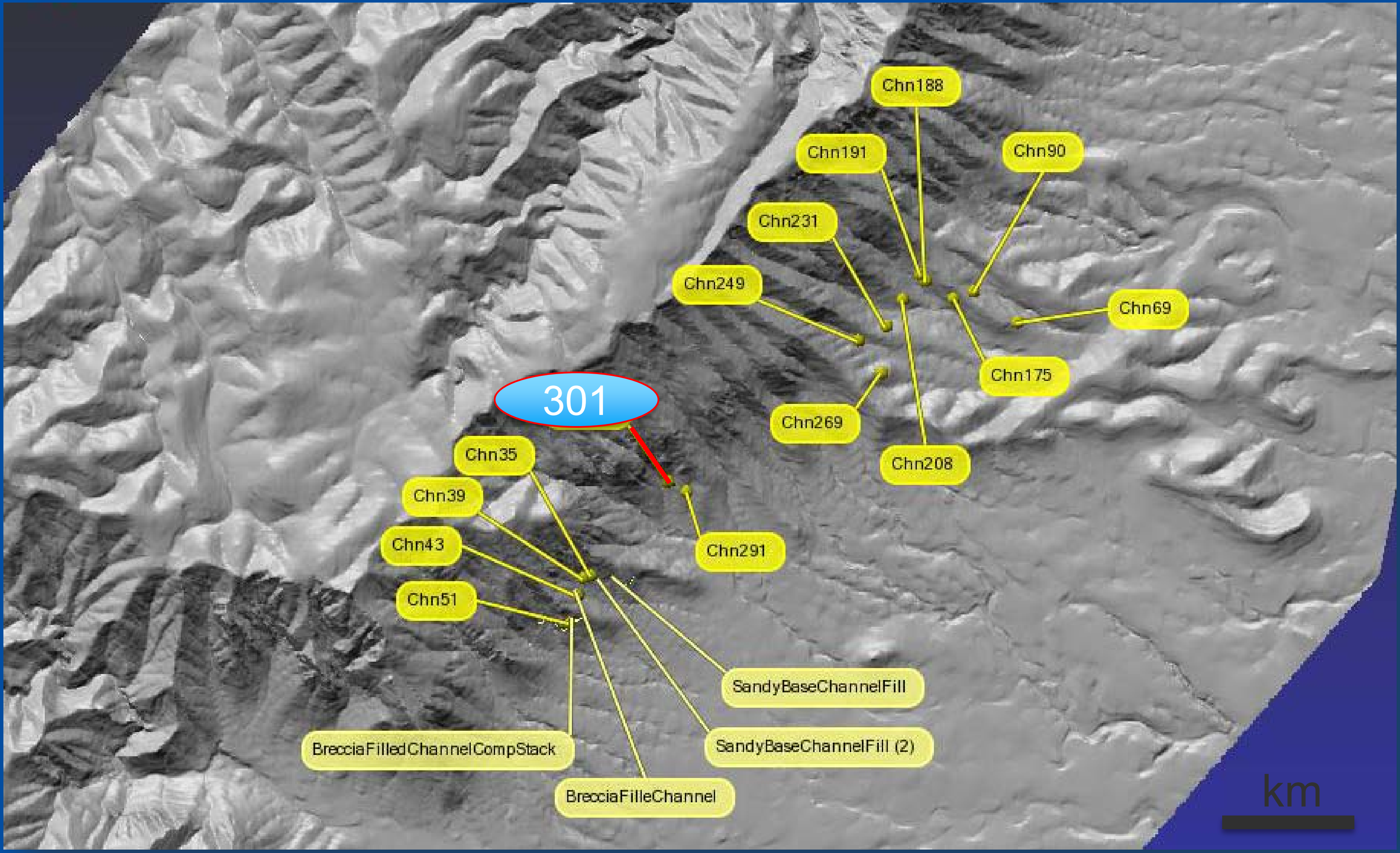
Platform/margin-derived dolomitized debris compacting siltstone and wacke-packstones; below, lower-slope mudstone to wackestones.

Evidence for Incision/Plowing and Backfill

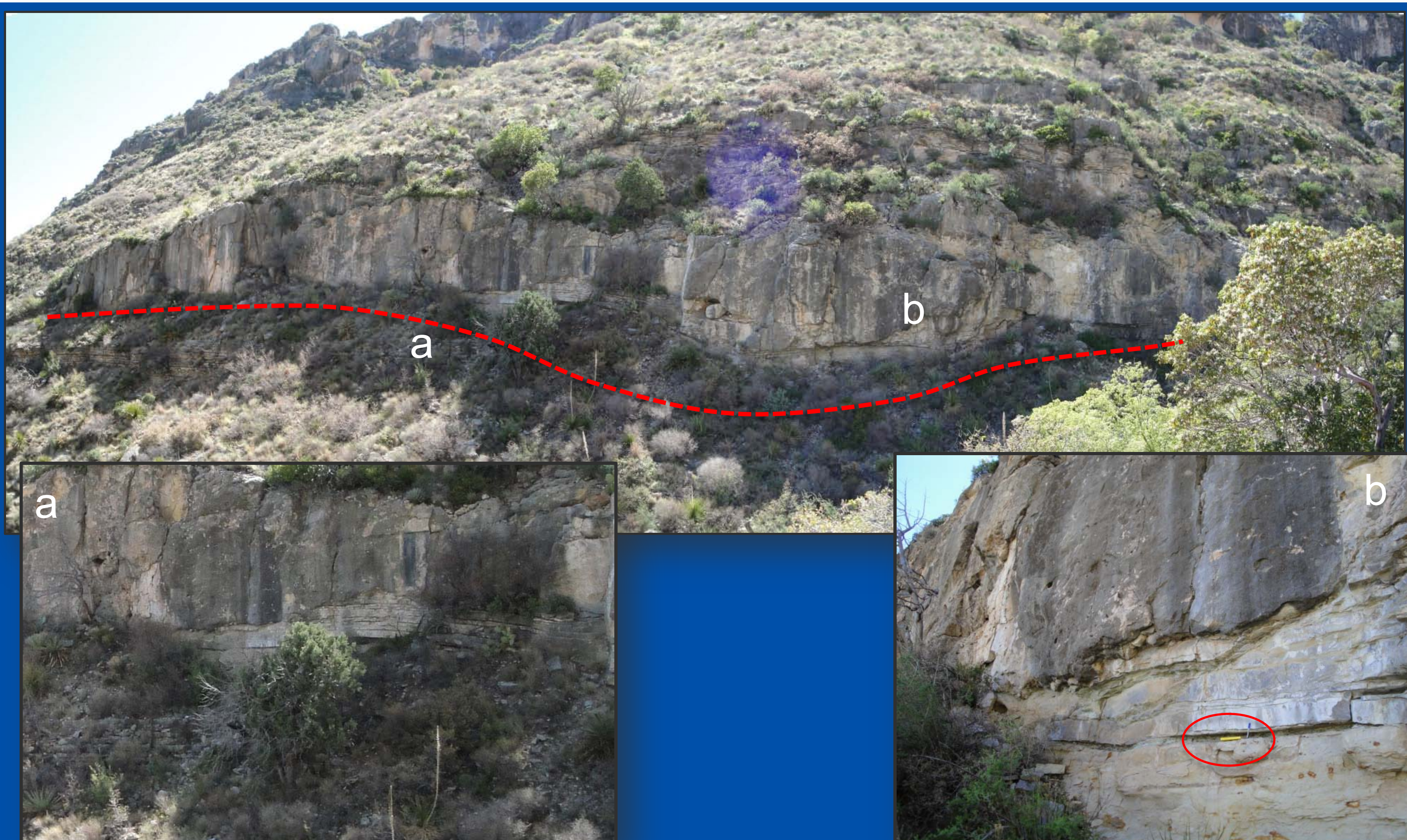
Margin Debris

Interbedded silts and wacke-packstones

Area of Investigation
Field-Mapped Evidence for Channels



A More Proximal Channel Exposure

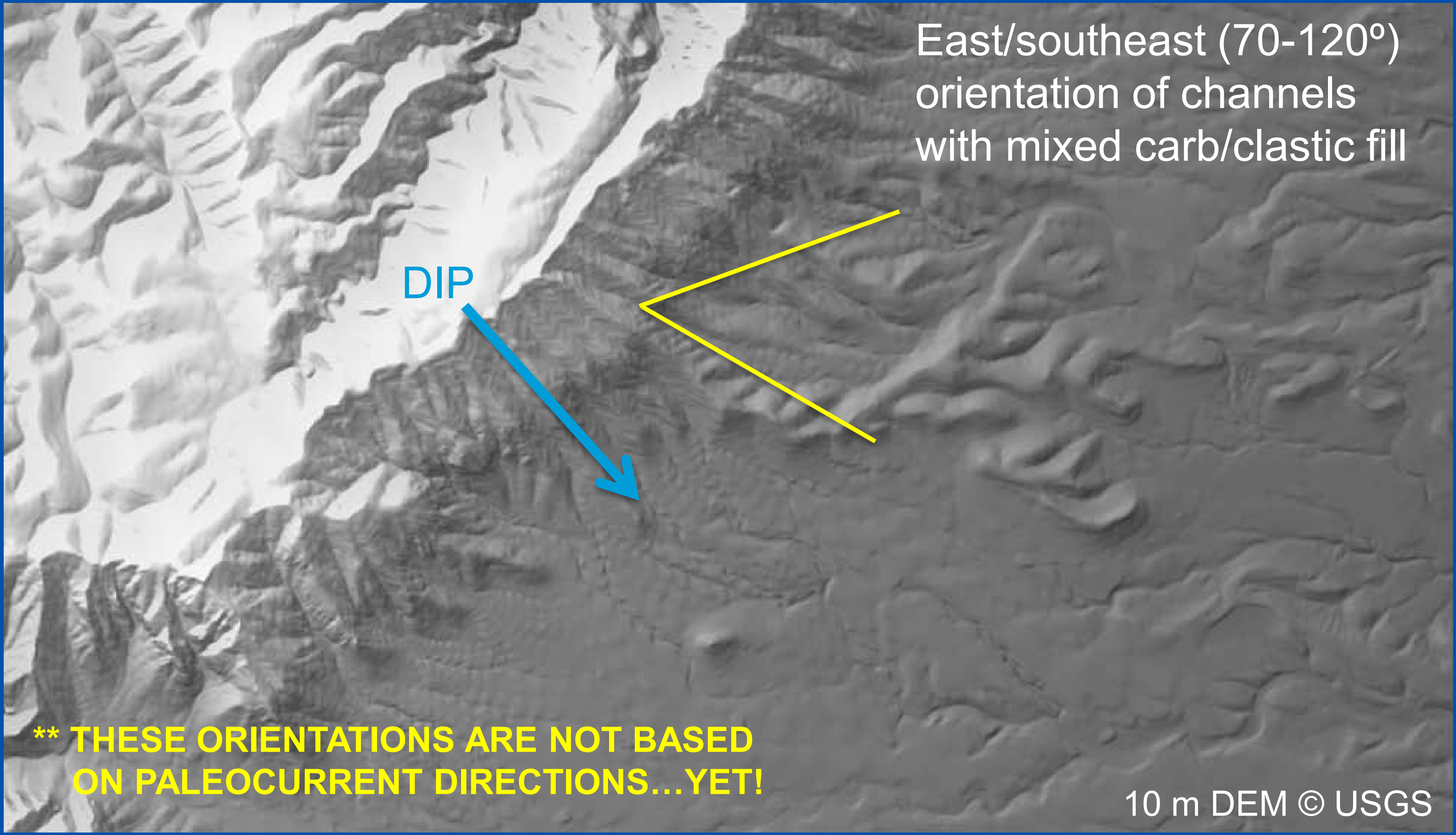


Carbonate Debrite Plow/Scour

Margin/Slope-derived debris

Interbedded siltstones and packstones

Estimated Channel Orientation



Summary of Observations
Rader Breccia and Related Channel Evidence

- Mapping of observations on lidar suggest oblique channel trends
  - although these findings need additional field validation, the first phase of field work integrated into the 3-D GIS indicates high-probability these measurements are correct.

- Field work shows complex channel fills
  - carbonate-clastic interaction within the Rader Member may offer additional information about timing of slope breccia delivery and further delineate sequence stratigraphy within the Capitan Formation.
  - “traditional” deep-water channel cut-and-fill morphologies have been recognized within carbonate-dominated channels (channel complexes?).
  - diagnostic criteria for recognition of channels versus slumps/ scours/gullies need to be established for this system and possibly refine our understanding of slope sediment delivery processes.

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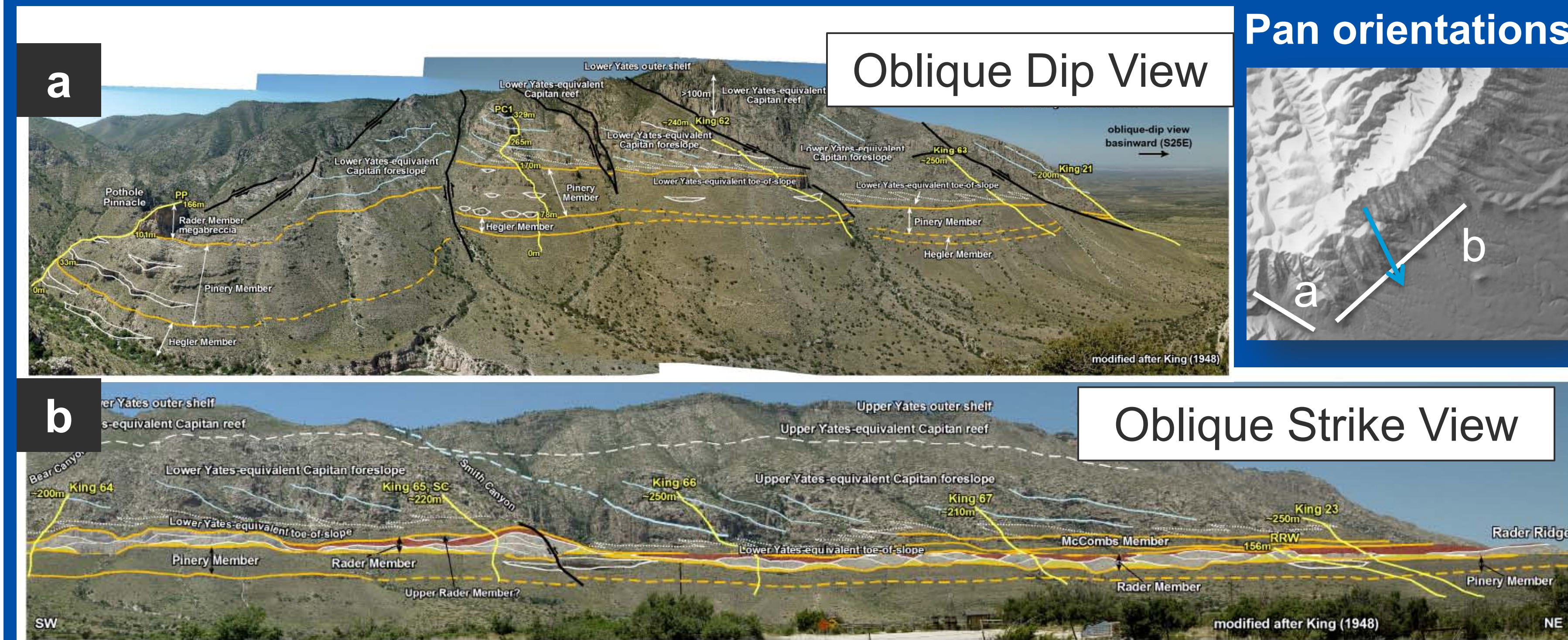
Previous Work

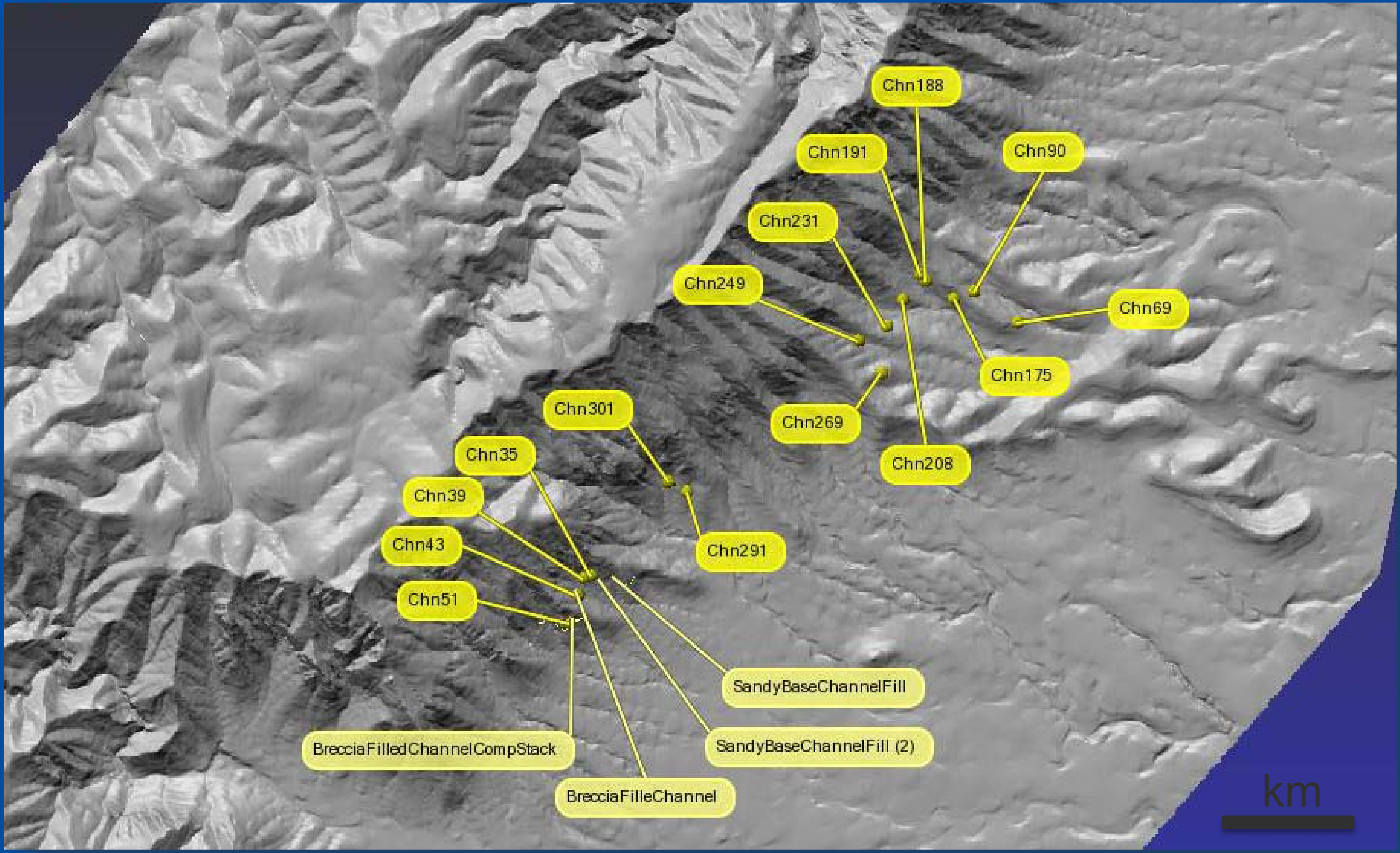
Pine Canyon and McKittrick Canyon



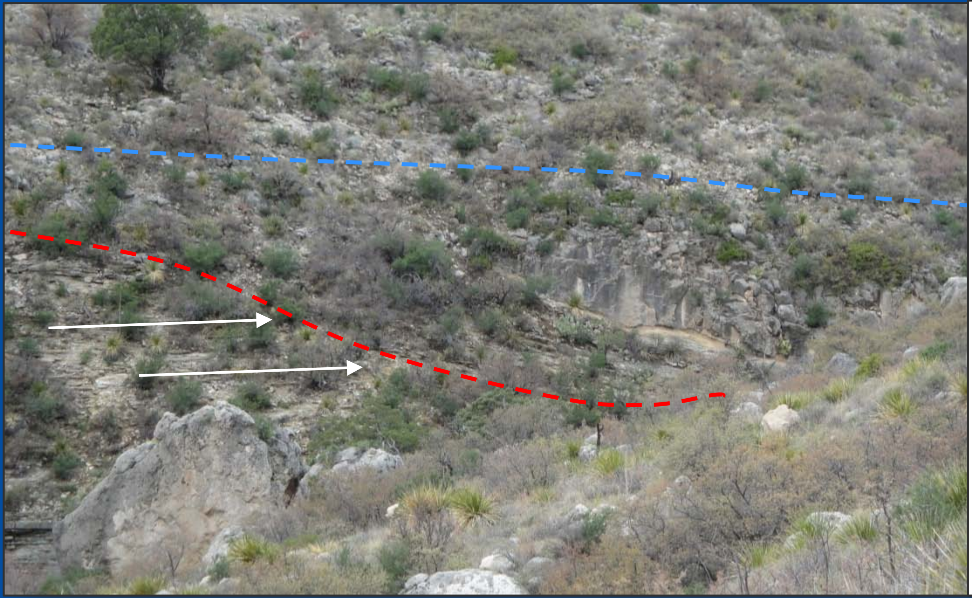
after Playton 2008

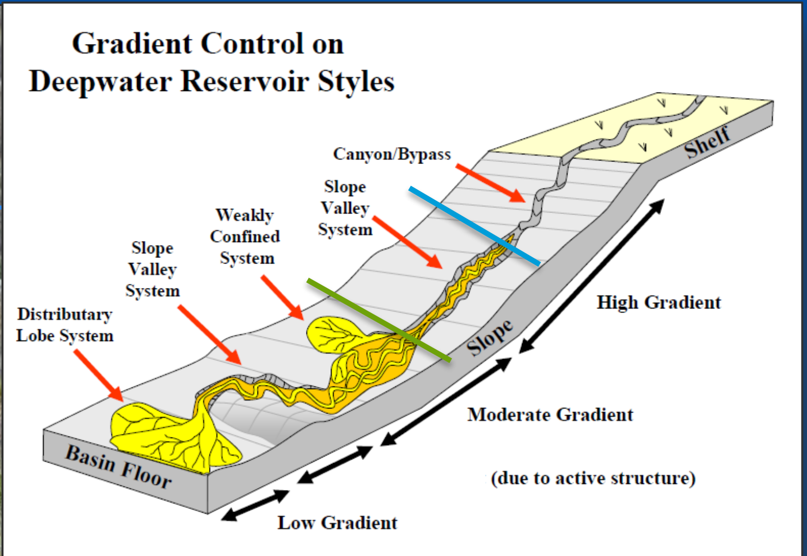
- Pinery Member (upper Seven Rivers Formation) grainstone channels (Playton 2008).
- Brown and Loucks (1993) Geology Loop Trail stop.

Additional Field Evidence for Channels
Exact Stratal Position is Still Unclear



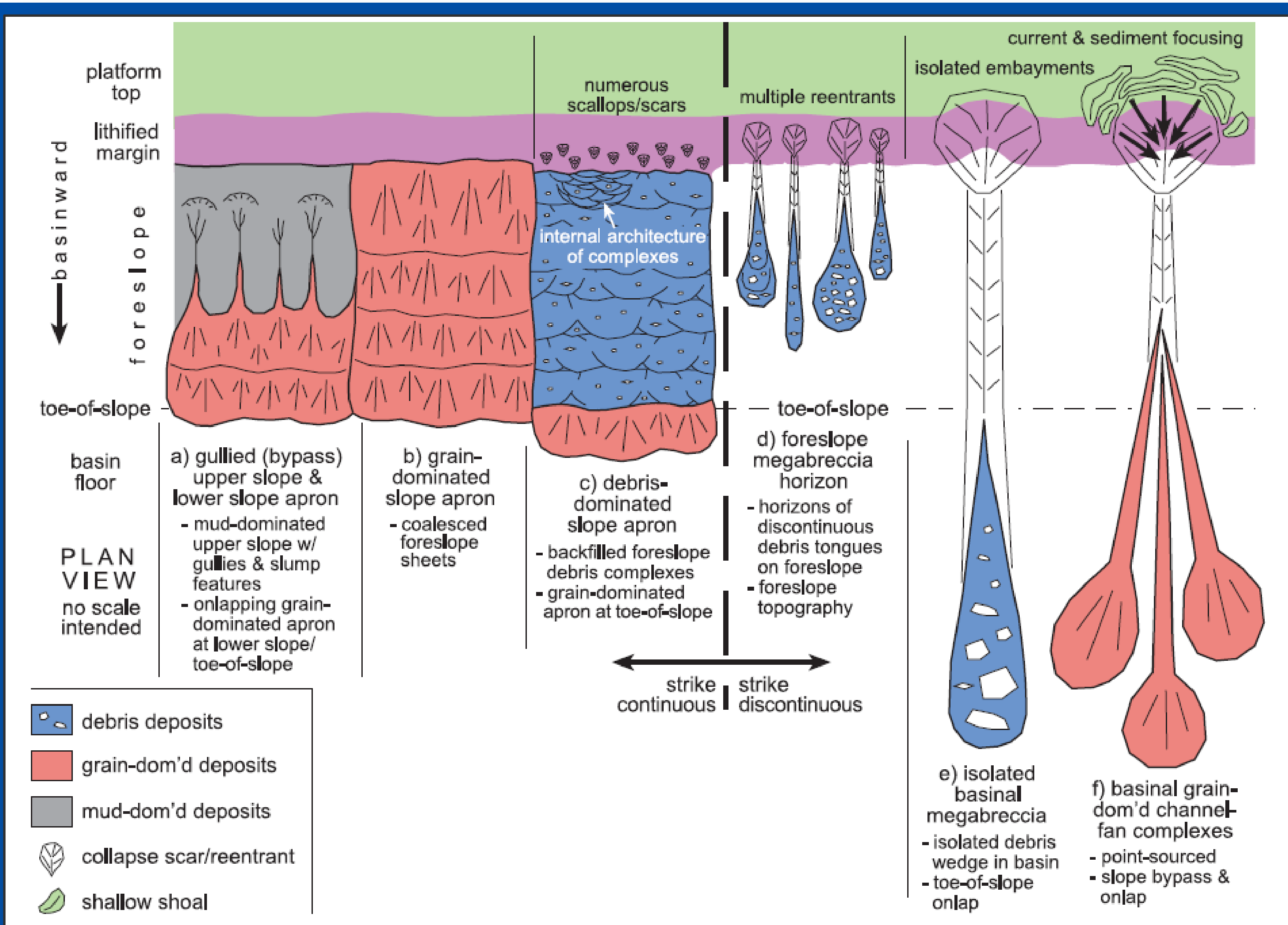
Channel Morphology
Updip-Downdip Relationship





after Sprague et al. 2002, Campion et al. 2008

Margin Heterogeneity Impact on Slope Styles



Playton et al. 2010

Conclusions
3-D GIS

- Integration of remote sensing data and traditional field work
  - spans different scales of observation.
  - helps identify spatial relationships that may not be obvious from direct field observations alone or visa versa.
  - direct field observations combined with 3-D GIS can help rethink or formulate ideas.

- Margin to basin strike variability and dip-facies transitions
  - mapping of foreslope clinoform variability will be possible in inaccessible (vertical) outcrop zones and is ongoing.
  - extend field observations into the subsurface (seismic/log data) at 1:1.
  - fracture trends at both regional and local scales can be compared to other canyons with the study area or elsewhere in the world.

Conclusions
Capitan Slope System

- Previously undocumented evidence for channels has been identified within the lower Capitan Slope.
- The lower-slope-carbonate breccias interfinger with what appears to be proximal siliciclastic deep-water channel fill.
- Further investigation may offer new insight on how these systems interact as well as a more clear understanding of the Capitan margin.
- Understanding the margin geometry may help to identify and quantify zones of higher compartmentalization within mid-to-lower slope carbonate reservoirs.