ANALYSIS AND DATING OF COMPOSITE BEDROCK LANDSLIDES IN THE GRAND CANYON

J. David Rogers, Conor Watkins and Francisca Oboh-Ikuenobe

Department of Geological Sciences & Engineering
University of Missouri - Rolla

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The Deer Creek Landslide as viewed from the east.

Several sequences of bedrock landslippage occurred in the Grand Canyon during the Pleistocene. These include rotational slump blocks that appear to translate along log-spiral shaped slip surfaces and composite landslides, exhibiting two of more kinds of movement simultaneously.

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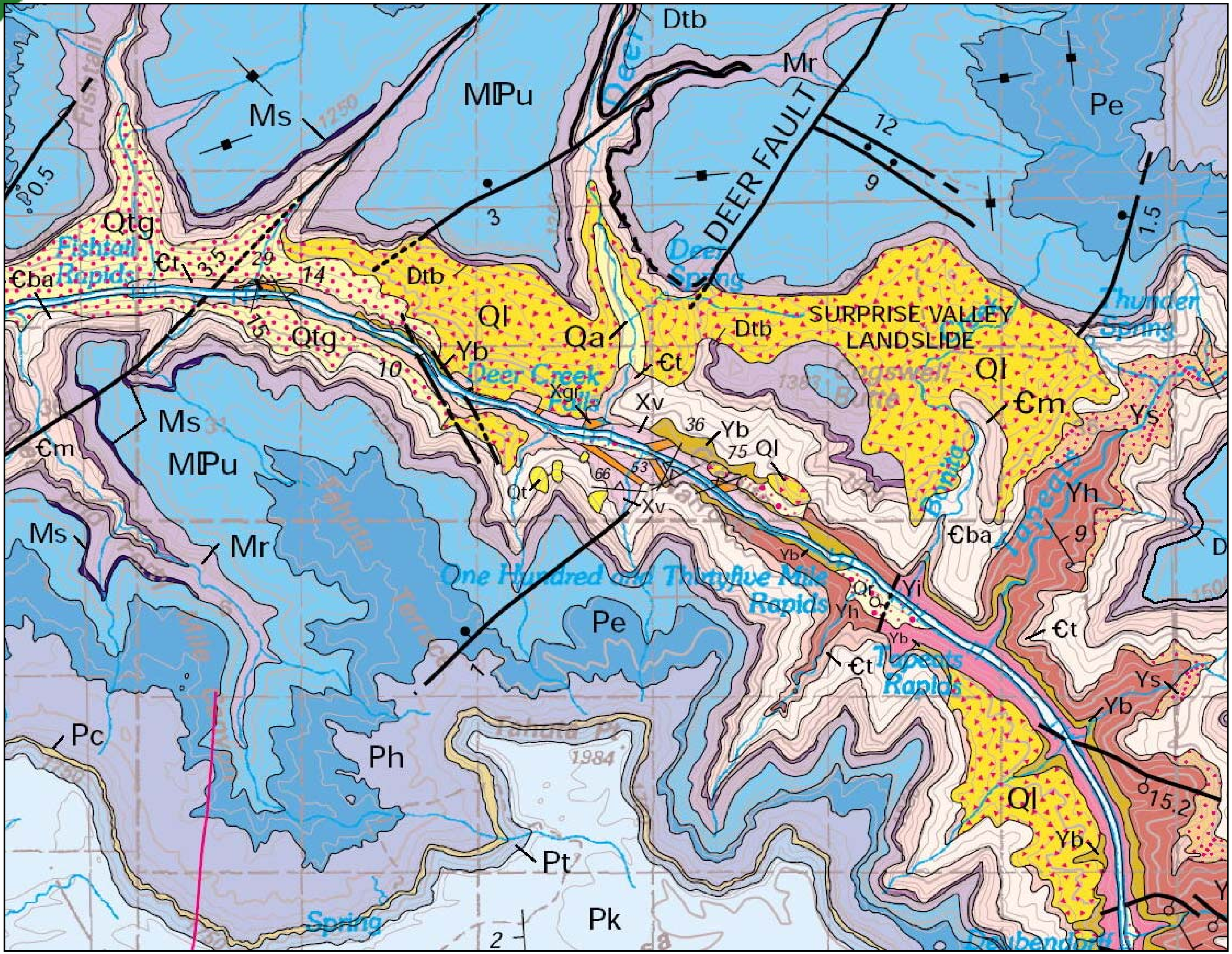
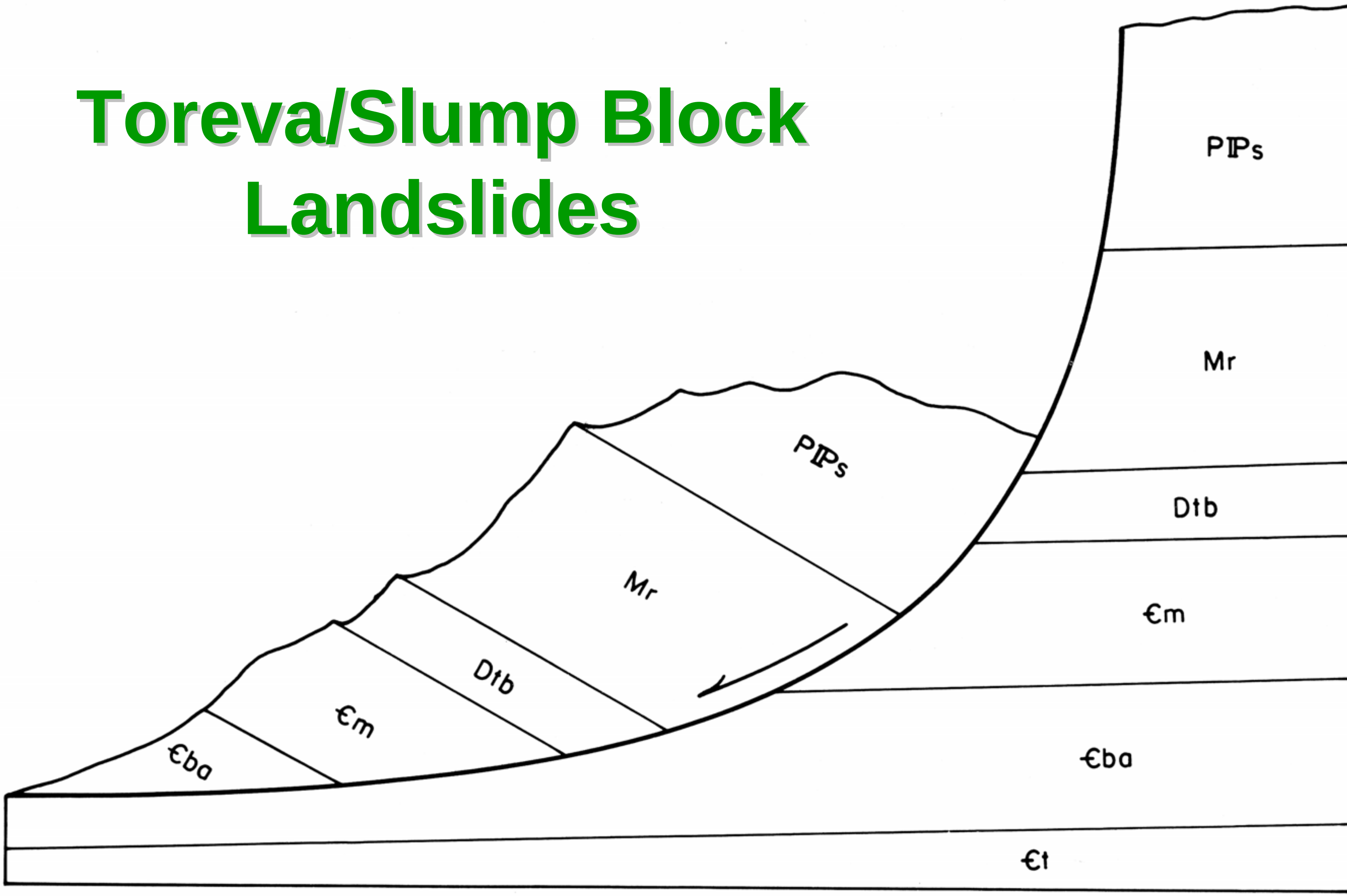


Portion of the Grand Canyon 30' x 60' Quadrangle Geologic Map showing landsliding in the Tapeats-Deer Creek area, including Surprise Valley, the largest landslide complex in Grand Canyon.

Toreva/Slump Block Landslides



Schematic of a simple Toreva or slump block typical of Surprise Valley in Grand Canyon (from Huntoon, 1978). This type of landslide exhibits rotational motion during movement.

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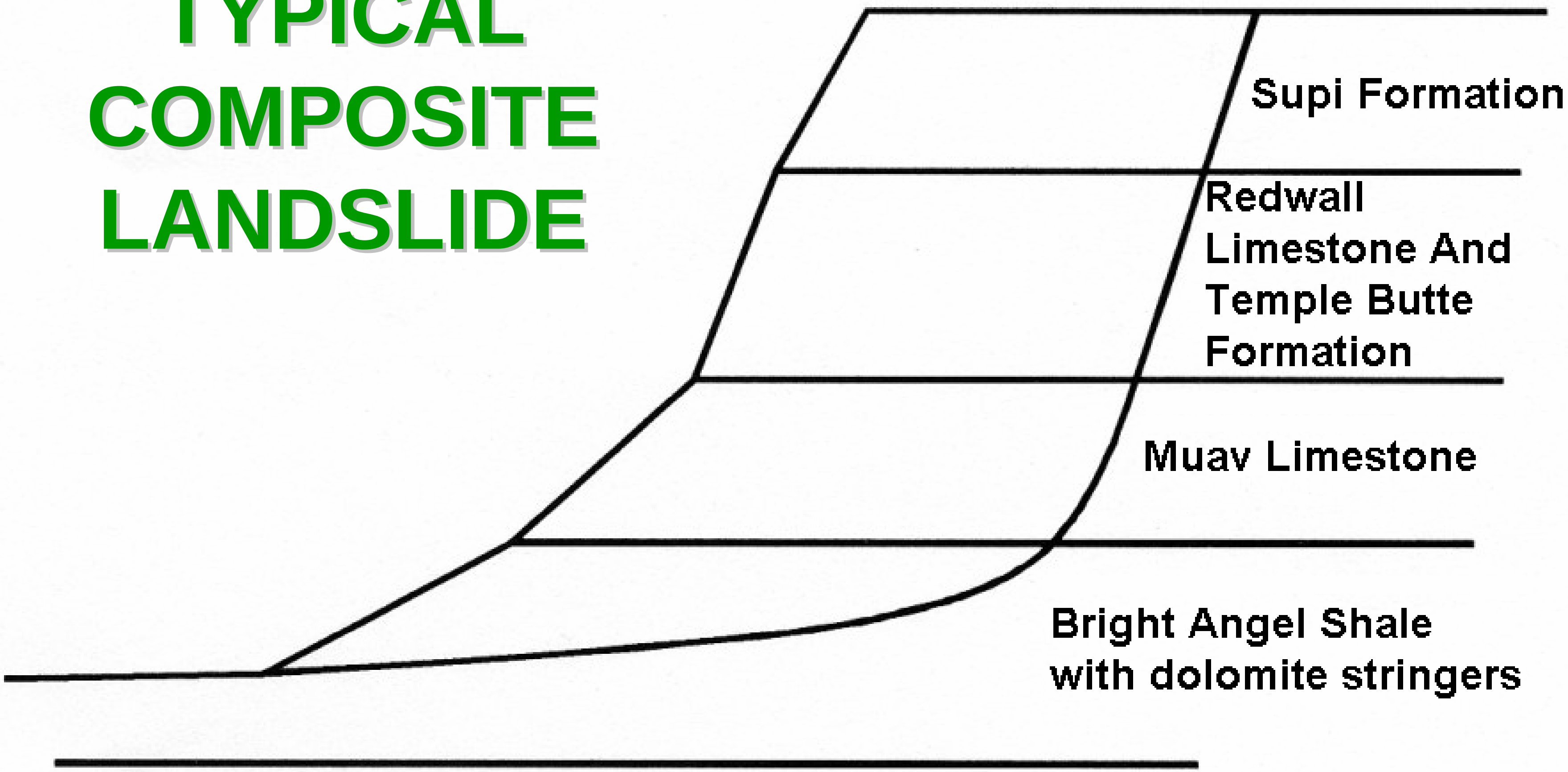
Three Toreva block slumps in Surprise Valley. These slides are secondary to other larger, composite landslides that left an oversteepened, unstable headscarp.

TYPICAL COMPOSITE LANDSLIDE



Schematic section thru the Thunder River Landslide at the eastern margin of Surprise Valley in Grand Canyon. Composite slides exhibit multiple forms of movement simultaneously. A slip surface develops and movement of the slide begins.

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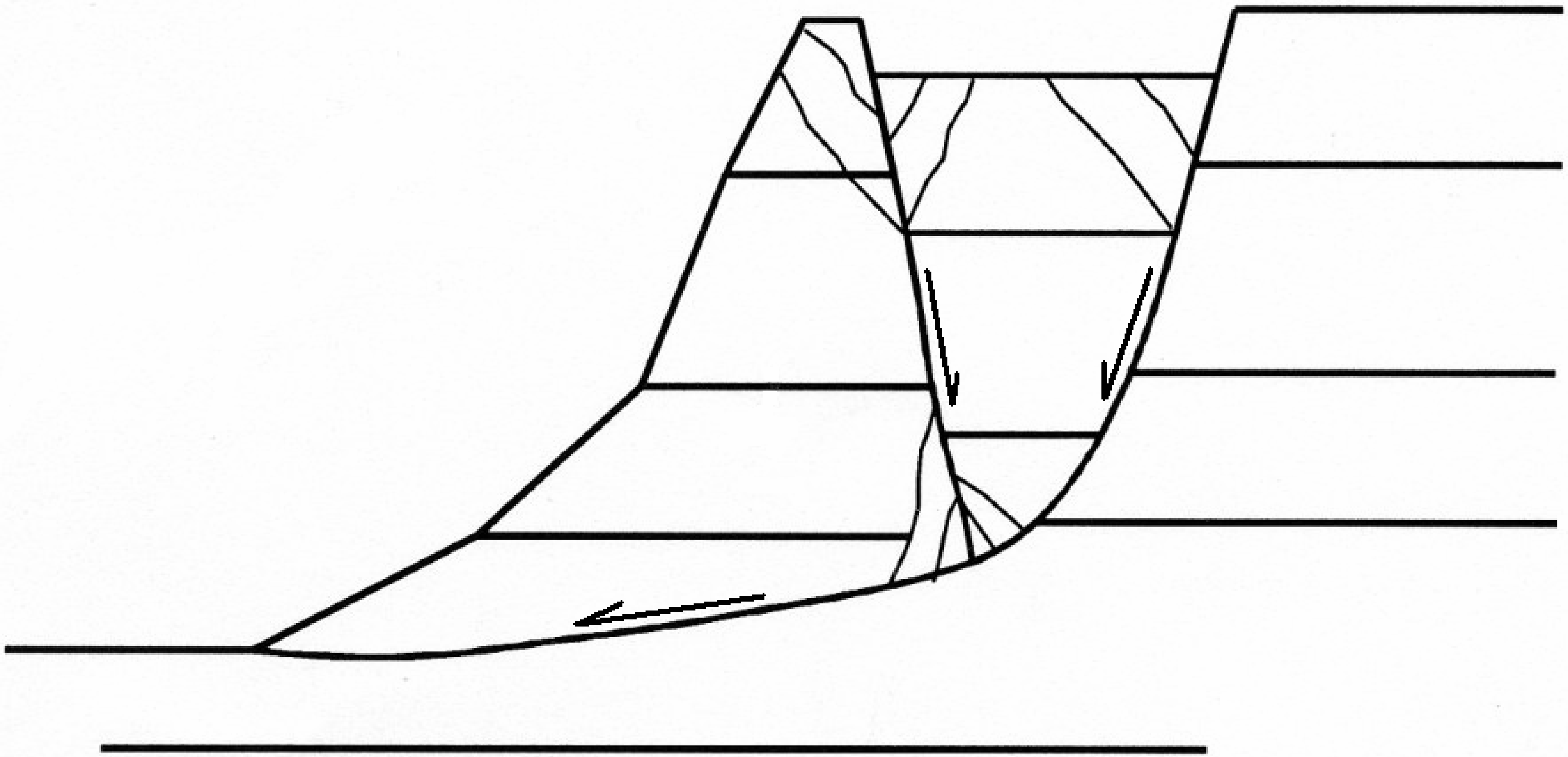
GRABEN and PASSIVE WEDGE DEVELOP



A headscarp graben develops as the passive wedge (forward block) of the slide begins to translate en-mass along micaceous shale.

BASAL RUPTURE SURFACE

- **Most of the basal rupture surfaces appear to have developed in fissile green micaceous shale beds overlying the Rampart Cave Dolomite Member of the Cambrian-age Bright Angel Shale**

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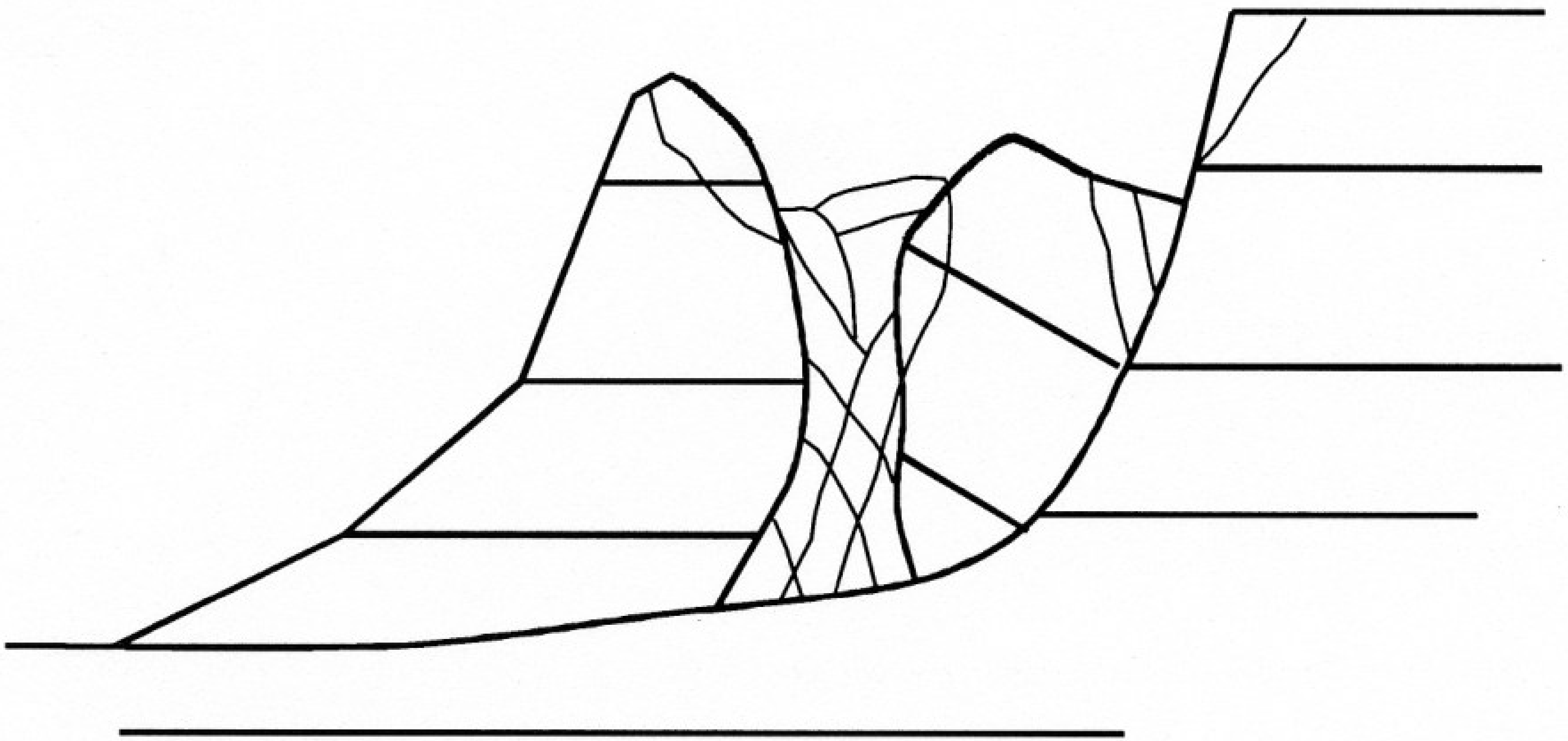
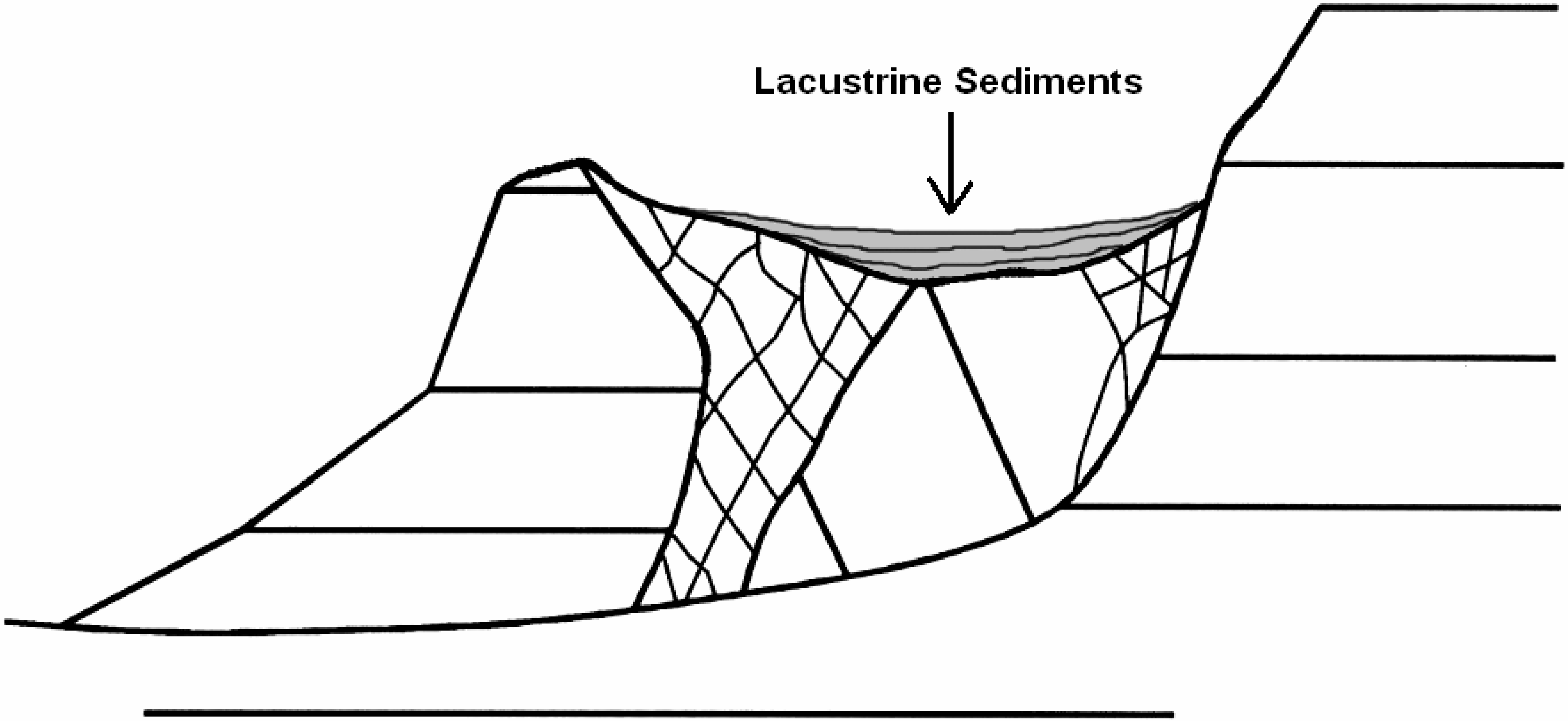
GRABEN BACK ROTATES



As the passive wedge translates horizontally, the graben begins to back-rotate towards the headscarp. A zone of breccia develops between the forward block and the graben.

- Oblique view showing 60 degrees of back rotation and a red wedge of Supai beds filling the headscarp graben of the Thunder River Slide

FINAL CONFIGURATION



The Thunder River Landslide as it appears today. The enormous headscarp graben created an enclosed basin that was infilled with lacustrine sediment. Headward erosion along Bonita Creek breached the depression and dissected the graben, exposing fine grained lacustrine deposits.

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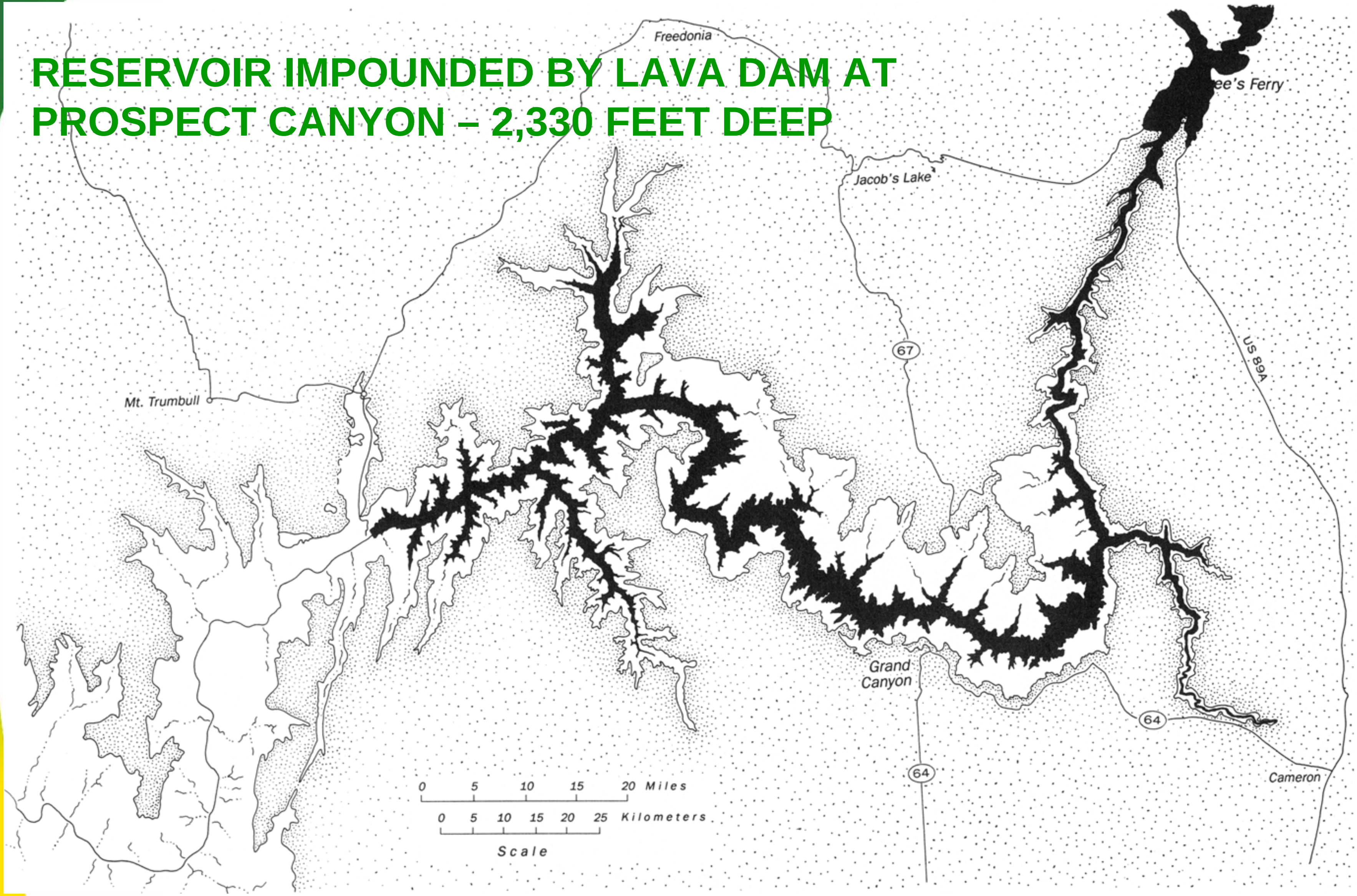
Aerial oblique view of the Thunder River Slide illustrating the marked back rotation and a portion of the translated forward block. At right Thunder River Spring discharges 20 MGD, making it the second largest spring in Grand Canyon.

Landslide debris litters Surprise Valley between Tapeats and Deer Creeks. Much of this debris appears brecciated and cemented with secondary travertine, giving it the consistency and appearance of graphic mass concrete.

RESERVOIR IMPOUNDED BY LAVA DAM AT PROSPECT CANYON – 2,330 FEET DEEP



Repeated impoundments of the Colorado River by lava dams may have caused saturation of shale toe slopes sufficient to trigger mass wastage

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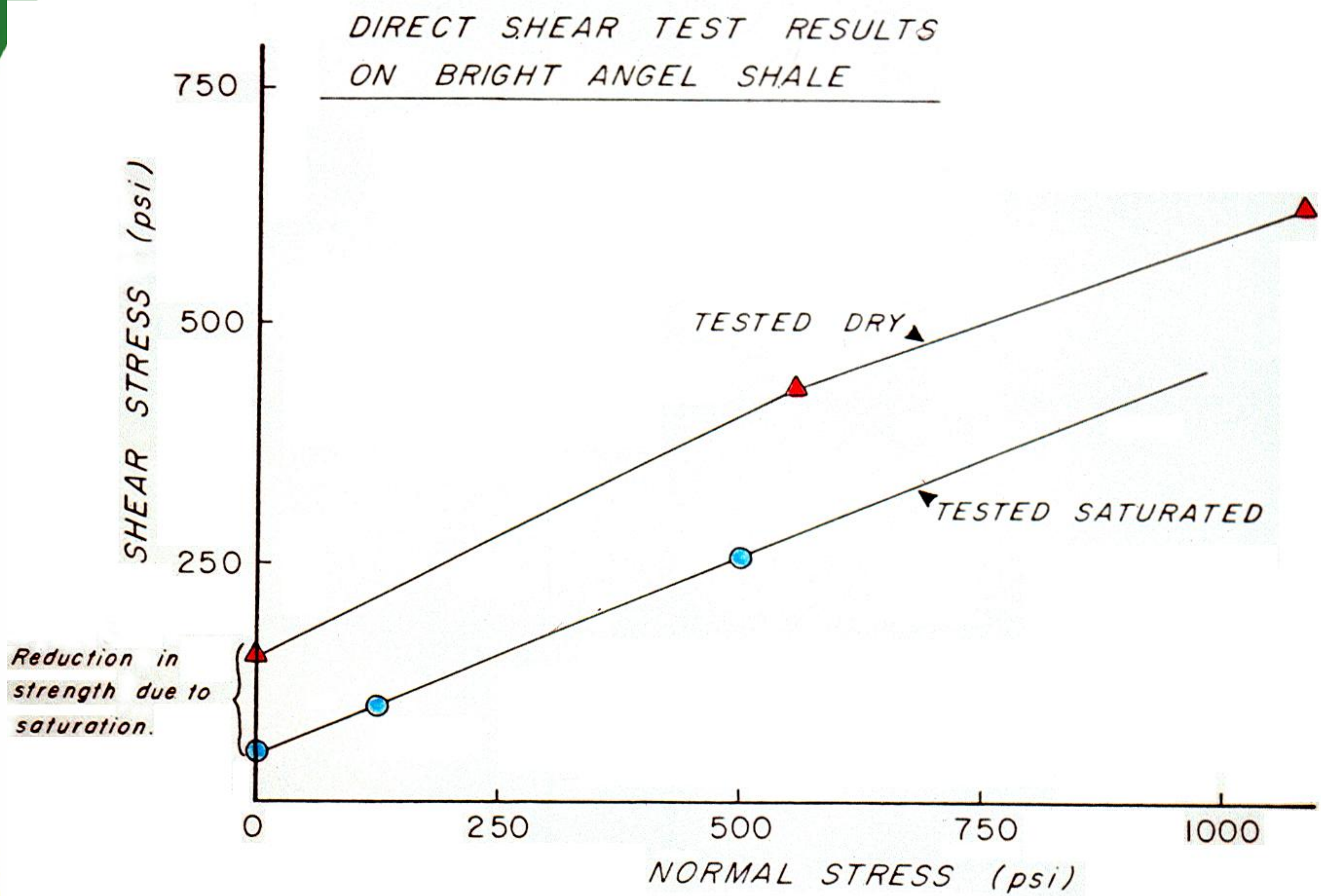
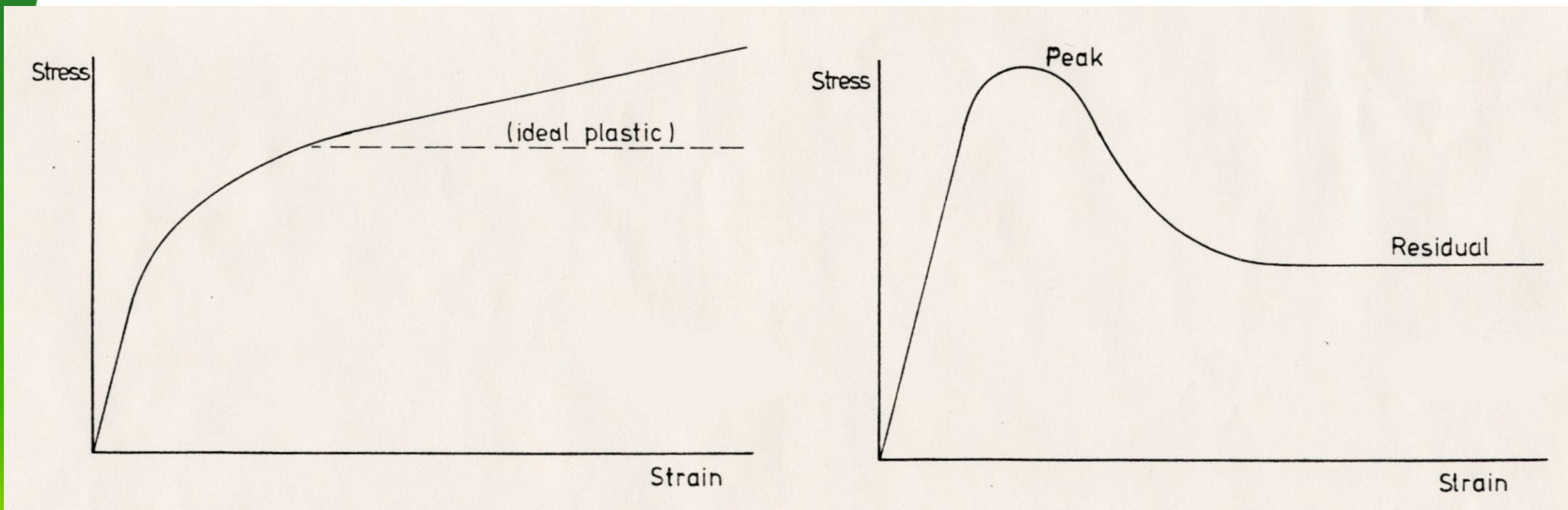
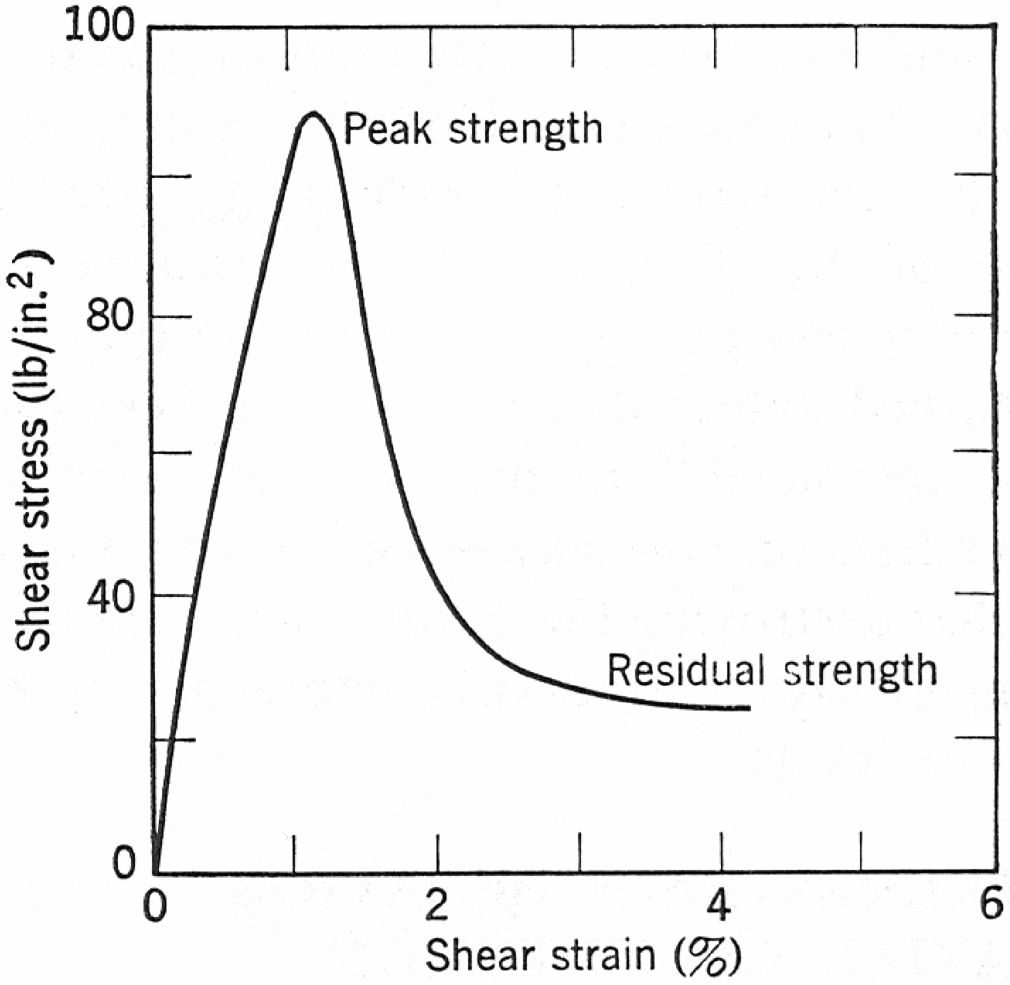


- **The Bright Angel Shale exhibits marked strength loss upon complete saturation, losing 2/3 cohesion**

STRAIN SOFTENING



- **Dense overconsolidated materials, such as shale and most sedimentary strata, tends to exhibit strain softening when undergoing macro shear, causing the shear strength to degrade markedly.**



- **One of the best known examples of strain softening is the Cucaracha Shale along the Panama Canal, which exhibits a residual shear strength only 28% of its peak strength**

PALYNOLOGY CAN BE APPLIED TO DATING LANDSLIDES

- Fine grained lacustrine sediments remain in the remnants of several landslide headscarp grabens and behind a number of landslide dams.
- Pollen recovered from Surprise Valley indicate that freshwater occupied the graben, with a more temperate climate than presently exists.
- Pollen, spores and algae are generally indicative of specific climatic regimes and provide a range of bounding dates.
- These dates could constrain the age of landslippage and be compared to the K-Ar derived ages for lava dams in the western Grand Canyon.

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Fine-grained lacustrine deposits in Surprise Valley have yielded 18 types of spores, fungal hyphae, and pollen, including that of freshwater algae. Although these deposits appear red and oxidized, their parent materials (mainly Hermit and Supai Formations) are red in color.

CONTENTS IDENTIFIED IN SURPRISE VALLEY LACUSTRINE SEDIMENT

- 1) <u>Pollen and spores</u>:
- *Ambrosia* (ragweed)
- *Anemopsis californica* (Saururaceae)
- Annoniaceae?
- Bryophyte spore
- *Chrysoplenium* (dominant pollen)
- Cruciferaceae
- *Dodocatheon*? (Primulaceae)
- *Ephedra fragilis* (Ephedraceae)
- *Equisetum*
- *Mitella?* (Saxifragaceae)
- *Picea* (spruce)
- *Pinus* (pine)
- Podocarpaceae (specimens similar to fossil *Zonalapollenites*)
- *Quercus* (oak)
- *Saxifraga* (Saxifragaceae)
- *Sequioia* (Taxodiaceae)
- Solaniaceae
- *Taxodium* and one unidentified genus of Taxodiaceae
- 2) <u>Freshwater algae</u>: *Botryococcus* and algal clusters are the dominant palynomorphs in
- both samples.
- 3) <u>Fungi</u>: Fungal hyphae are present.

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- The Deer Creek Landslide as viewed from immediately upstream. It extends along the north bank of the Colorado River for 3.7 km. The enclosed depressions are indicated by arrows.

The main headscarp graben of the Deer Creek Landslide formed a closed basin that has been accumulating lacustrine sediments and talus since its formation. The deposits may be 100 + meters thick. In order to date the landslide one would need to obtain pollen samples from the lower horizons of this deposit.

Sampling the Deer Creek headscarp graben using a 1-inch diameter soil auger with plug sampler. This is simple, but limited to 1.5 m depth. Accurate dating of this landslide will require sampling much deeper than is possible with a hand auger.

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The Deer Creek Landslide also contains several secondary failures along its front including this small graben, which contains a modest volume of infill, which is lacustrine. Note person for scale.

A small sinkhole about 2 m deep observed in the secondary graben of the Deer Creek Slide. Fine grained sediments have piped into underlying voids. Samples from depths of up to 2.5 m were recovered from this site.

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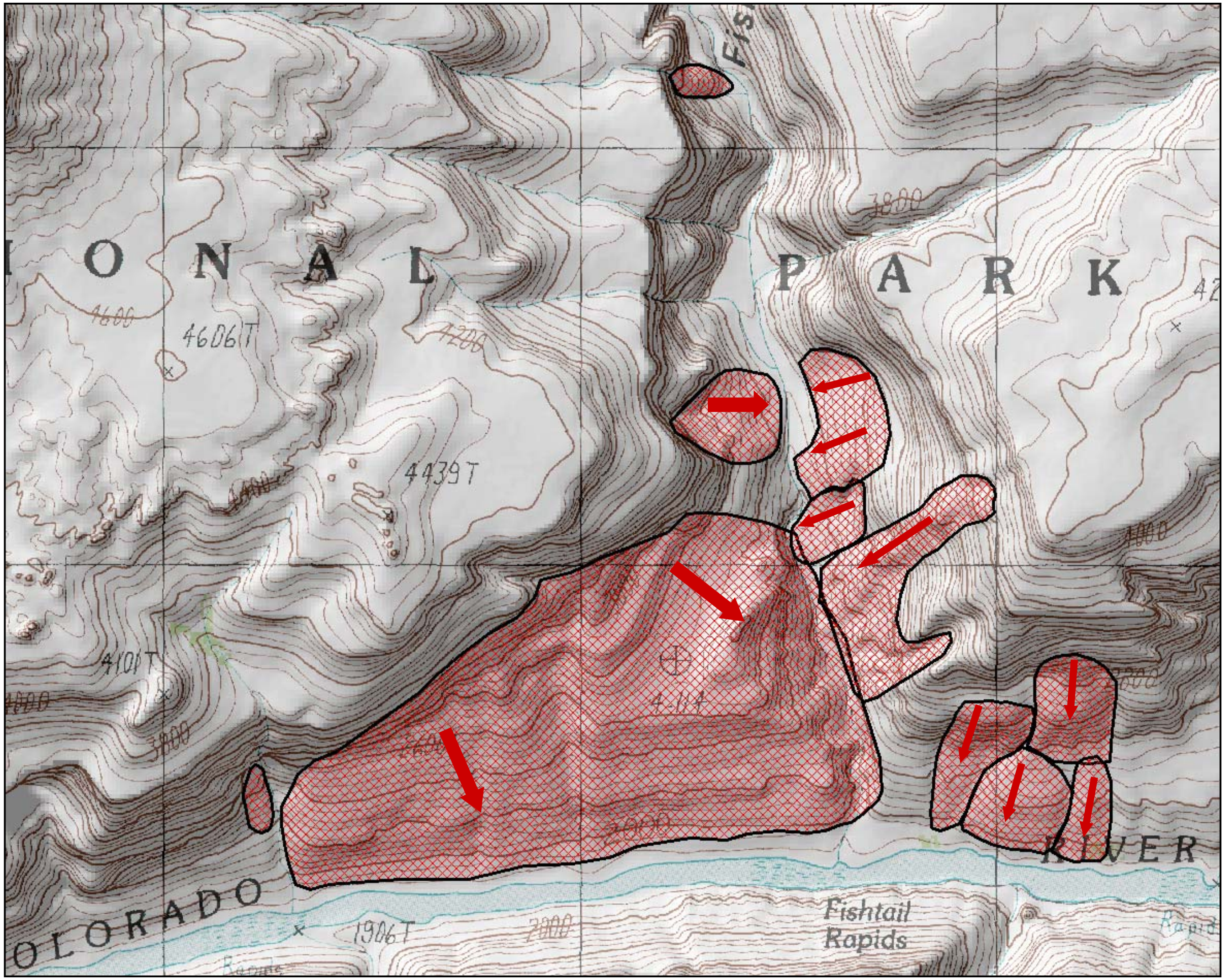
Sediment Behind Landslide Dams



Fishtail Canyon was blocked by the approximately 340 million cubic yard Fishtail Landslide. This caused thick sequences of lacustrine deposits to be trapped upstream, along Fishtail Creek.

The old buried channel of Fishtail Creek which has been diverted easterly by the Fishtail Landslide. This diversion has led to the incision of a narrows similar to that at Deer Creek.

Indurated beds of lacustrine sediment deposited in the lake behind the landslide dam in Fishtail Canyon. They are between 45 and 60 m above the bed of Fishtail Creek.

Detail view of the alternating bands of coarse and fine materials preserved in these indurated sediments.   The fine grained nature of these interbeds are indicative of lacustrine deposition.

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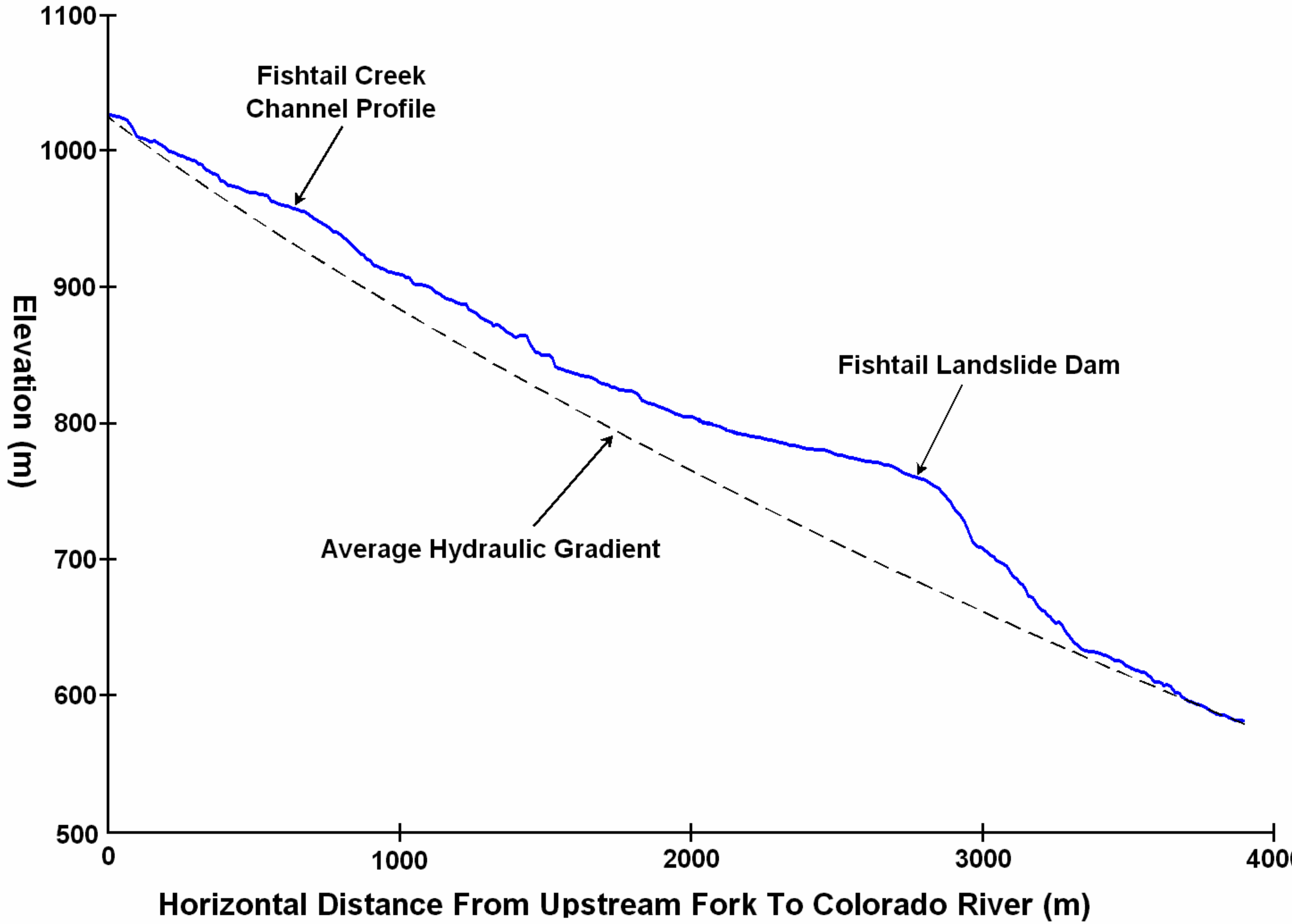
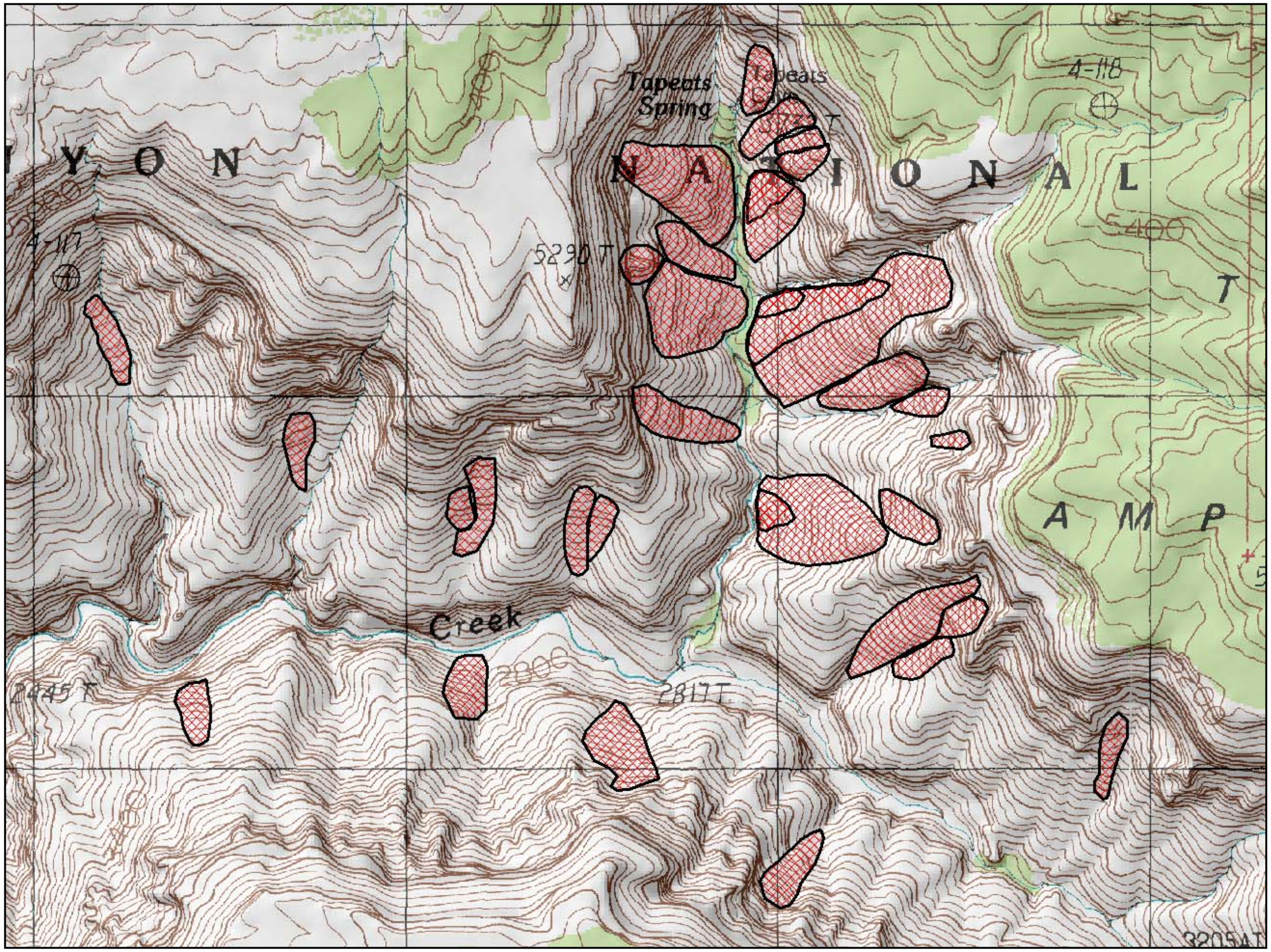
Lacustrine sediments were collected from this indurated lacustrine unit for palynology assessment. Fine grained sediments were sampled near the basal contact with the underlying slide breccia.

Fishtail Canyon Channel Profile



Landslide Dams In Tapeats Cave Canyon



Tapeats Cave Canyon is the source of Tapeats Spring, at 50 mgd the largest spring in Grand Canyon. The channel is choked with landslide debris and appears to have been dammed on at least two different occasions. Mapped landslides are shown in above figure.

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View showing Tapeats Cave Canyon and its jumble of landslide debris. The canyon, spring, and cave are structurally controlled by Tapeats fault and a related splay.

Tapeats Fault (left) and its splay (right) control the alignment of Tapeats Cave Canyon.

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A slump block landslide floored in the Bright Angel Shale dammed Tapeats Cave Canyon. It presently chokes the outlet of Tapeats Spring with large blocks of slide debris.

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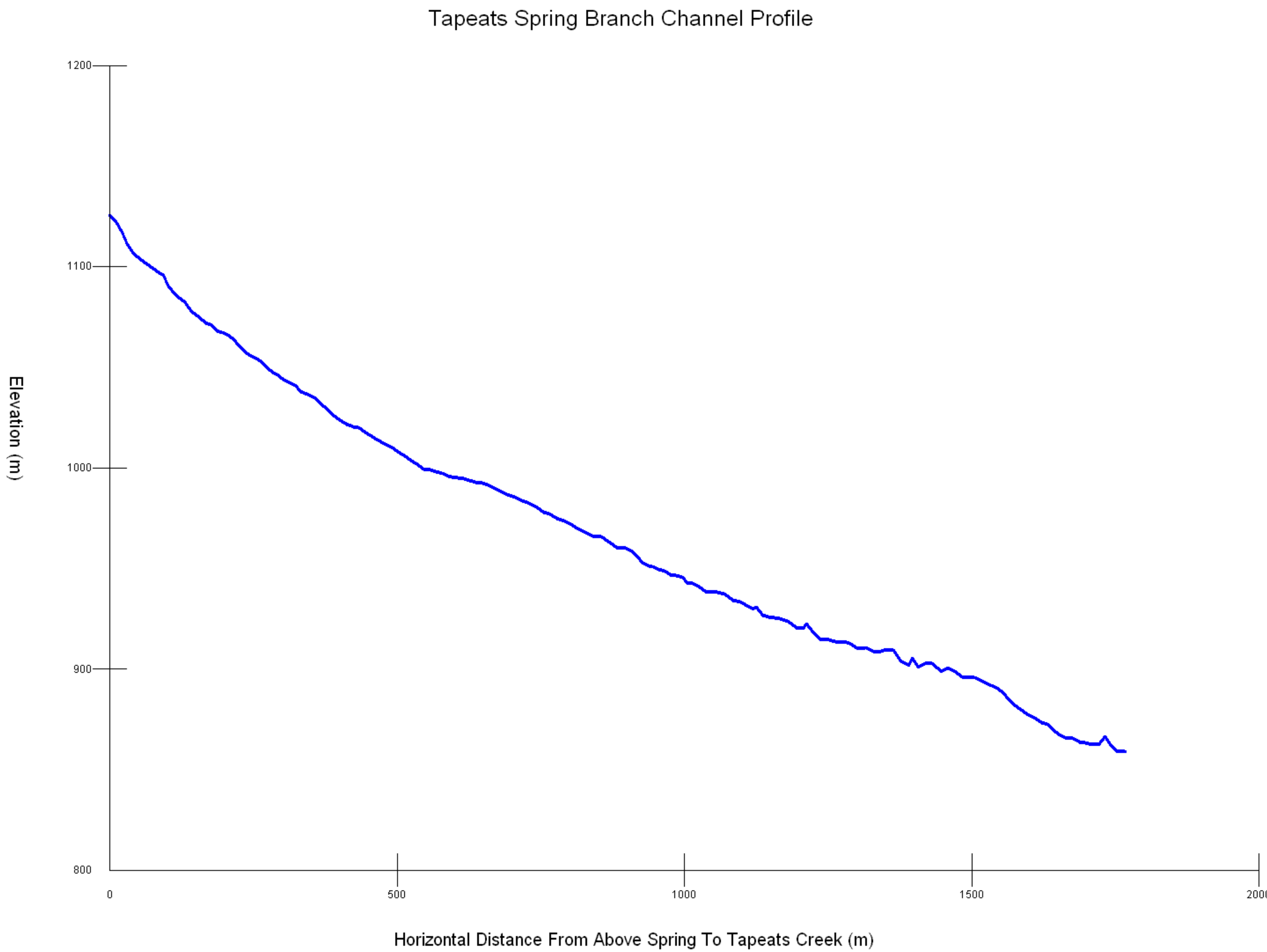
Tapeats Spring is percolating through landslide debris that blocks the spring's well-developed pre-slide outlet.

Reddish colored indurated Quaternary sediments mantle much of Tapeats Cave Canyon. Some material is coarsely stratified parallel to the slope and appears to be talus. Other material is horizontally stratified and more fine-grained. This appears to be lacustine sediments mixed with debris flow packages that were likely deposited in temporary reservoirs caught behind landslide dams. It would appear that significant portions of much larger landslide dams have likely been excavated by the discharge from Tapeats Spring.



Tapeats Canyon channel profile showing two anomalous chokes, which are likely indicative of landslide obstructions.