RECONNAISSANCE OF MEGALANDSLIDES ALONG THE VERMILION CLIFFS OF THE COLORADO PLATEAU, ARIZONA

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Introduction

The Vermilion Cliffs of northern Arizona are a 30 mile escarpment separating the Marble Platform from the Paria Plateau. The escarpment is mantled by landslides and stretches from Lee's Ferry to House Rock. Landslides include slump blocks, earth flows, and composite slides that exhibit a combination of both types of movement.

Sliding is mostly confined to the Petrified Forest Member of the Chinle Formation, a highly plastic, montmorillonite-rich shale that erodes to form badlands topography.

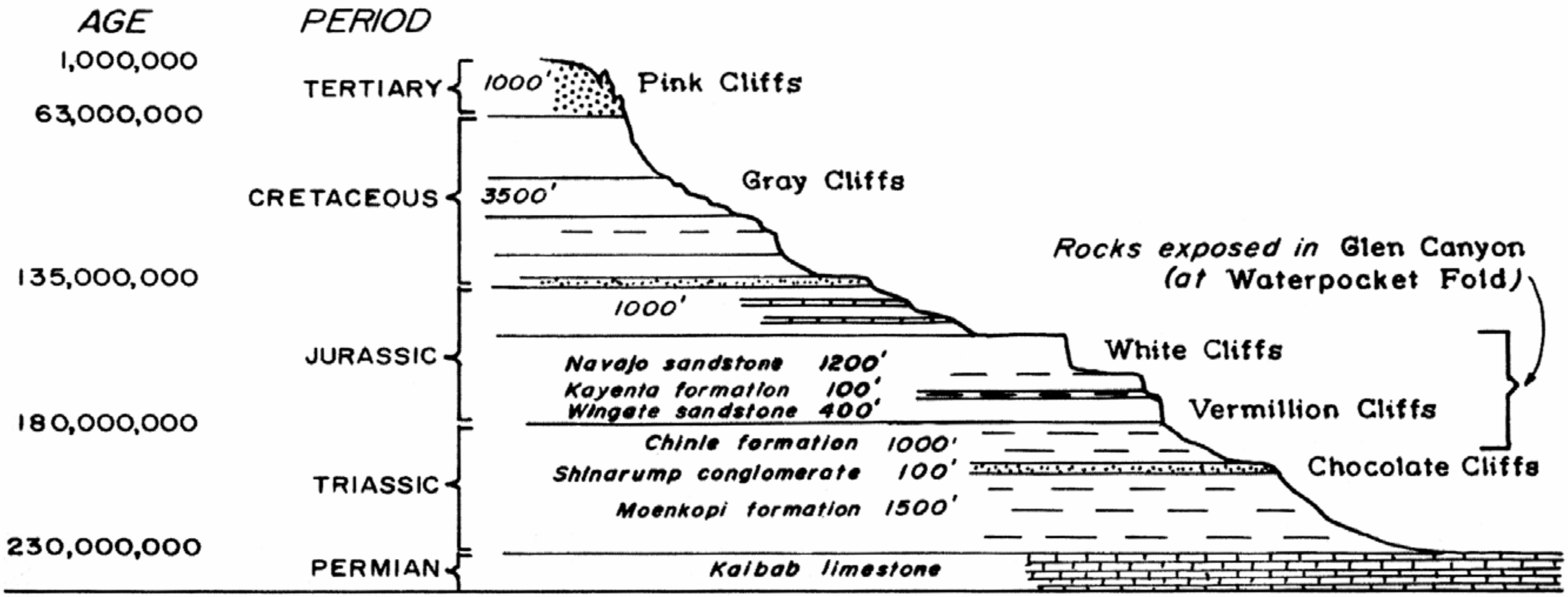

Diagram (from Baars, 1995) showing formations present along the Vermilion Cliffs.

Exposure of the entire stratigraphic column of the Vermilion Cliffs near the mouth of the Paria River, by Lee's Ferry.

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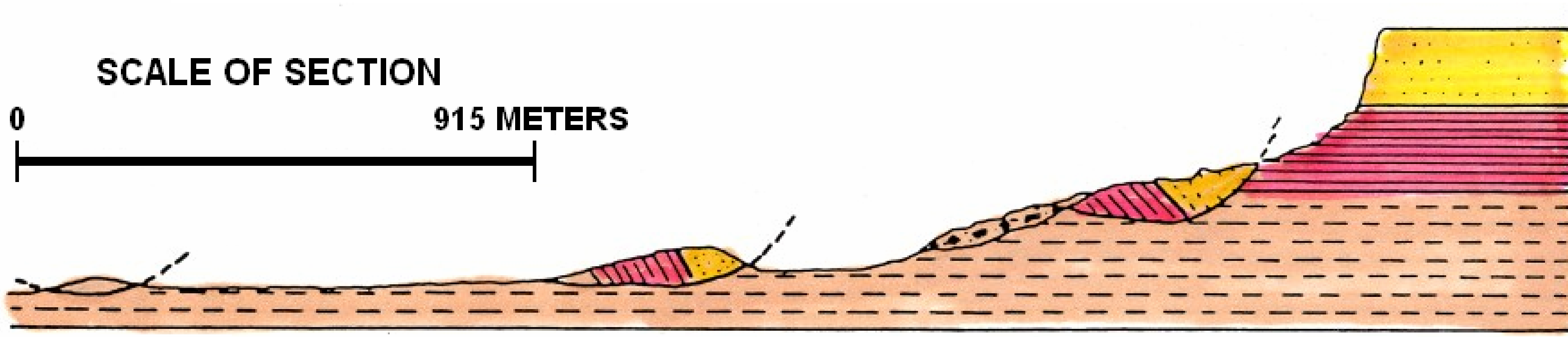
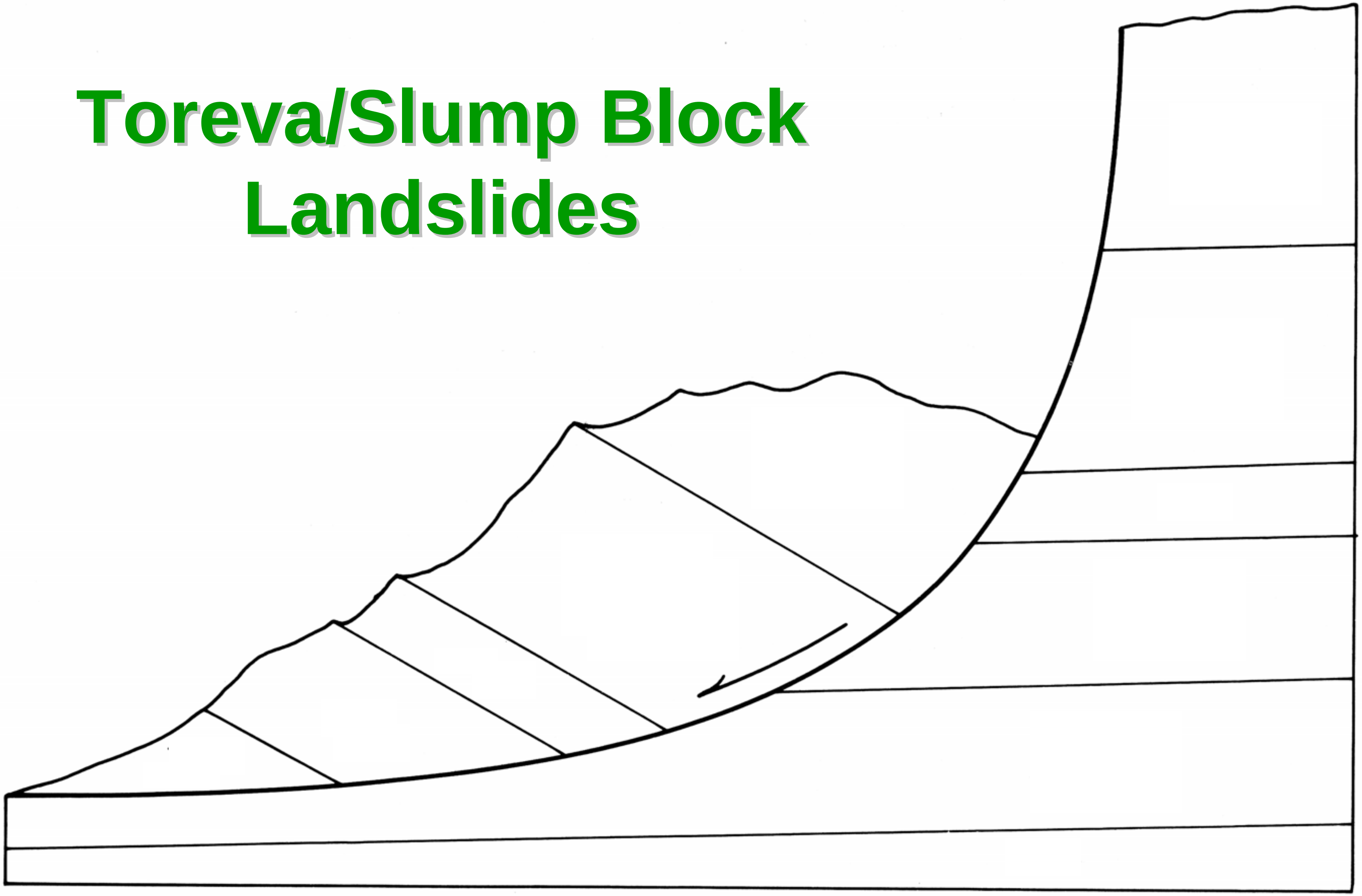


Several episodes of sliding and rapid cliff retreat along the escarpment appear to have occurred during the Quaternary, as multiple sequences of sliding are present. Each sequence of sliding is slightly higher in elevation and older slides are increasingly mollified and dissected. Sliding appears to have ceased in the Holocene and intermittent streams are deeply incised. The above diagram is taken from Strahler (1940).

Toe thrust of a landslide that has been dissected by surface streams.

Toreva/Slump Block Landslides



Schematic of a simple Toreva or slump block typical along the Vermilion Cliffs (from Huntoon, 1978). This type of landslide exhibits rotational motion during movement.

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Back-rotated strata typical of Toreva block style landslides along the Vermilion Cliffs.

Possible Causes of Slope Instability Along The Vermilion Cliffs

- **Wetter climate during the Pleistocene likely heightened groundwater levels within the cliffs. This may have led to gross instability because of reduced effective stress and loss of cohesion in the Chinle and Moenkopi Formations.**
- **Saturation and strength loss of the Petrified Forest Member of the Chinle Formation might have been caused by lava dams in the western Grand Canyon. These dams impounded reservoirs with a pool elevation of up to 1200 m (4000 ft).**
- **Pore pressure imbalances caused by rapid drawdown during failure of the lava dams may have triggered flows.**
- **Reservoir induced seismic activity may have triggered slides.**
- **Seismic activity related to nearby volcanism may have been triggering mechanism.**
- **Strain softening caused by relaxation of slopes may have acted to reduce slope stability in combination with other processes. It is possible that straining of the Chinle Formation is responsible for the open joint planes seen near the edge of the cliffs.**

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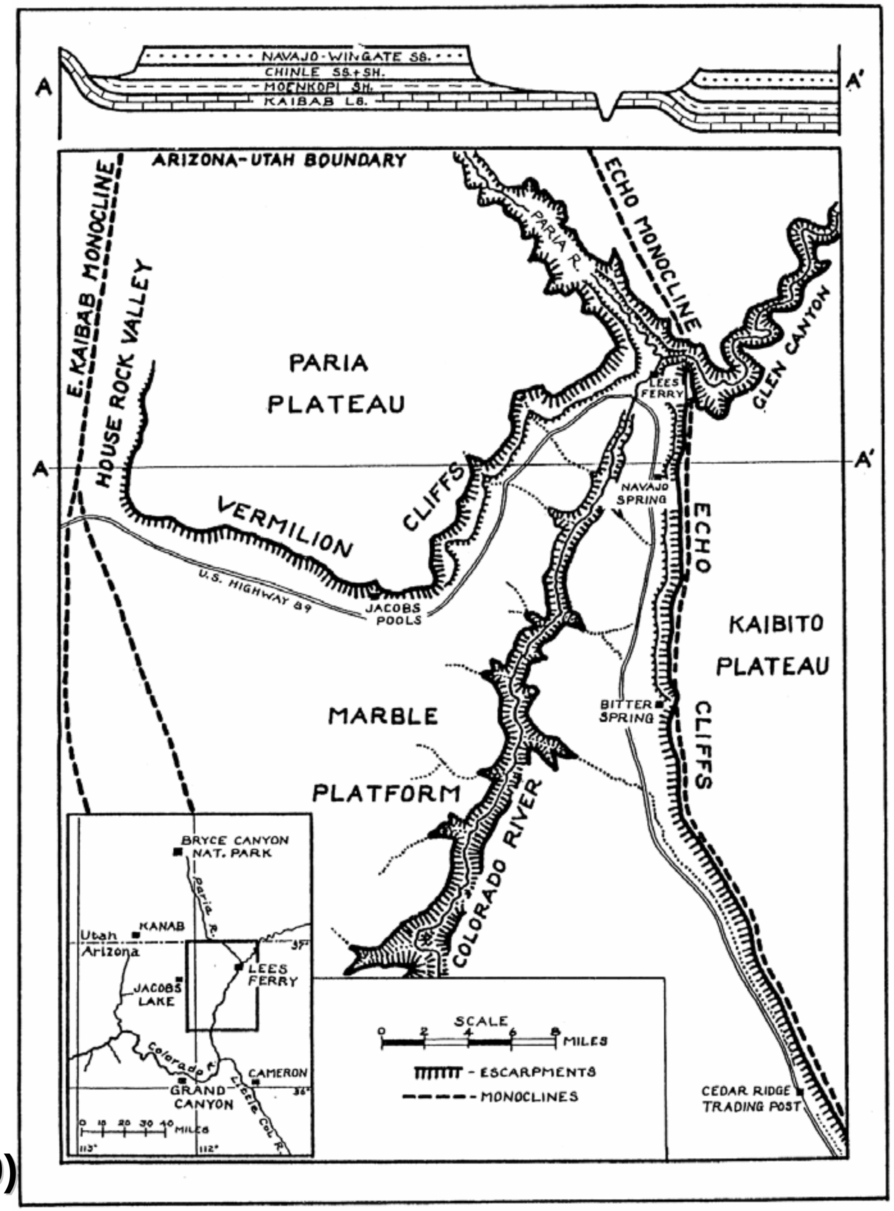
Possible Influence of Lava Dams

The strata comprising the Vermilion Cliffs and Paria Plateau dip northeasterly, between the East Kaibab and Echo Monoclines. Relief increases easterly, towards the Colorado River. The higher Pleistocene lava dams in western Grand Canyon created reservoirs that extended well beyond Lee's Ferry, placing the base of the easternmost cliffs under more than 300 m of water. This section of cliffs contains numerous earthflows. Earthflows did not occur along the western cliffs although the stratigraphy is similar. Large slump blocks have formed instead.



(from Strahler, 1940)

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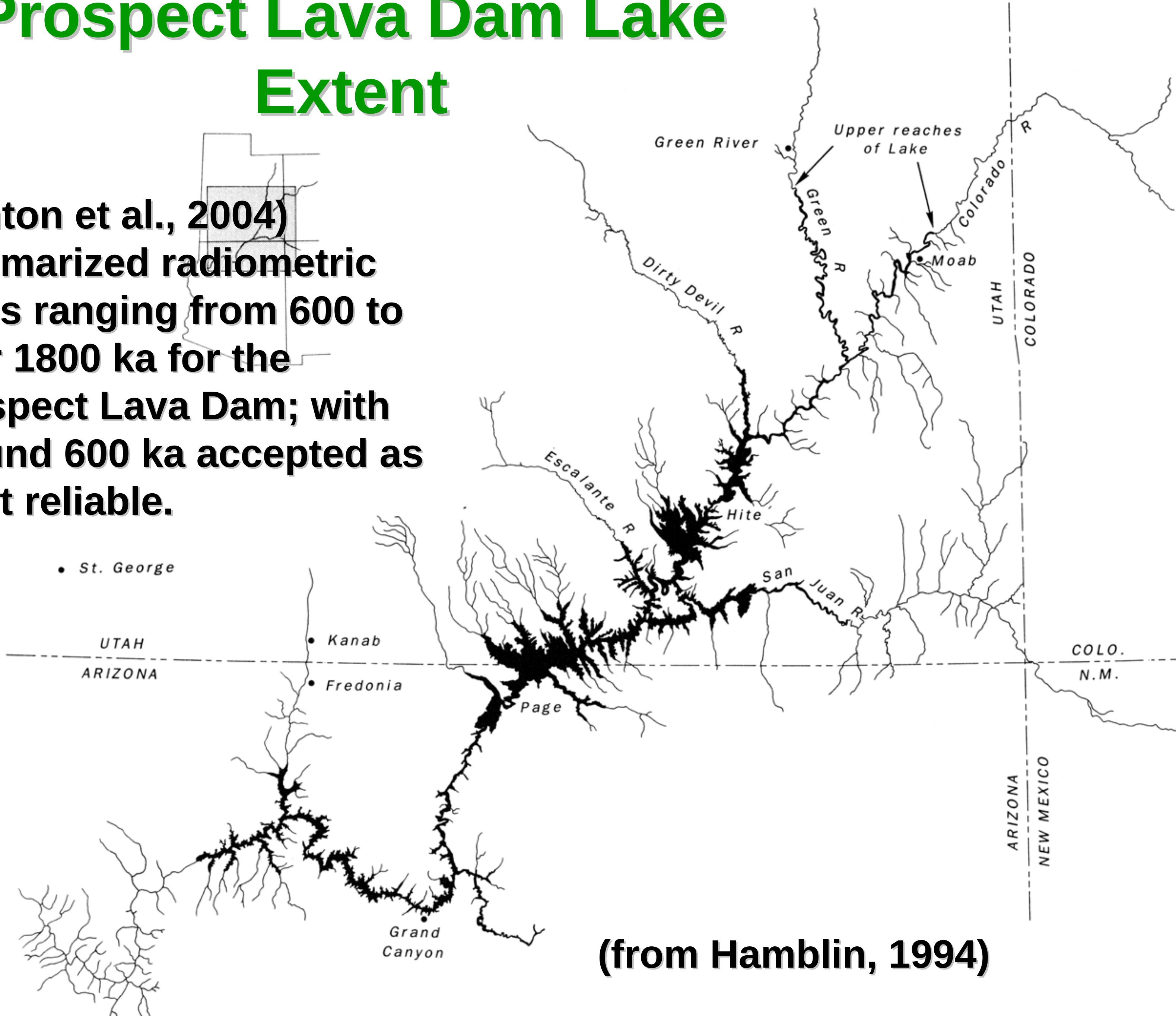
Prospect Lava Dam Lake Extent

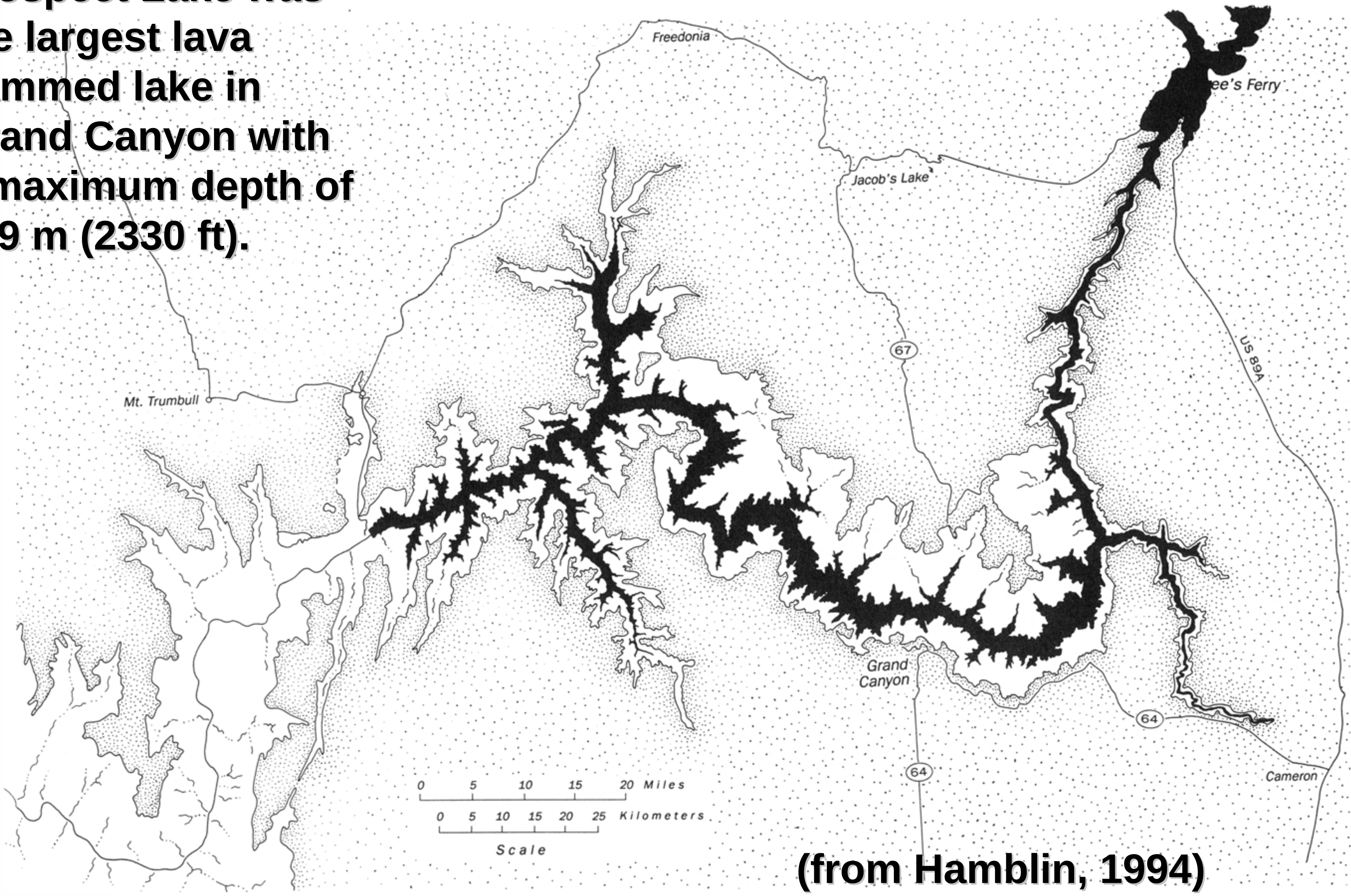
(Fenton et al., 2004) summarized radiometric dates ranging from 600 to over 1800 ka for the Prospect Lava Dam; with around 600 ka accepted as most reliable.



(from Hamblin, 1994)

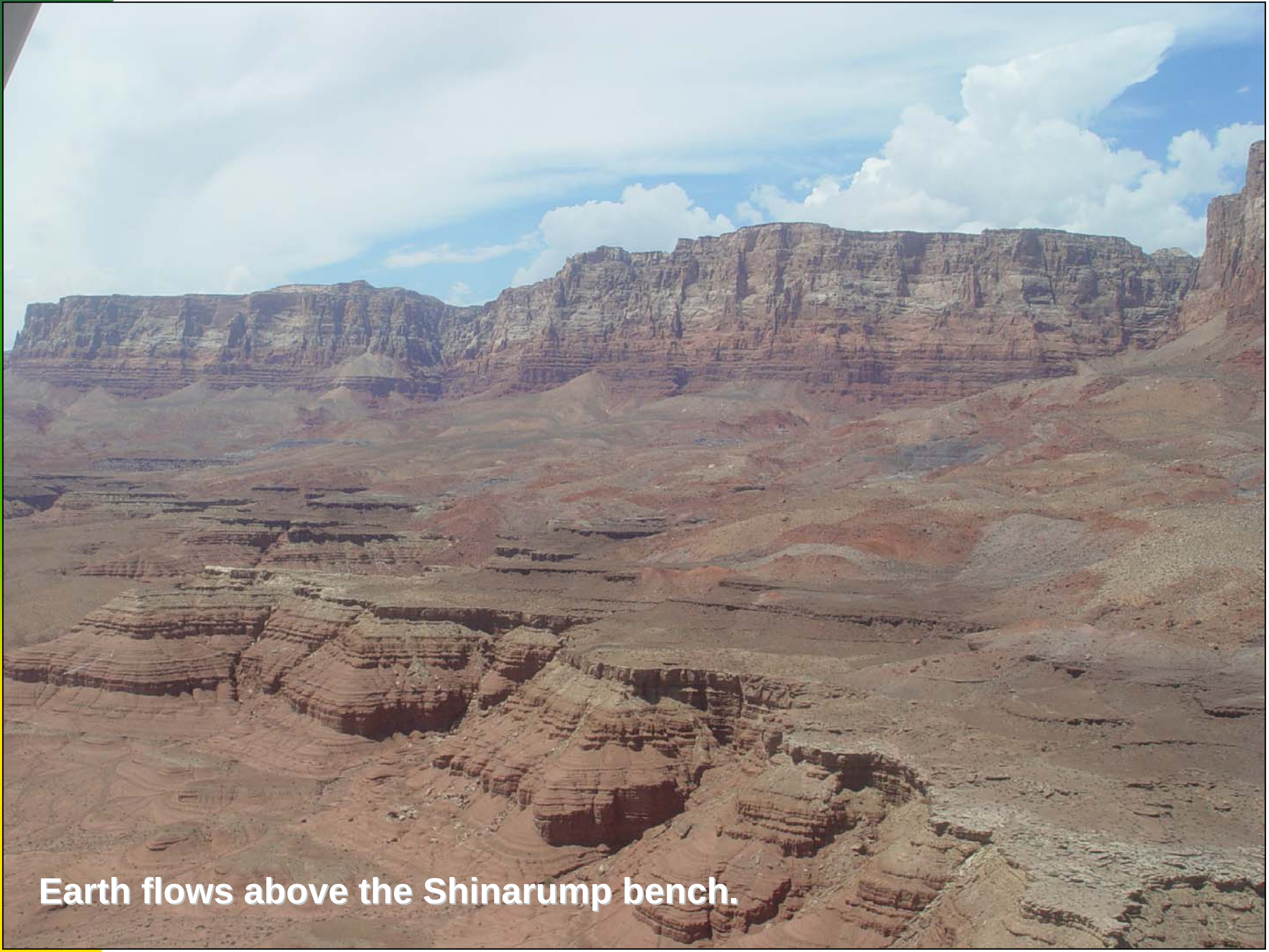
Prospect Lake Extent

Prospect Lake was the largest lava dammed lake in Grand Canyon with a maximum depth of 699 m (2330 ft).

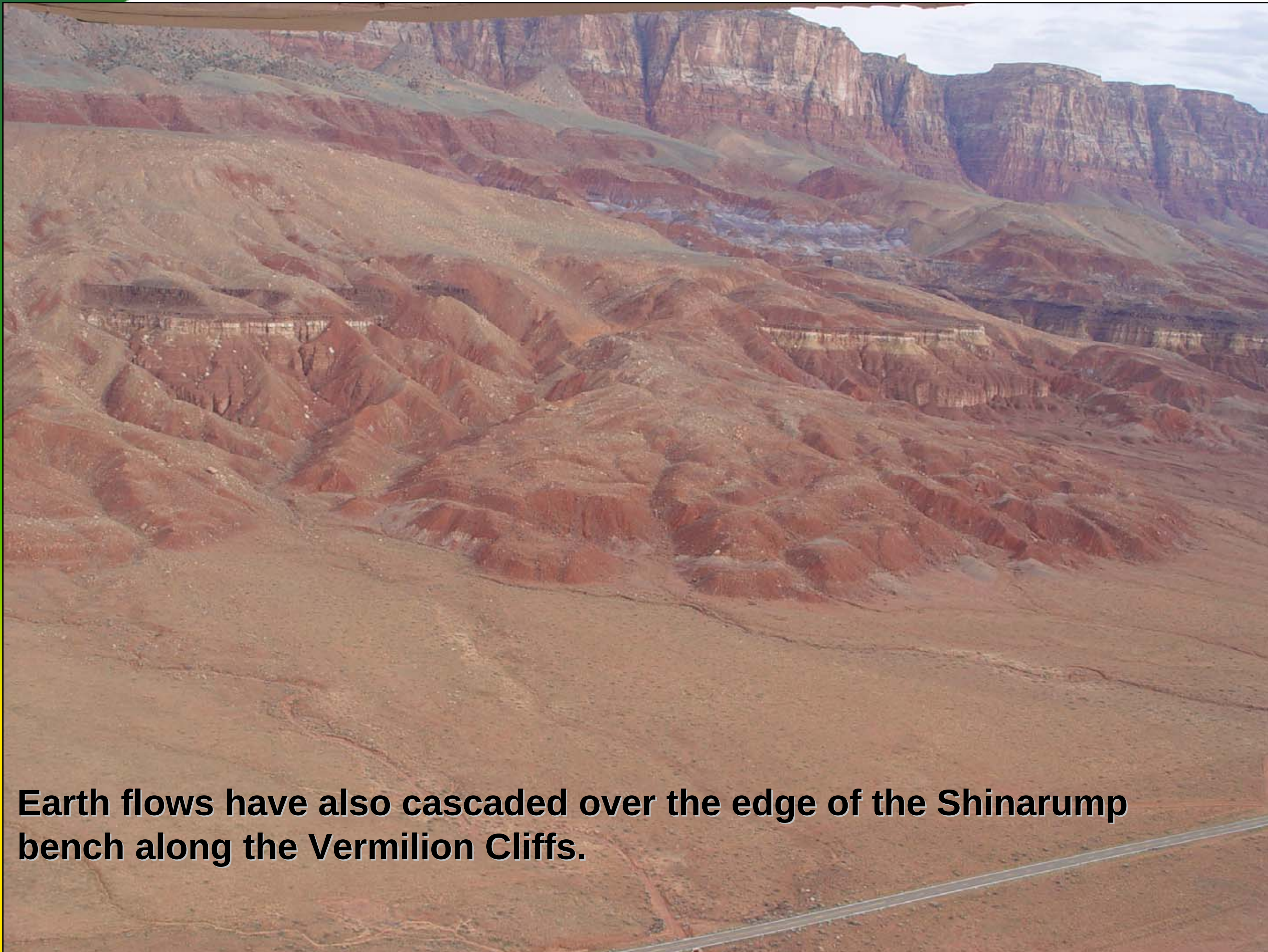


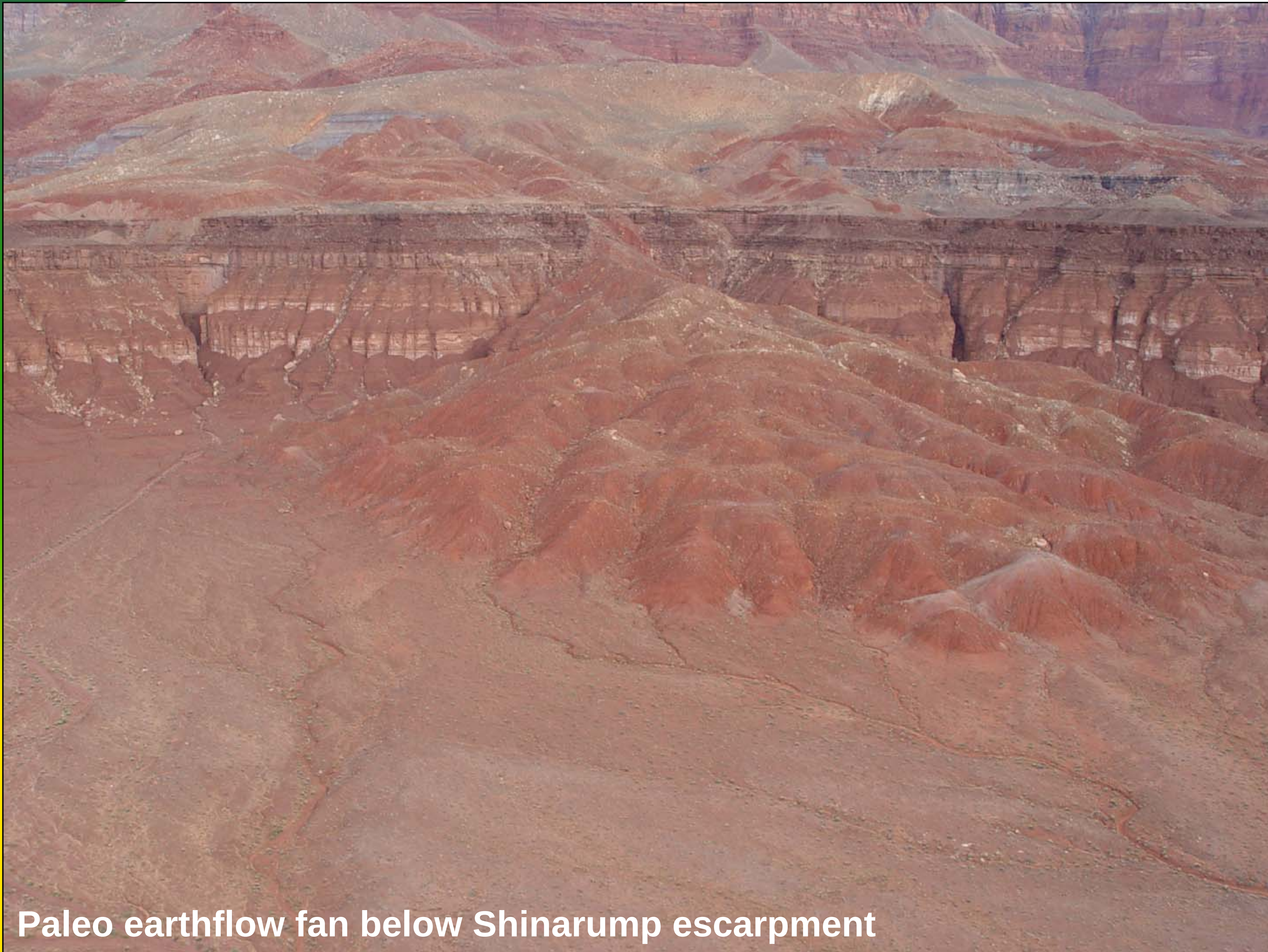
(from Hamblin, 1994)

Earthflows consisting of highly disaggregated Chinle, Moenave, and Navajo Formations are present along the Vermilion and Echo Cliffs near Lee's Ferry. Strahler (1940) suggested that these flows occurred when rotational slumps developed in the Chinle dropped over the Shinarump bench. But, earthflows are also present well above the Shinarump.



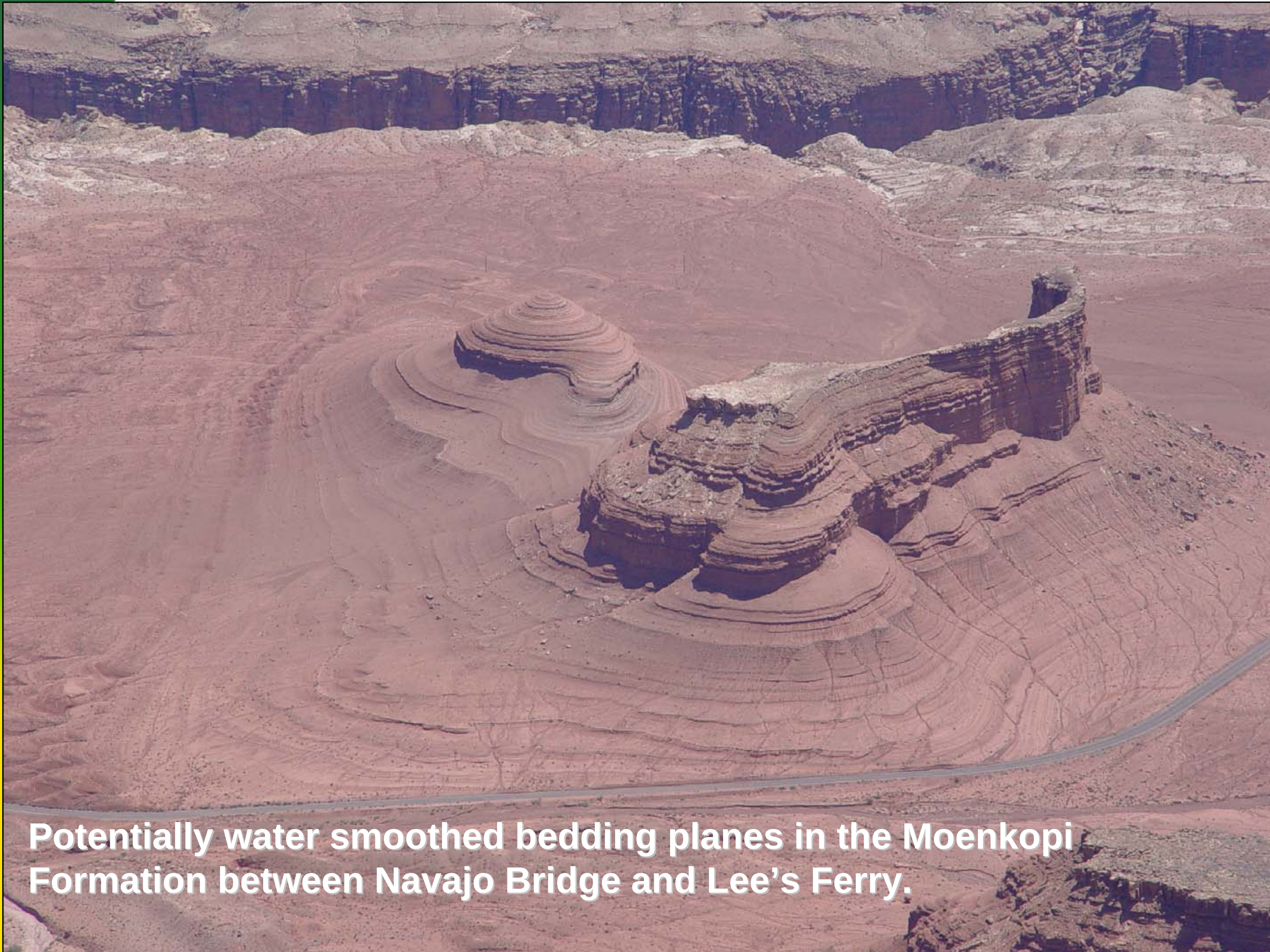
Earth flows above the Shinarump bench.


Earth flows have also cascaded over the edge of the Shinarump bench along the Vermilion Cliffs.



Paleo earthflow fan below Shinarump escarpment

The earthflows may have occurred during rapid drawdown, when the lava dam impoundment inundating the cliffs suddenly dropped and drained away. The Moenkopi beds appear rounded by inundation.

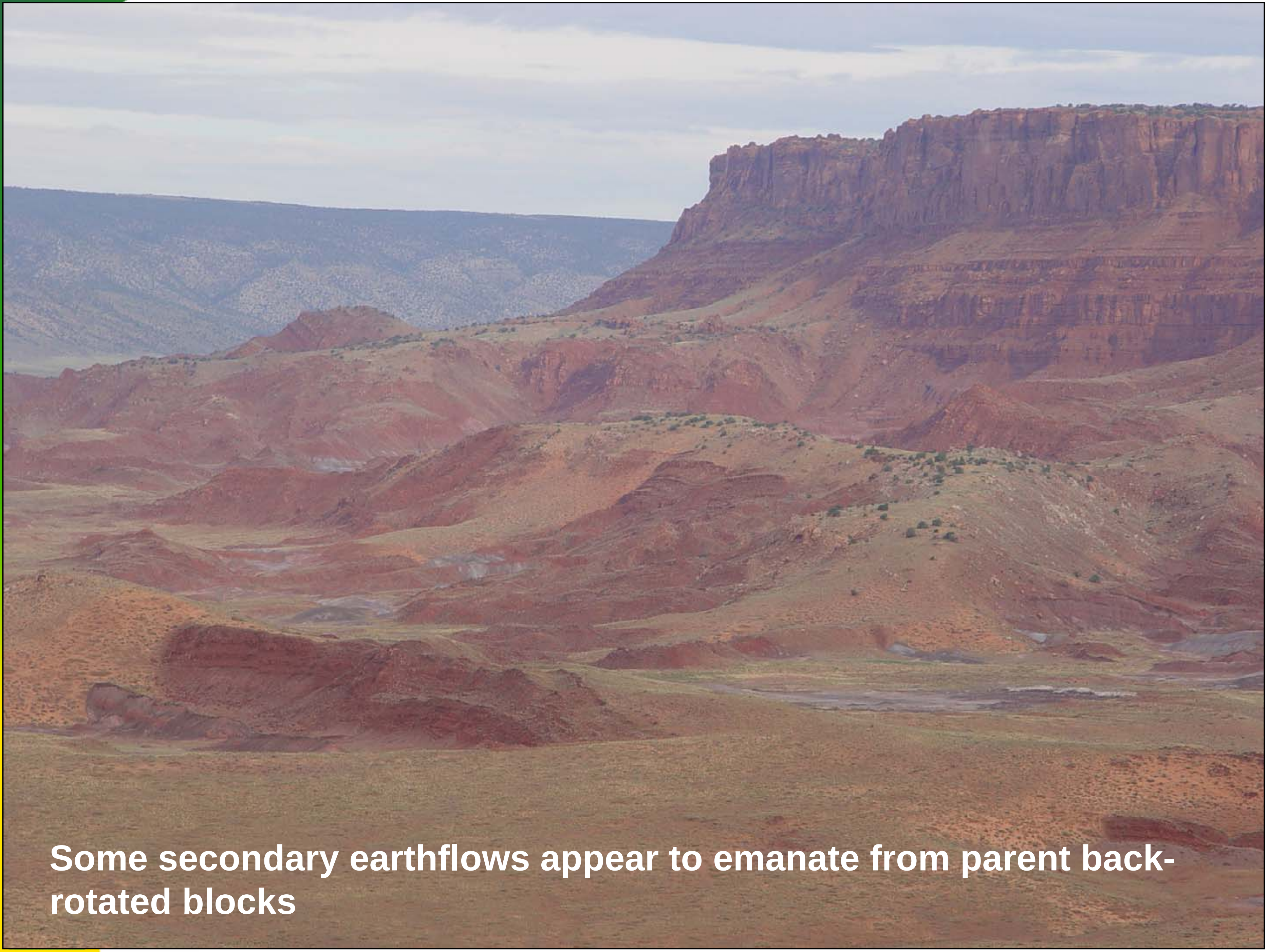


Potentially water smoothed bedding planes in the Moenkopi Formation between Navajo Bridge and Lee’s Ferry.

Close-up of potentially water smoothed bedding planes in the Moenkopi Formation at Navajo Bridge. The Moenkopi doesn't exhibit this texture elsewhere in the Colorado Plateau.

Landslide complex along the face of the Vermilion Cliffs near House Rock. The rotational Toreva or slump type block is more common along the western part of the cliffs.

Dissected slump blocks near House Rock, AZ.


Some secondary earthflows appear to emanate from parent back-rotated blocks

Possible Influence of a Pluvial Climate On Landsliding

It is possible that a wetter climate during pluvials of the Pleistocene led to the saturation and failure of slopes along the Vermilion and Echo Cliffs. Both Strahler (1940) and Ahnert (1960) make mention of open joints in the Navajo Sandstone on the Paria Plateau above the Vermilion Cliffs. The open joints could channel large quantities of water into the underlying formations and are possibly related to straining of the underlying shales.

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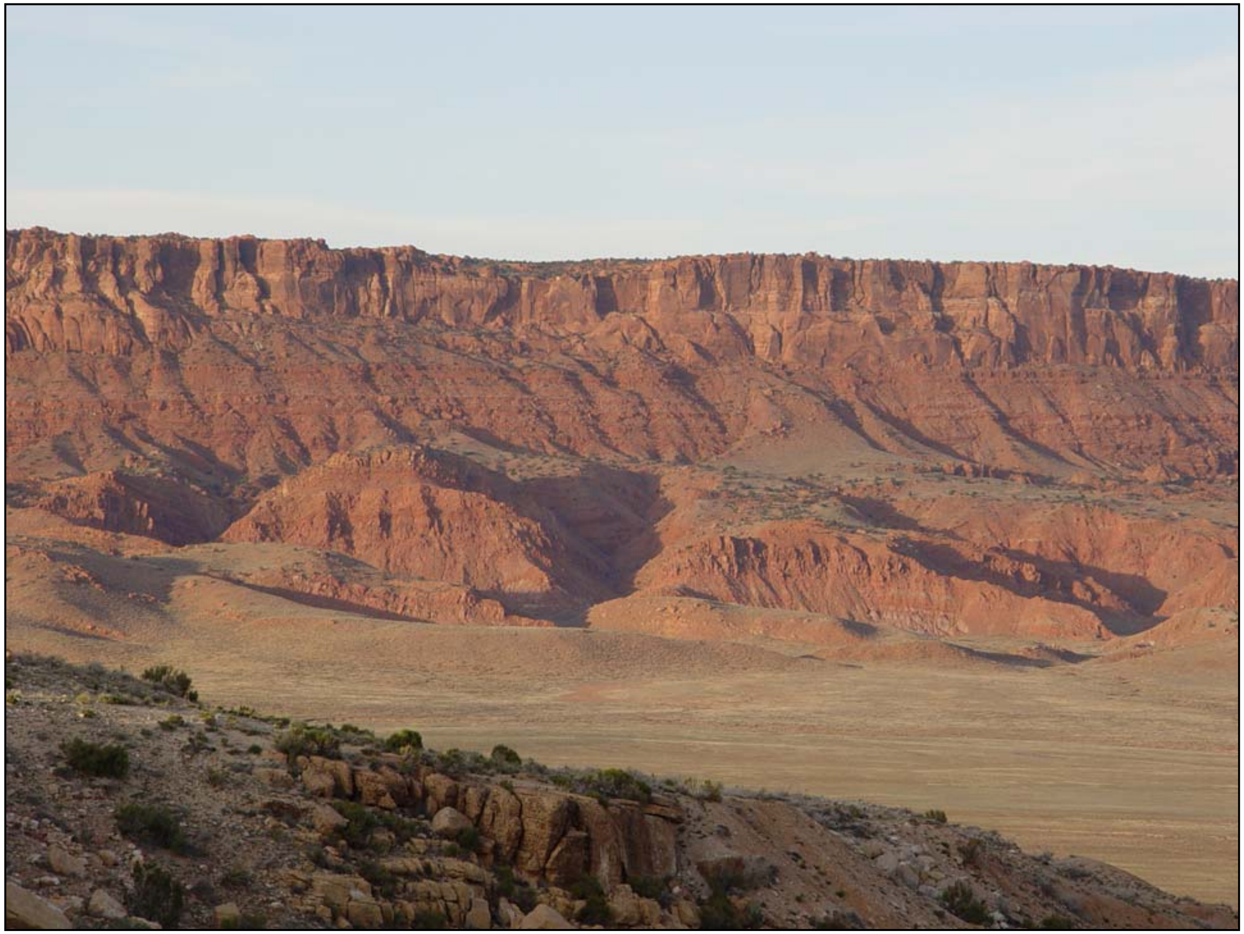


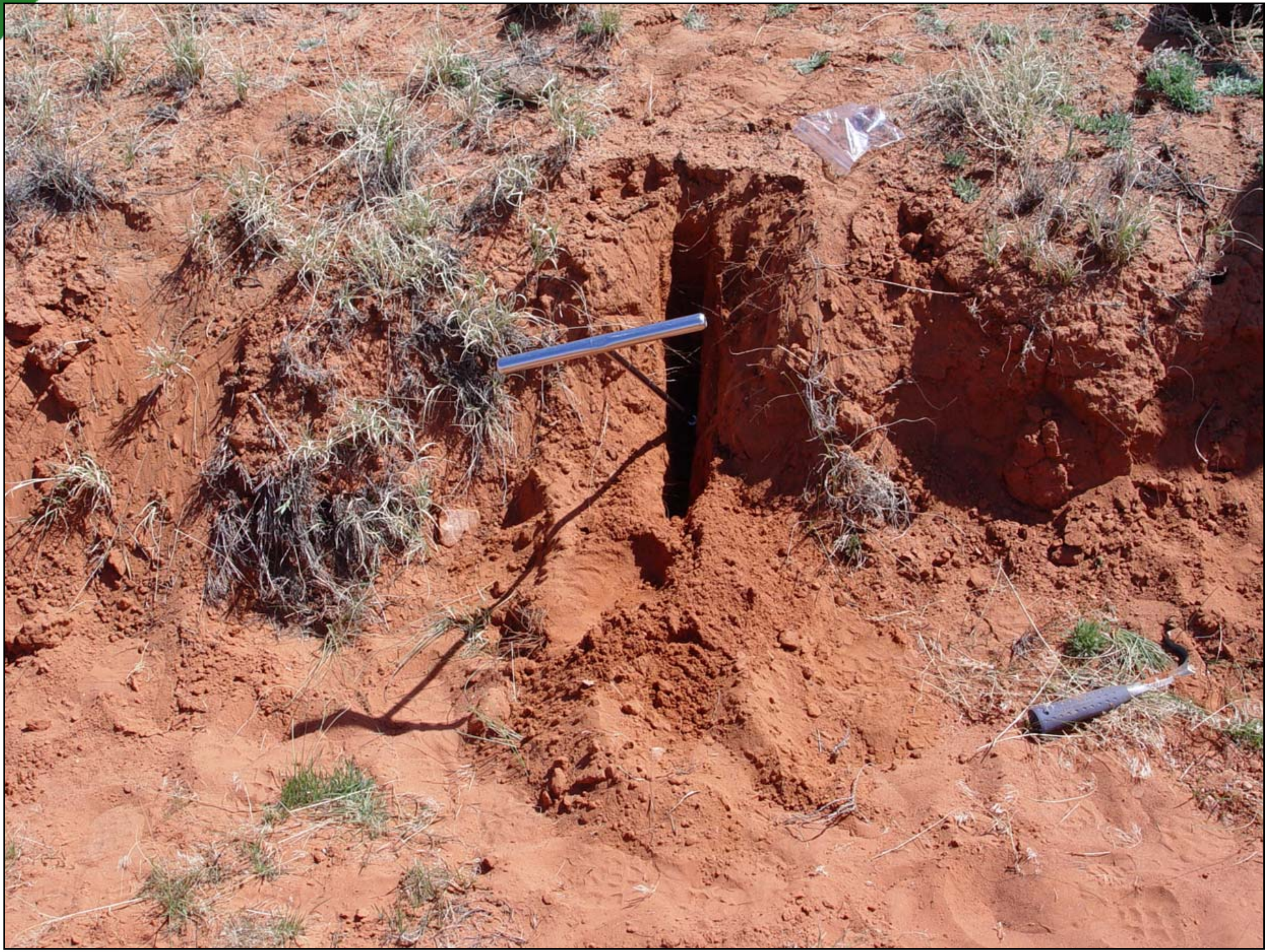
The rotational slump blocks near House Rock have occurred well above the level of any Pleistocene lake caused by nearby lava dams. Some other cause may be responsible. The nearby lake may have allowed groundwater levels to rise nearby, causing a different form of landslide. Similar slides exist throughout the southern Colorado Plateau and appear related to some widespread cause. These include slides described by Rieche (1937) at Toreva, AZ in the Mancos Shale near Black Mesa and others in the Grand Canyon region.

Using Palynology To Date Landslides

Some large headscarp grabens behind the landslides formed closed depressions. These basins trapped sediment washed down from the cliffs above, capturing pollens in the bottom of shallow ephemeral ponds.

The closed basins were eventually breached by headward erosion of adjacent streams. Gullies are presently being incised by these intermittent watercourses, exposing old lacustrine sediments.

Most workers have assumed that reddish lacustrine sediments in the Southwest are oxidized, which would destroy entrained pollen. But the source units, the Kayenta and Navajo Formations, are also reddish in color. Samples similar in appearance have been recovered from Grand Canyon and were found to contain pollens from a wide variety of species, as well as spores and freshwater algae.



Samples of fine grained sediments contained in several headscarp grabens have been recovered using a 1” diameter soil auger and plug sampler.

A 1” diameter soil auger can recover soil samples up to 1.5 m deep, or farther if subsurface conditions permit. Palynology can be used to date the age of the ponds and therefore, the landslides. It can also provide paleoecology and paleoclimatology information which could provide insights on why the slides occurred.

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Conclusions

- The Vermilion Cliffs are mantled by multiple sets of prehistoric landslides, which appear to have occurred over a considerable range of time.
- Slides formed mostly in the montmorillonite-rich Petrified Forest Member of the Chinle Formation.
- The conditions fostering the landslides no longer appear active, as slides appear old and dissected.
- Old slides buttress the base of the cliffs, forcing more recent slides to fail at increasingly higher elevations.

Conclusions

- Although the stratigraphy is similar, slides at opposing ends of the Vermilion Cliffs are noticeably different, indicating multiple factors have likely played a role in their formation.
- Similar slides occur throughout the southern Colorado Plateau.
- Analysis using palynology may provide a better idea of when and why the slides occurred.

References

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