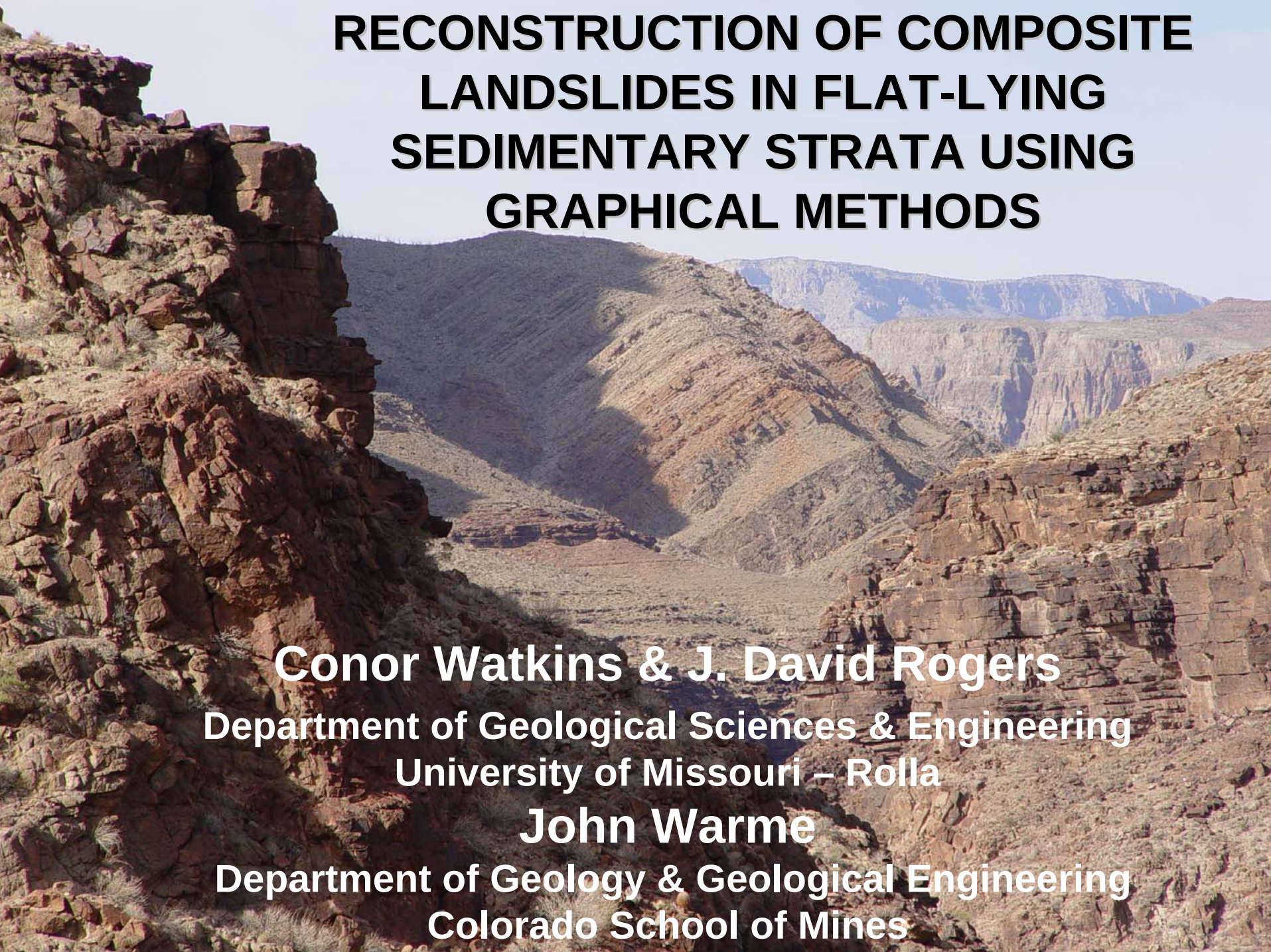
RECONSTRUCTION OF COMPOSITE LANDSLIDES IN FLAT-LYING SEDIMENTARY STRATA USING GRAPHICAL METHODS



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INTRODUCTION

- Large megalandslide complexes are common in the western United States, especially where competent sedimentary sequences are underlain by overconsolidated shales, and incised by watercourses.
- We have been studying these features in the Colorado Plateau, and particularly, in and around the Grand Canyon.
- We are creating kinematic models using the concept of balanced structural cross sections to re-create likely failure scenarios for a few of these slide complexes, felt representative of the mix.

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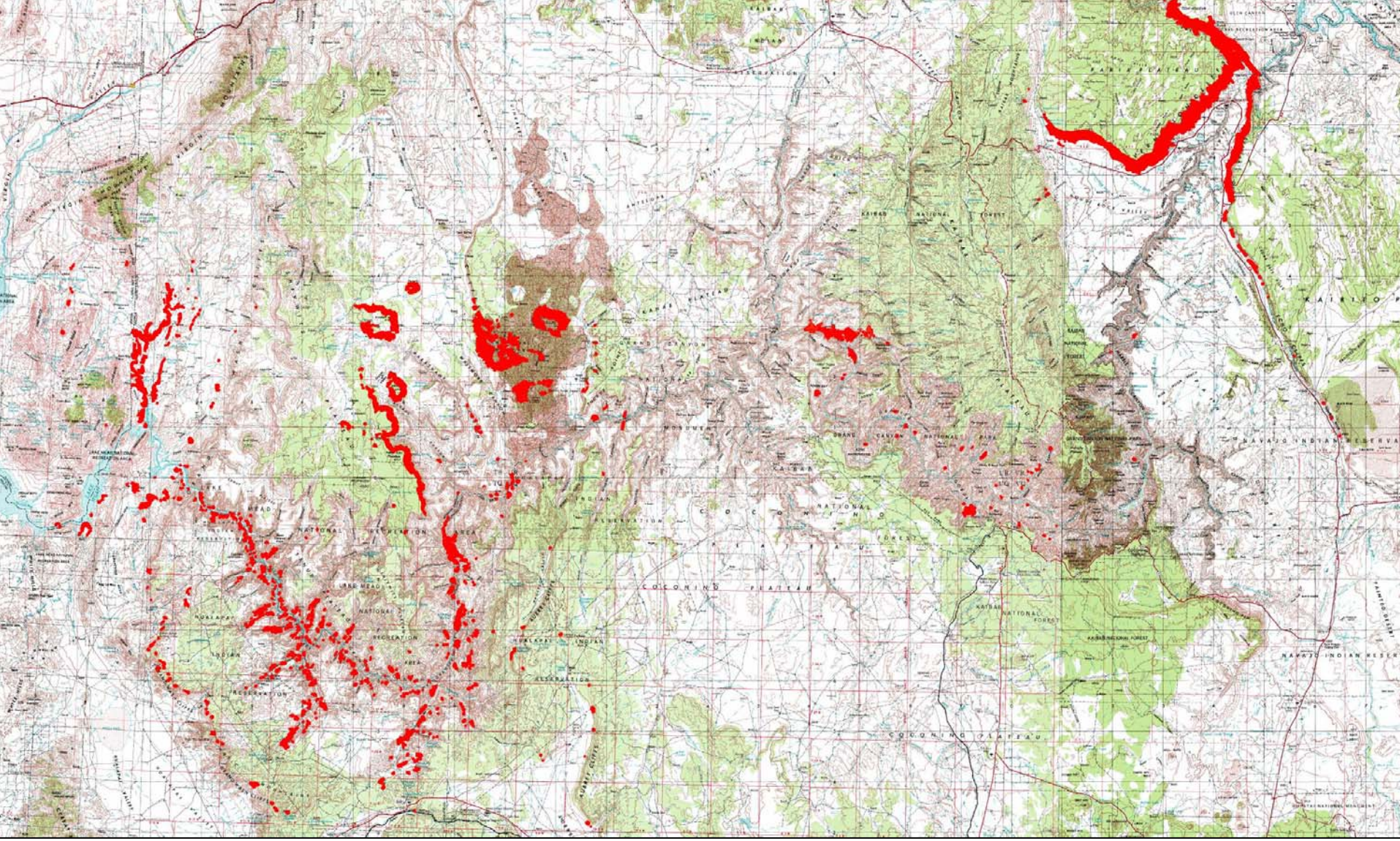
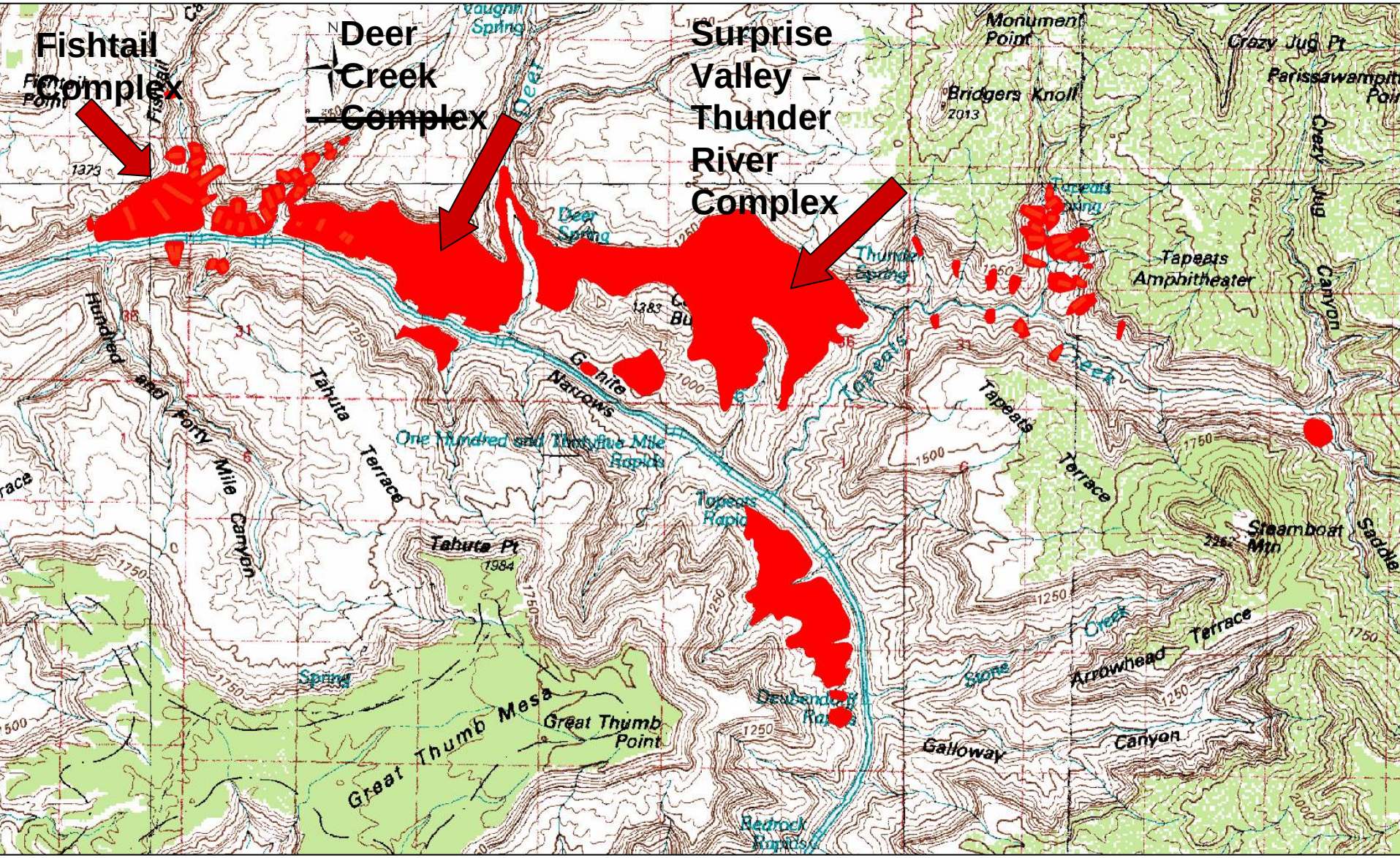
This work began in 1978 when Dave Rogers was mapping bedrock topples in the Vishnu Schist in the Grand Canyon, along with Jim Mitchell at U.C. Berkeley. We became fascinated by the enormous composite landslides exposed in the western Grand Canyon, downstream of River Mile 131.



This map shows the landslides mapped by ourselves and past researchers. Although the slides around Surprise Valley have garnered the most attention, most of these slides are located in the western part of the canyon, with volumes ranging between a few hundred to almost two billion cubic meters.

Slides in the Surprise Valley area of the central Grand Canyon, between RM 131-141



SEQUENTIAL SECTIONS

- **The following series of cross sections illustrate plausible kinematic models that describe how some of these composite landslides likely evolved**
- **The concept of balanced structural cross sections was used in the creation of these models.**

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Surprise Valley – Thunder River Landslide

Surprise Valley - Thunder River Landslide Complex

- This is one of the largest landslide complexes in Grand Canyon.
- It consists of a dozen or more back-rotated and translated blocks.
- The largest blocks involve ~600m of strata, some of which have translated nearly a kilometer.
- Thunder River Spring discharges >20 million gpd and it likely played a role in triggering this slide.

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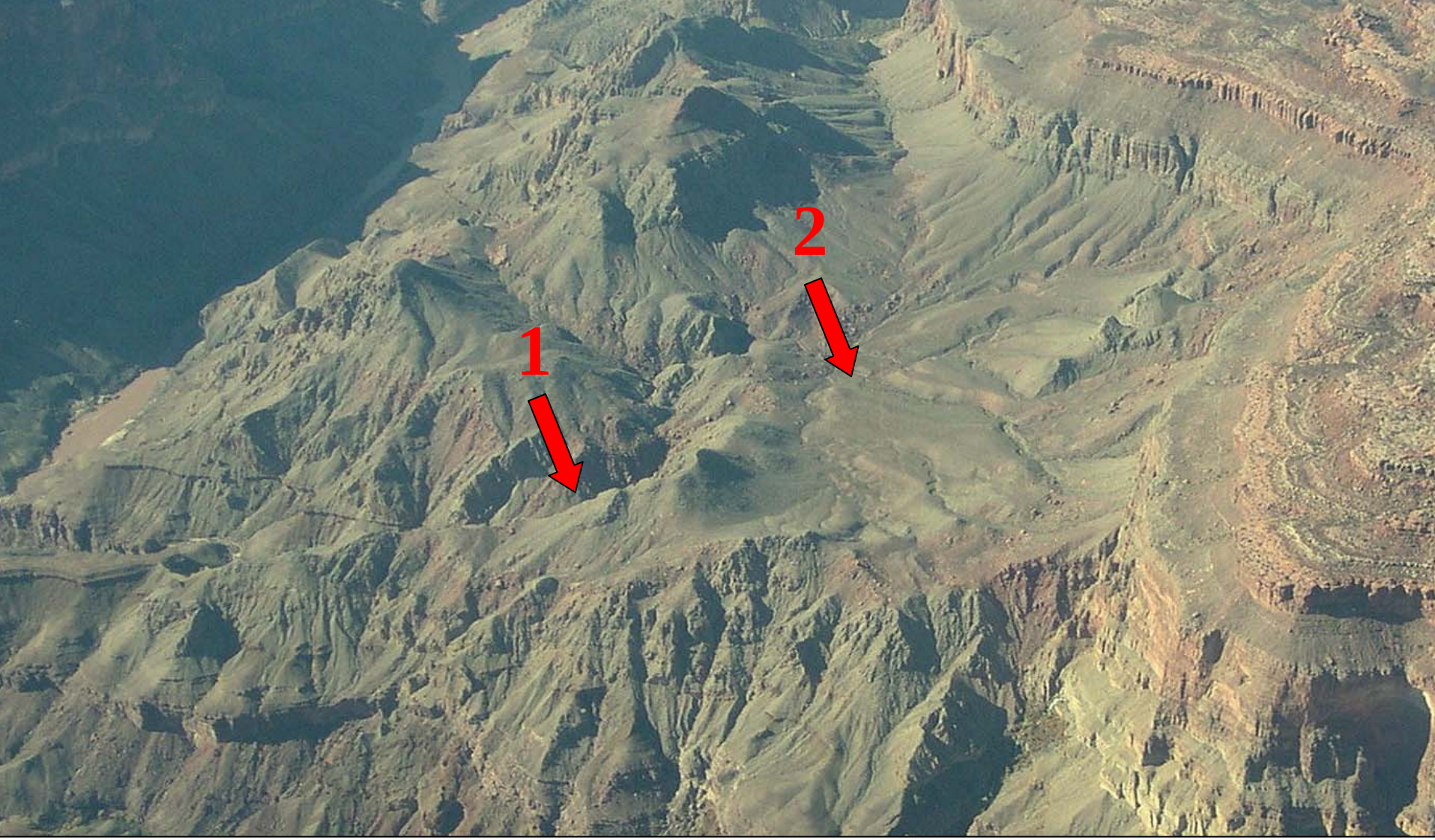


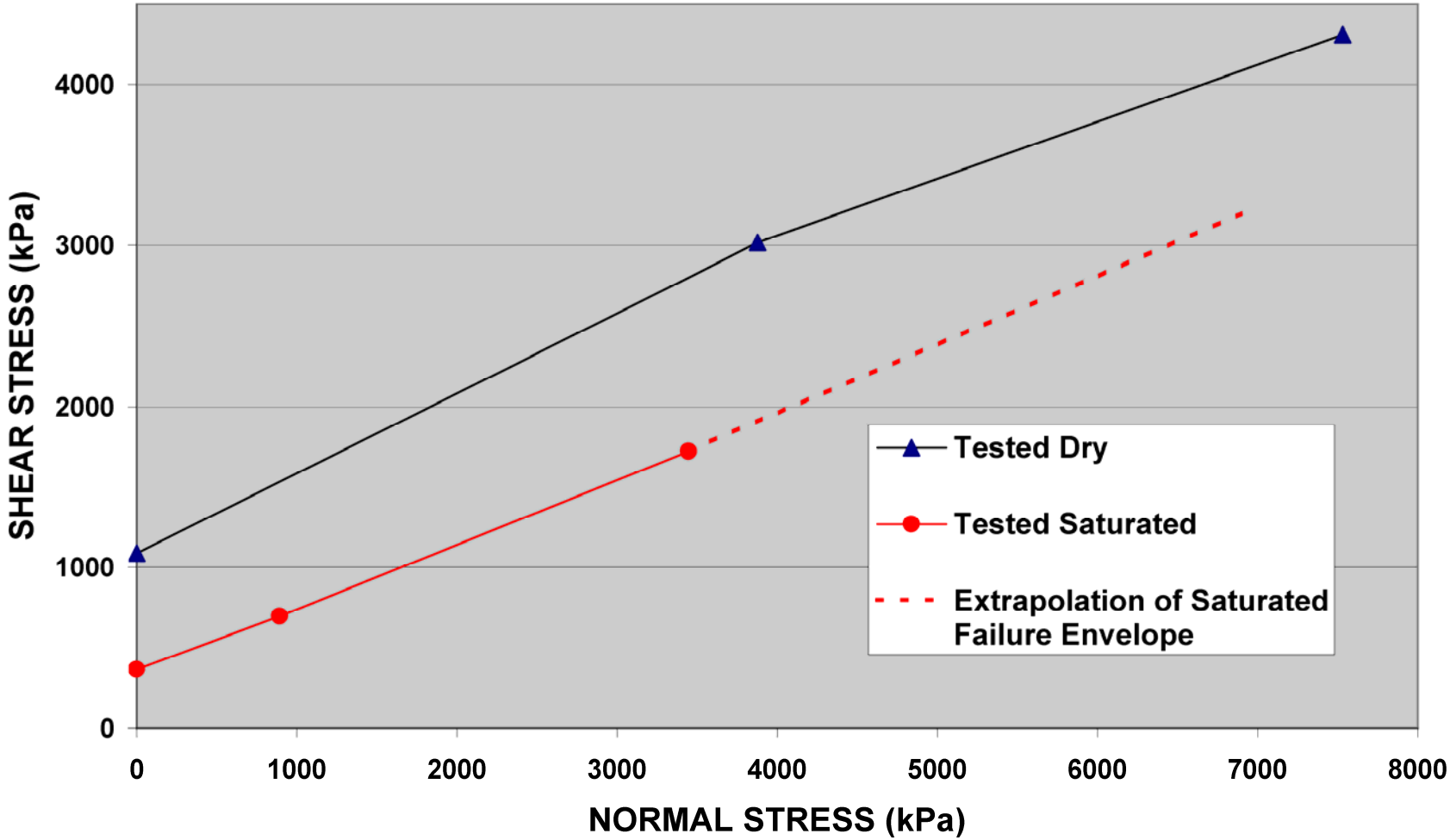
Overview of the Surprise Valley area. The headscarp graben of this landslide complex once formed a closed basin, which allowed sediments to accumulate, until it was breached by the headward erosion of Bonita Creek (1). These sediments are exposed in Surprise Valley, at location (2). (Photo courtesy of Alan Herring).

Aerial oblique view of the Thunder River Slide showing pronounced back rotation and a portion of the block that has translated horizontally. At right Thunder River Spring discharges 20 MGD, making it the second largest spring emanating from the North Rim of the Grand Canyon.

- The Thunder River Slide extends all the way to the margins of the spring and was possibly influenced by its water.
- Many other springs in Grand Canyon are also associated with landslides, indicating a probable correlation.

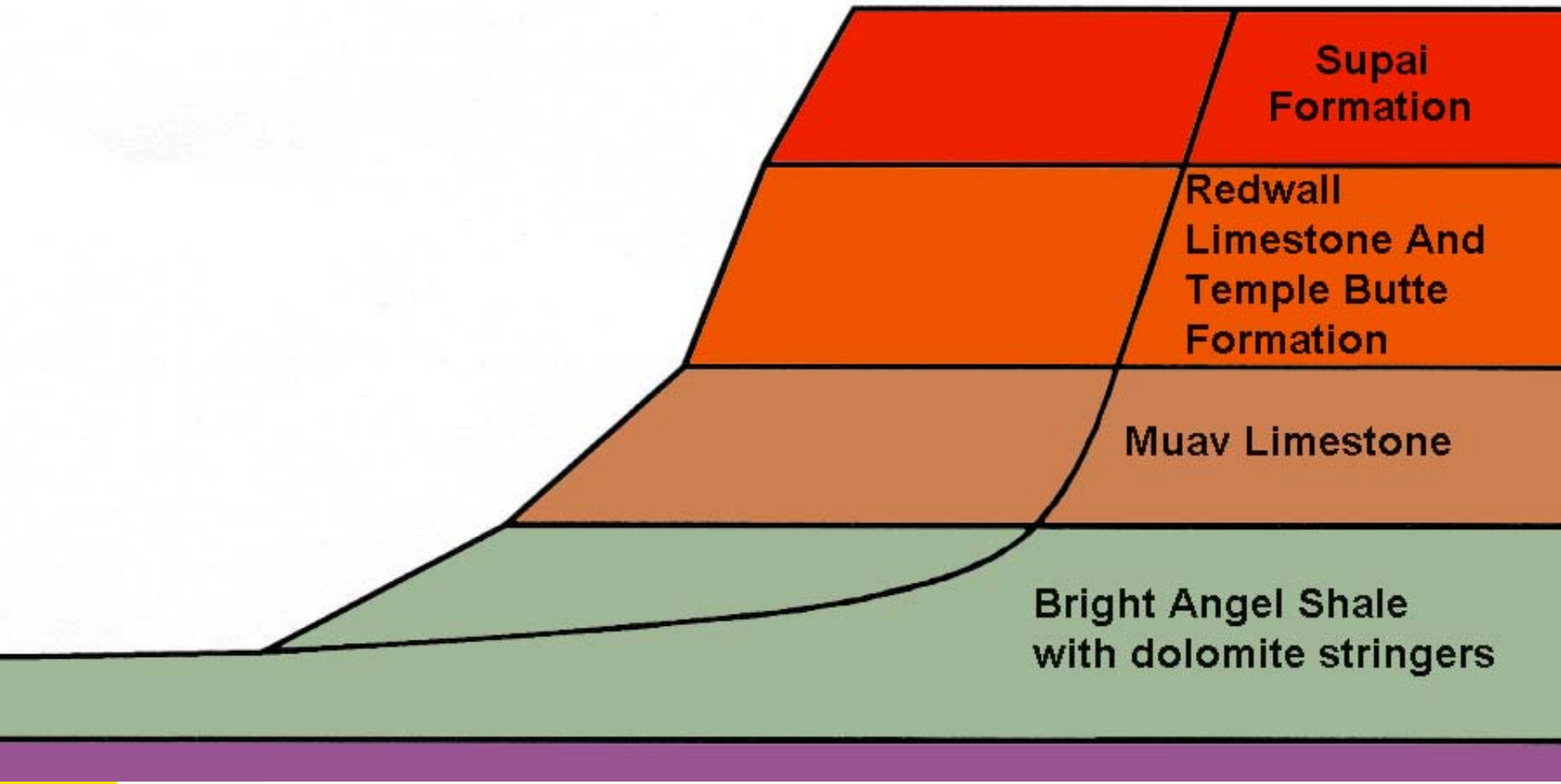
Thunder River

DIRECT SHEAR TEST RESULTS ON BRIGHT ANGEL SHALE

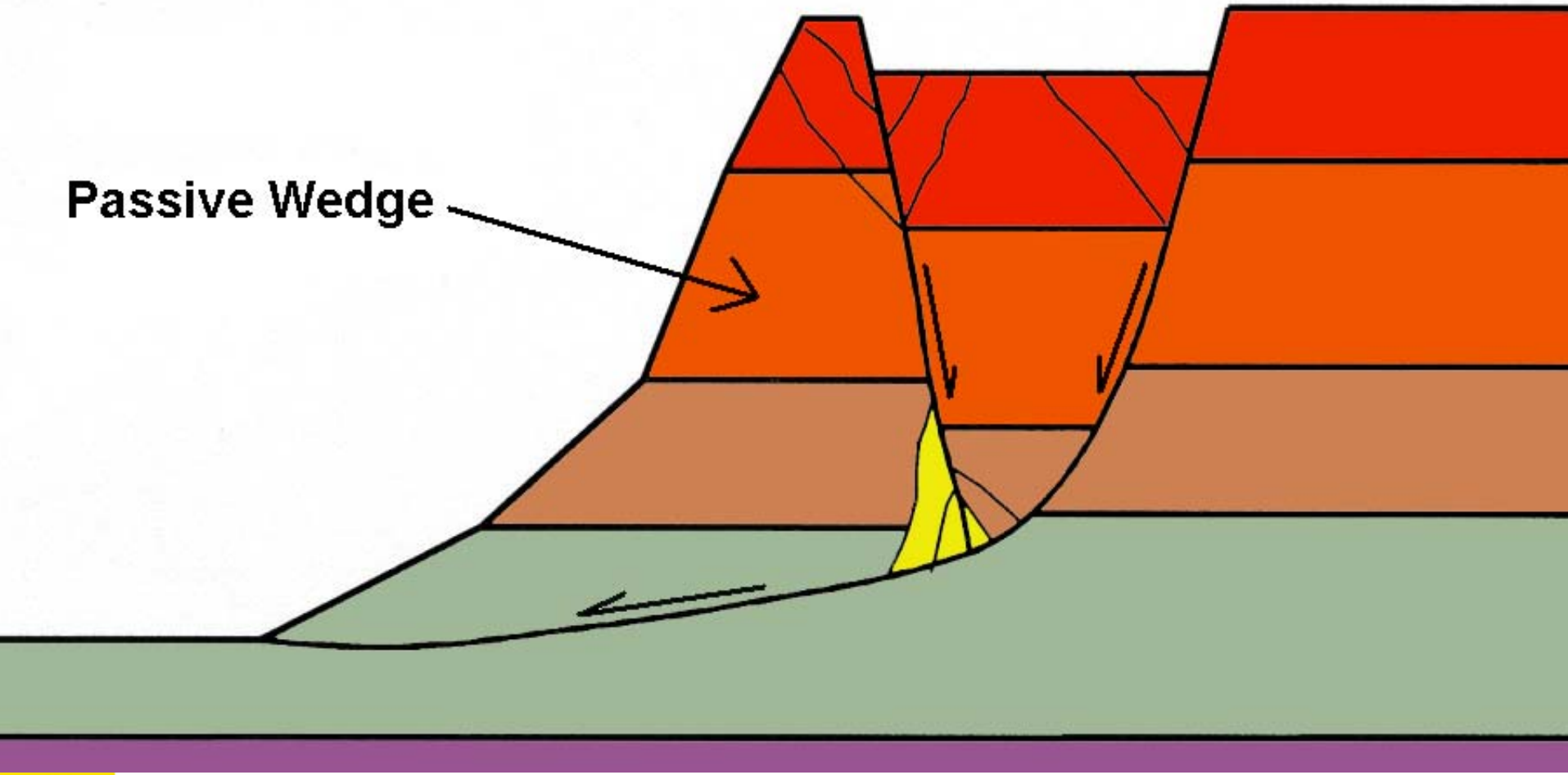


Direct shear tests on Bright Angel Shale, just beneath the basal slip surface of the Thunder River Landslide, modified from Rogers and Pyles (1980). It took 6 months to saturate the micaceous shale under back-pressuring. Note the marked decrease in apparent cohesion upon saturation.

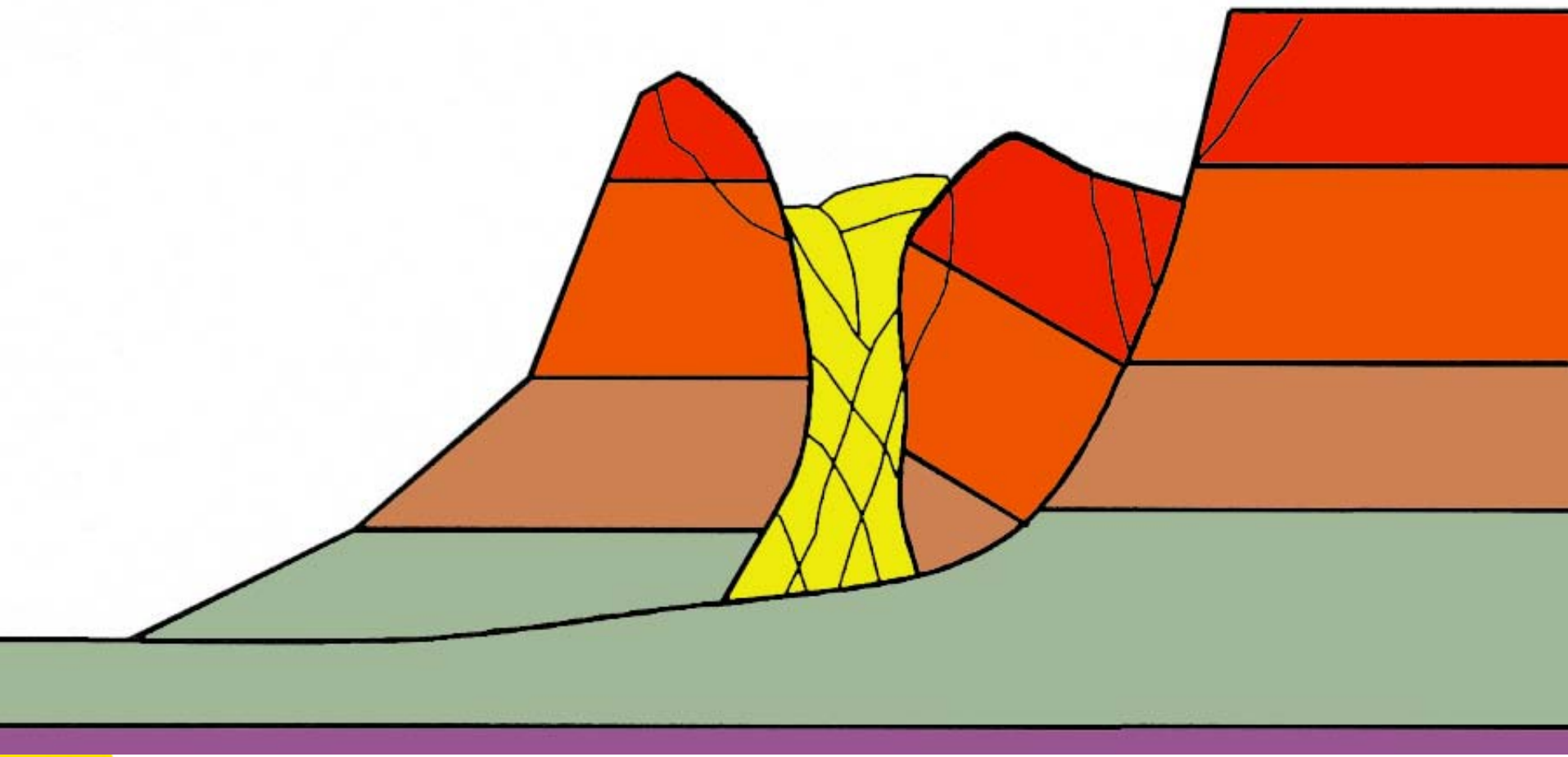
Thunder River Landslide - 1



Thunder River Landslide - 2



Thunder River Landslide - 3



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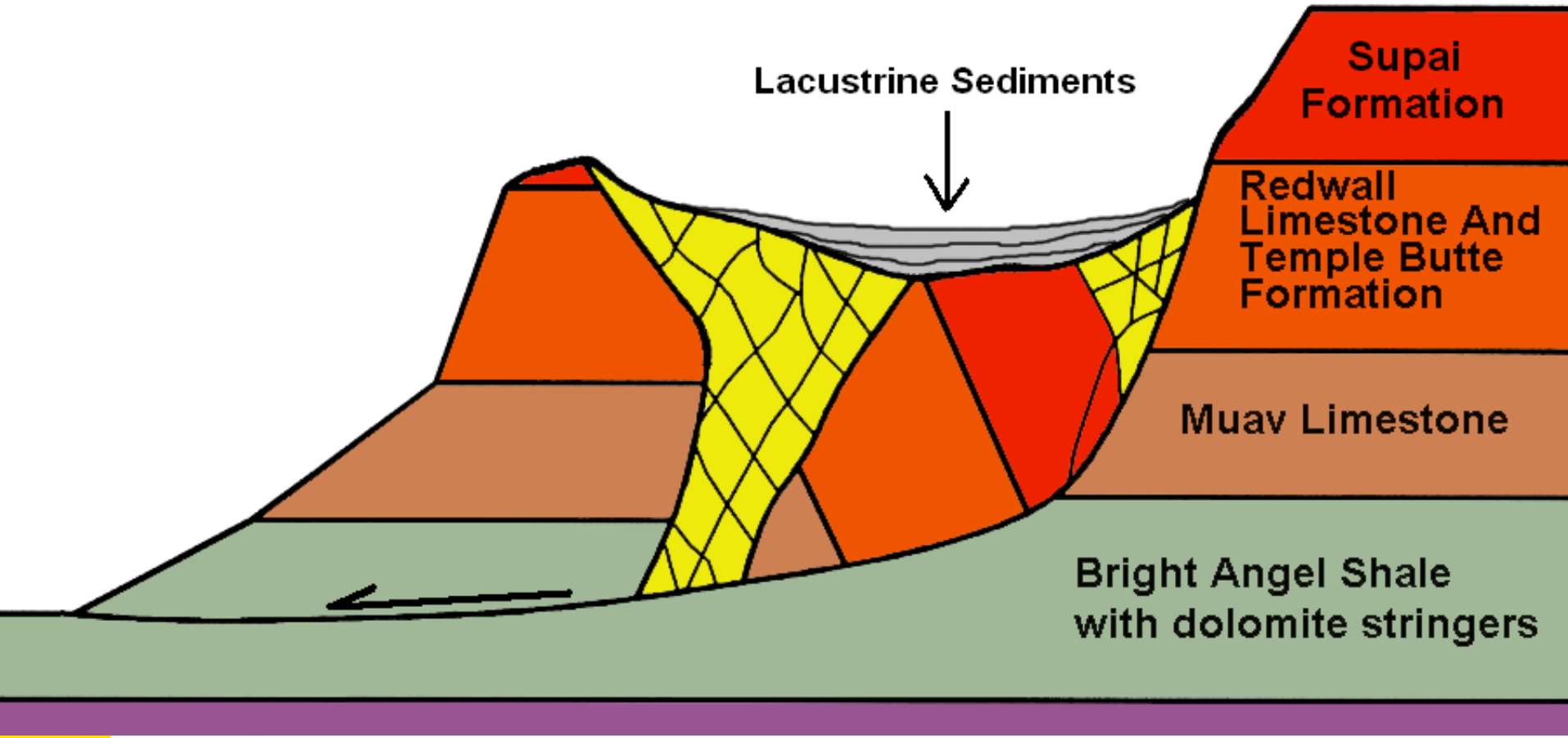
Thunder River Landslide - 4



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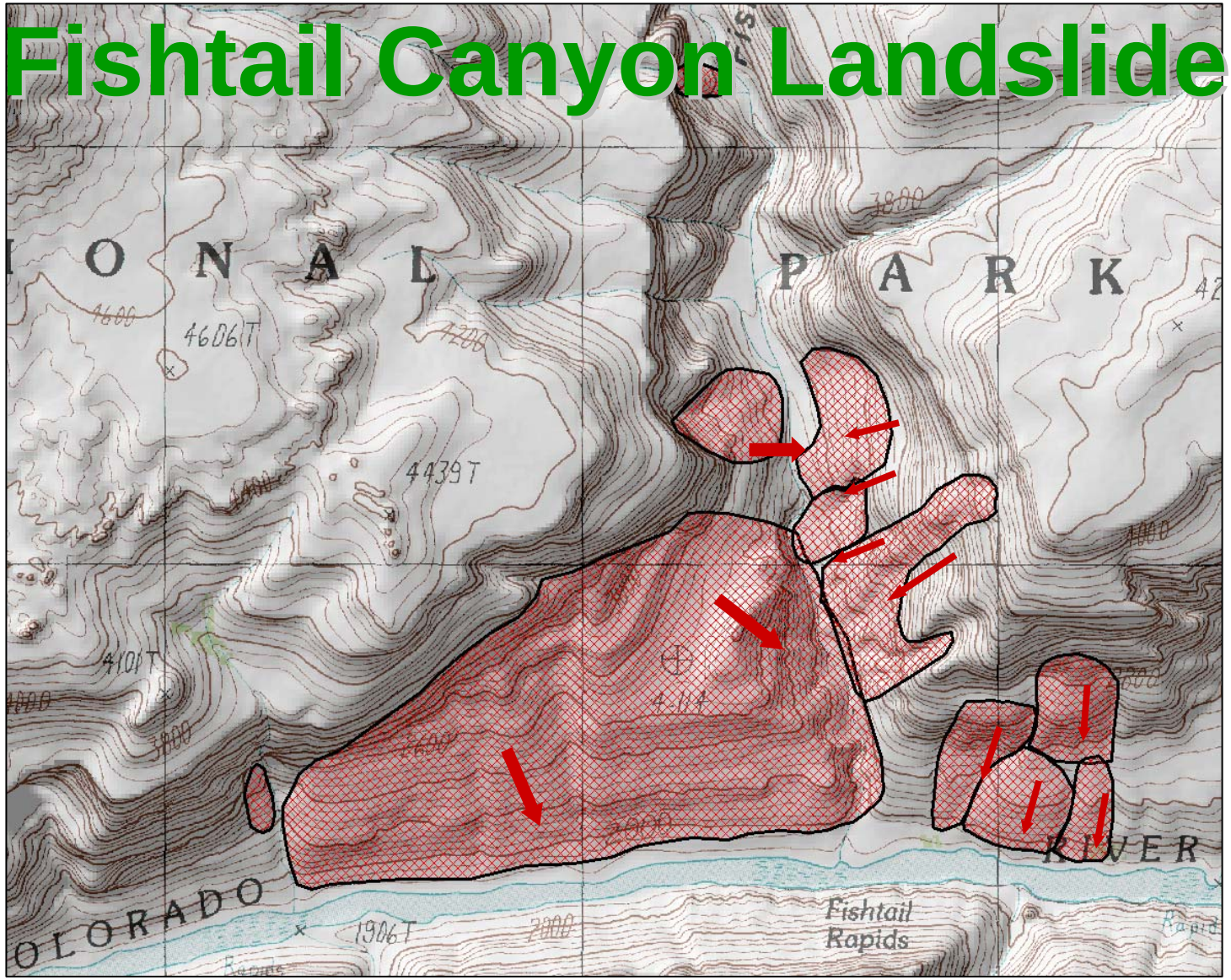
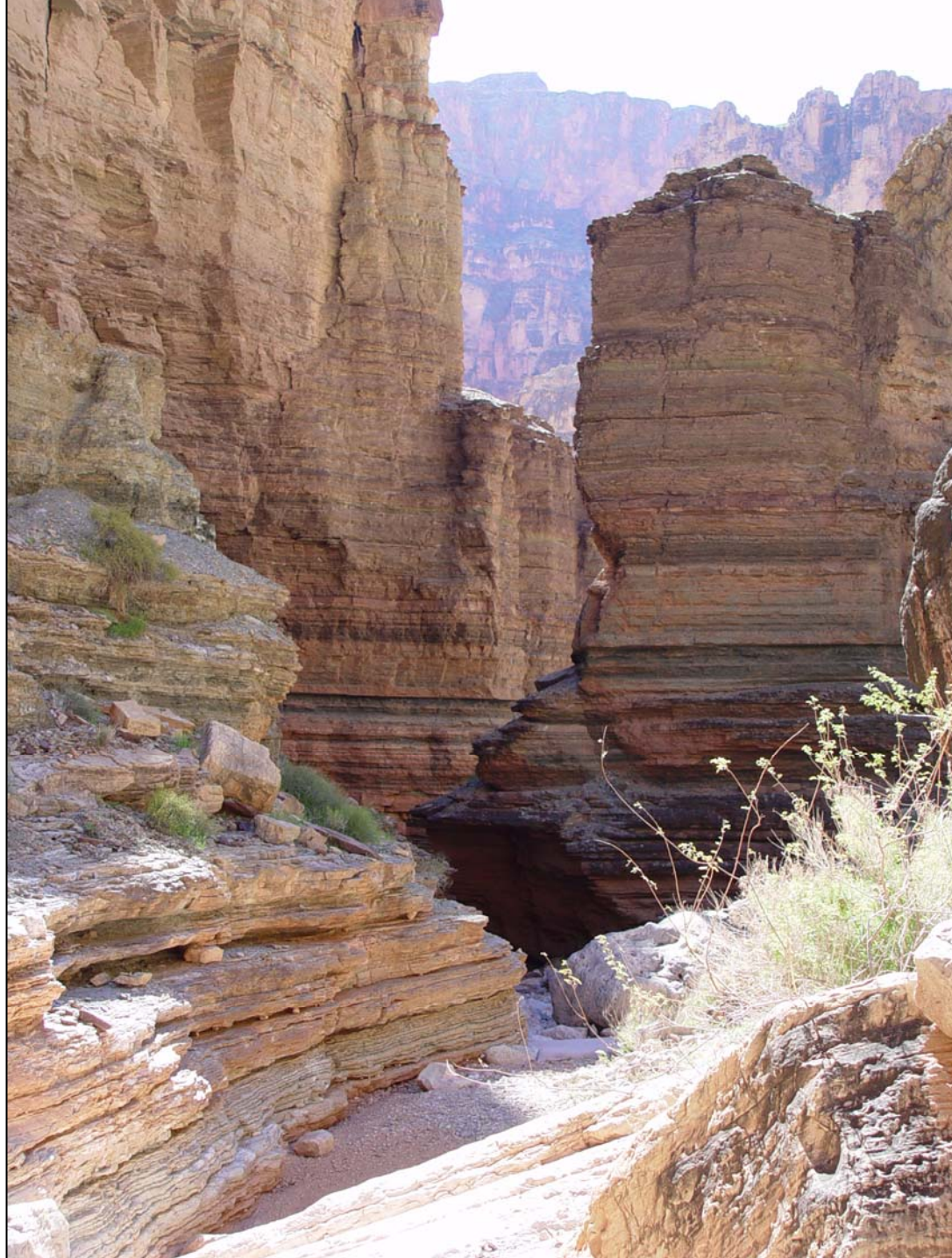
Fishtail Canyon Landslide



The mouth of Fishtail Canyon was blocked by a massive landslide, likely in two main episodes. Total slide volume is about ~340 million cubic meters. This blockage allowed lacustrine sediments to be trapped upstream, along Fishtail Creek.

The pre-slide channel of Fishtail Creek was buried by the Fishtail Landslide. The creek has been diverted around the eastern side of the slide, through deeply incised narrows, similar to Deer Creek.

This shows the mouth of Fishtail Canyon, which is deeply incised into the fissile members of the Bright Angel Shale and upper Tapeats Sandstone, testifying to rapid entrenchment by the diverted overflow channel.



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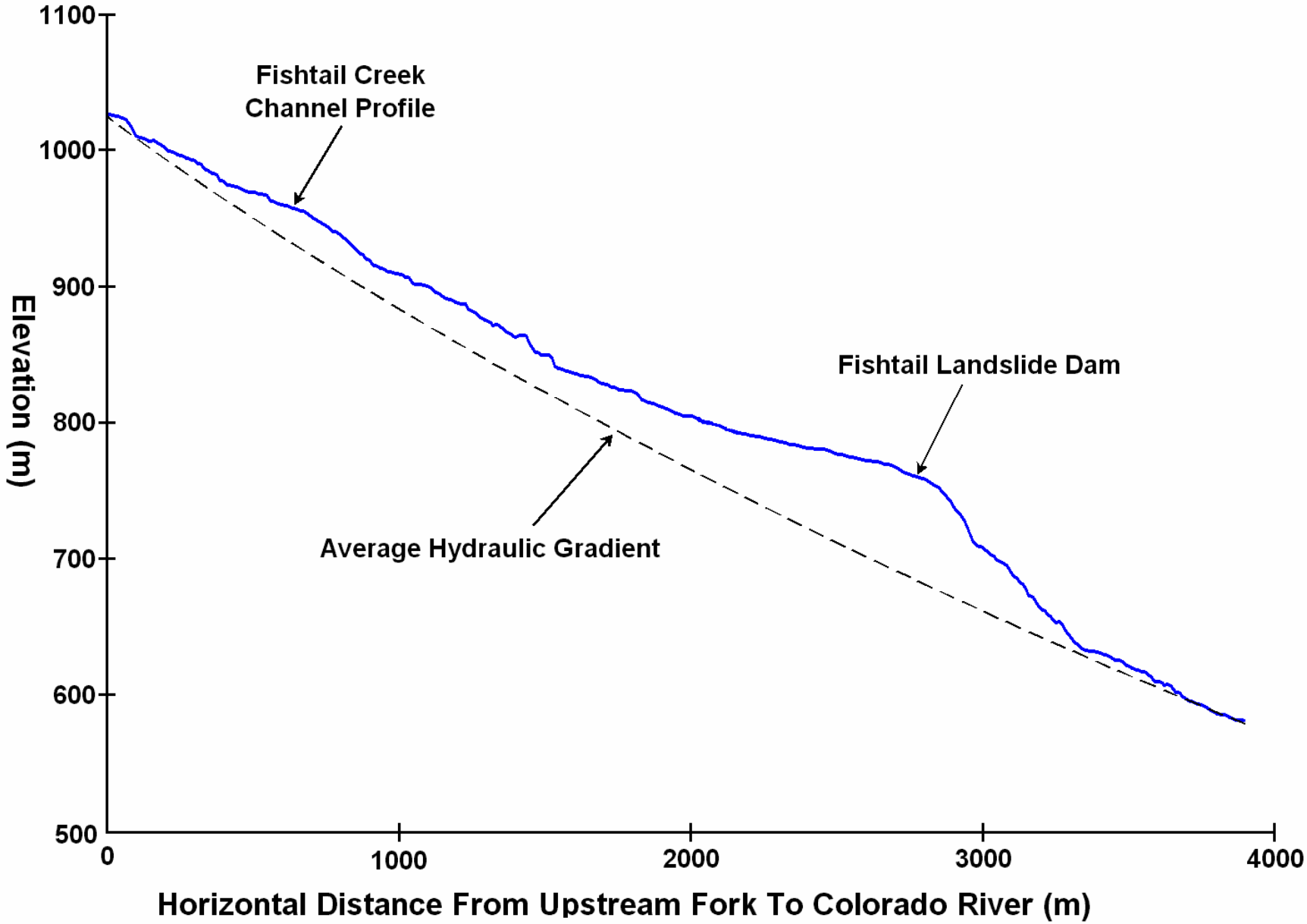
Indurated beds of lacustrine sediments deposited behind the landslide dam in Fishtail Canyon. They are between 45 and 60 m thick.

Fishtail Canyon Channel Profile



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Kinematic Model of Fishtail Canyon Landslide

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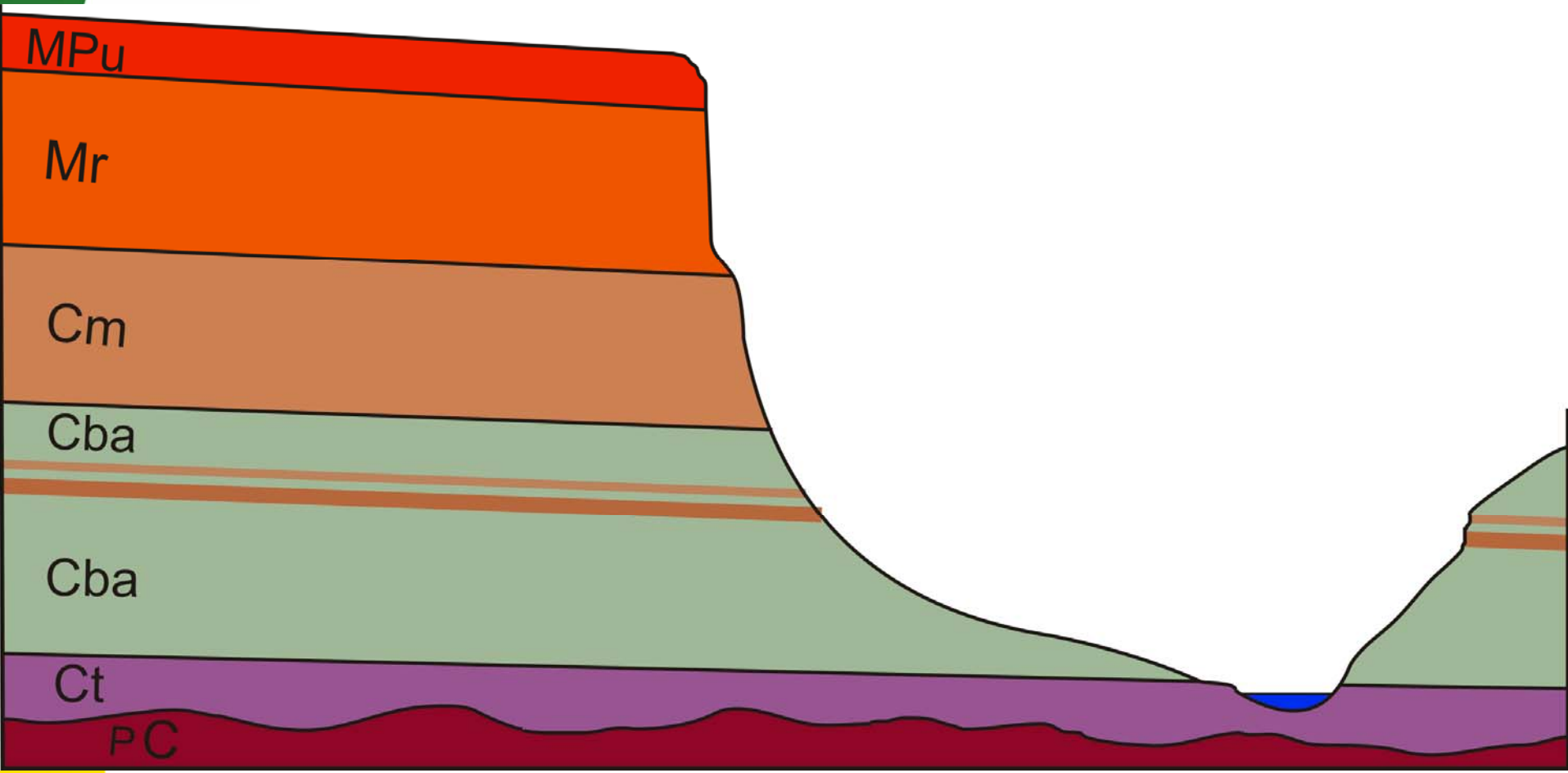

Note dip of strata, about 5^{o} towards the Colorado River

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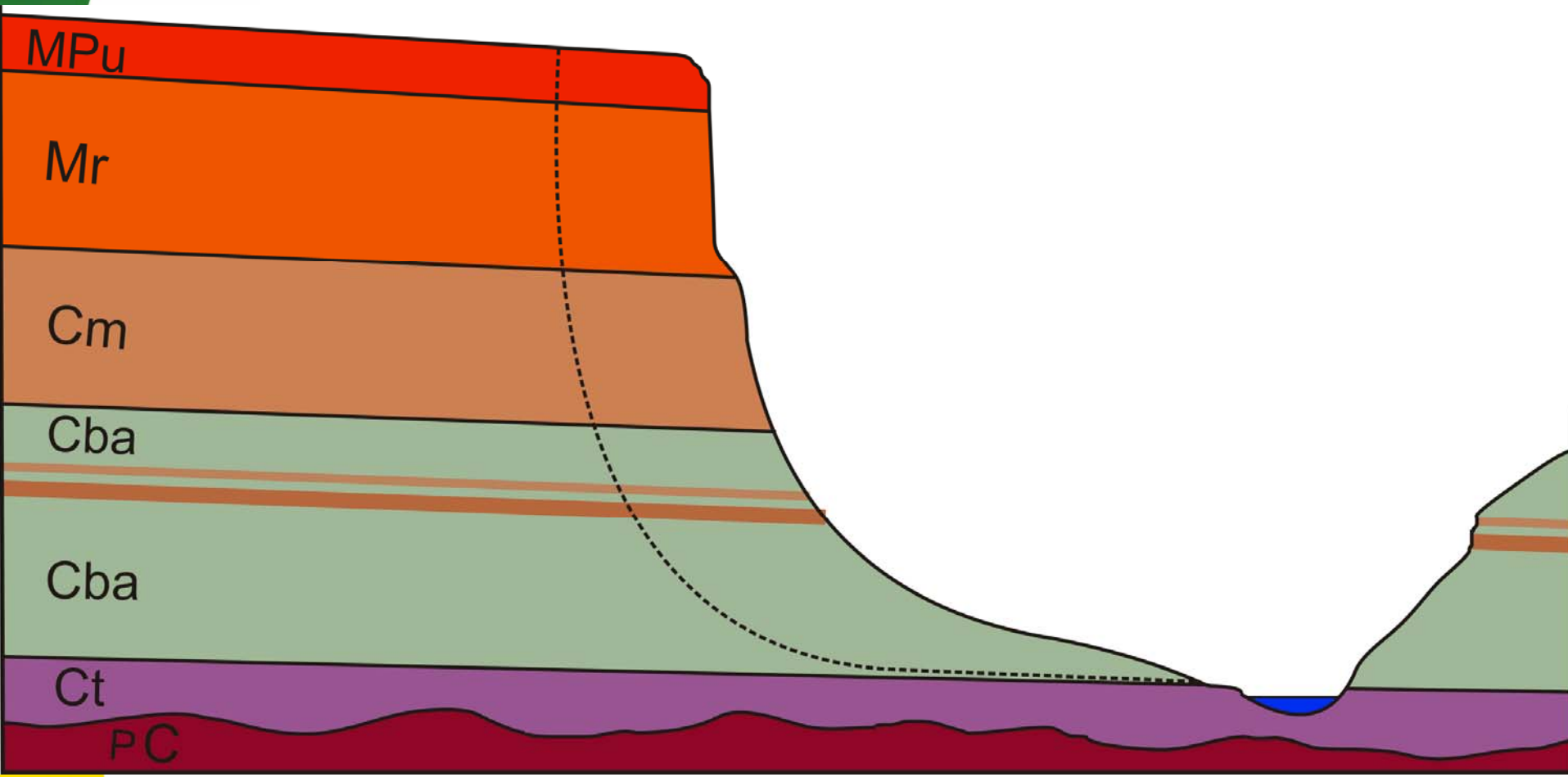
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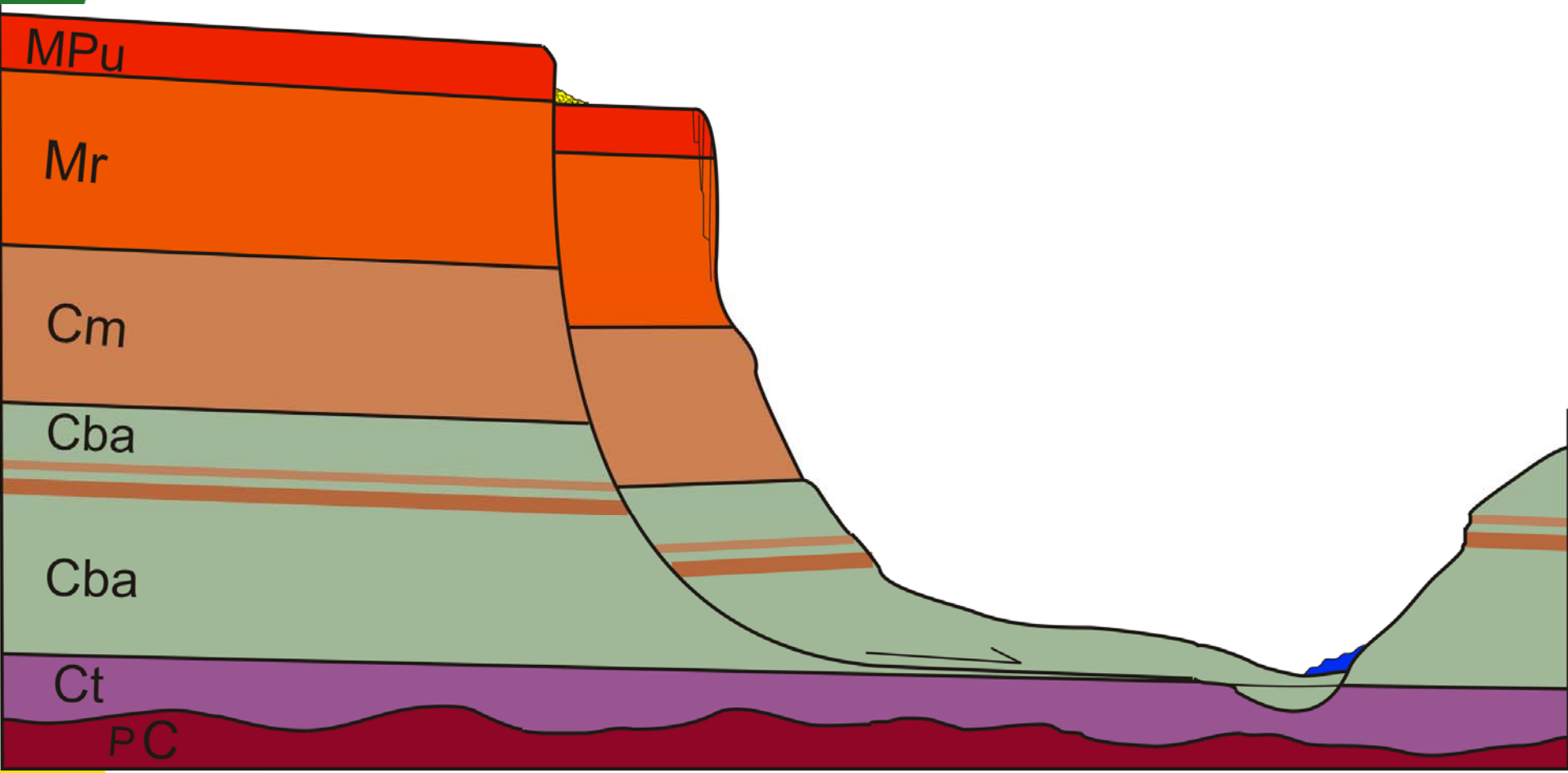
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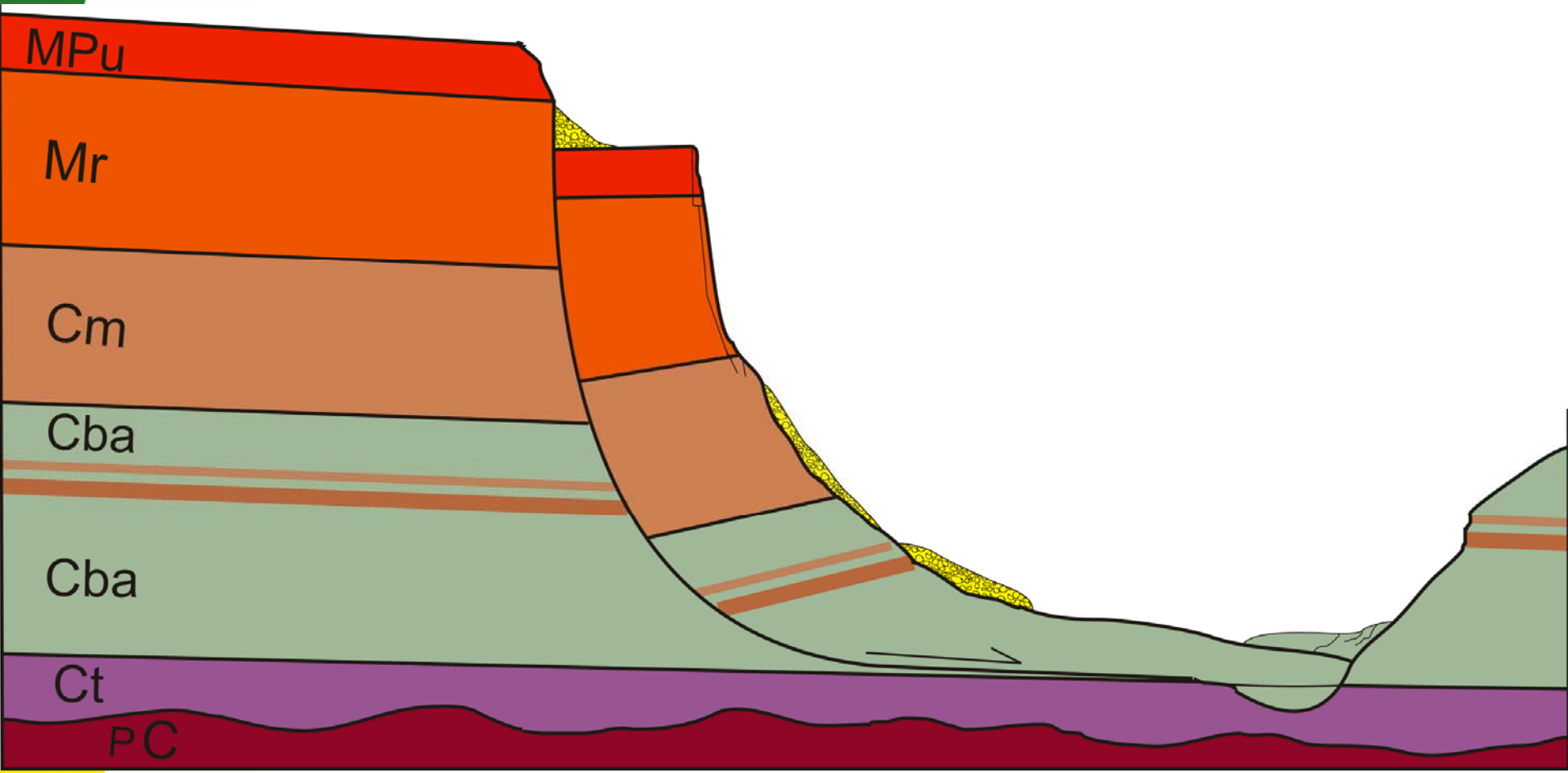
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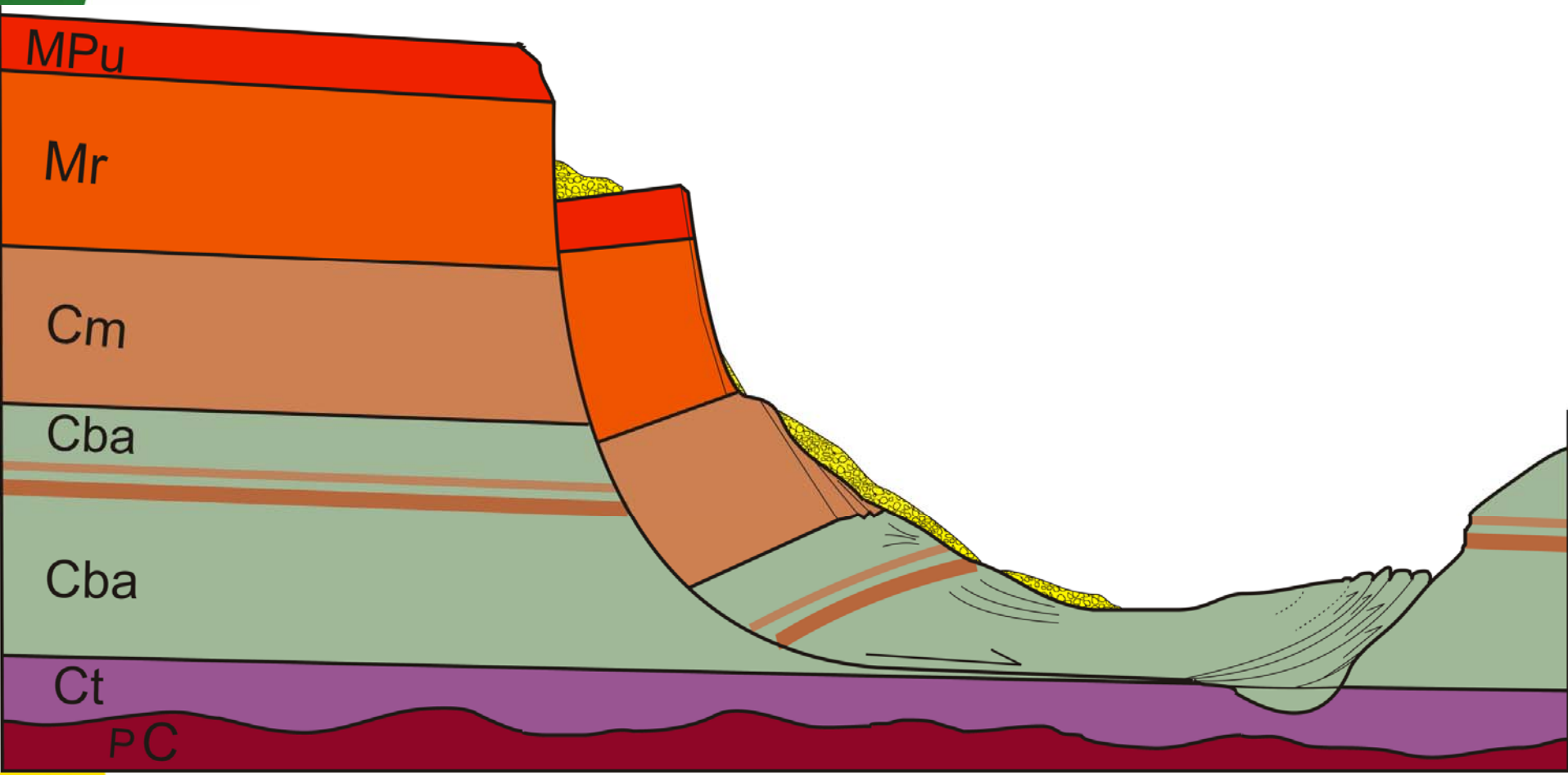
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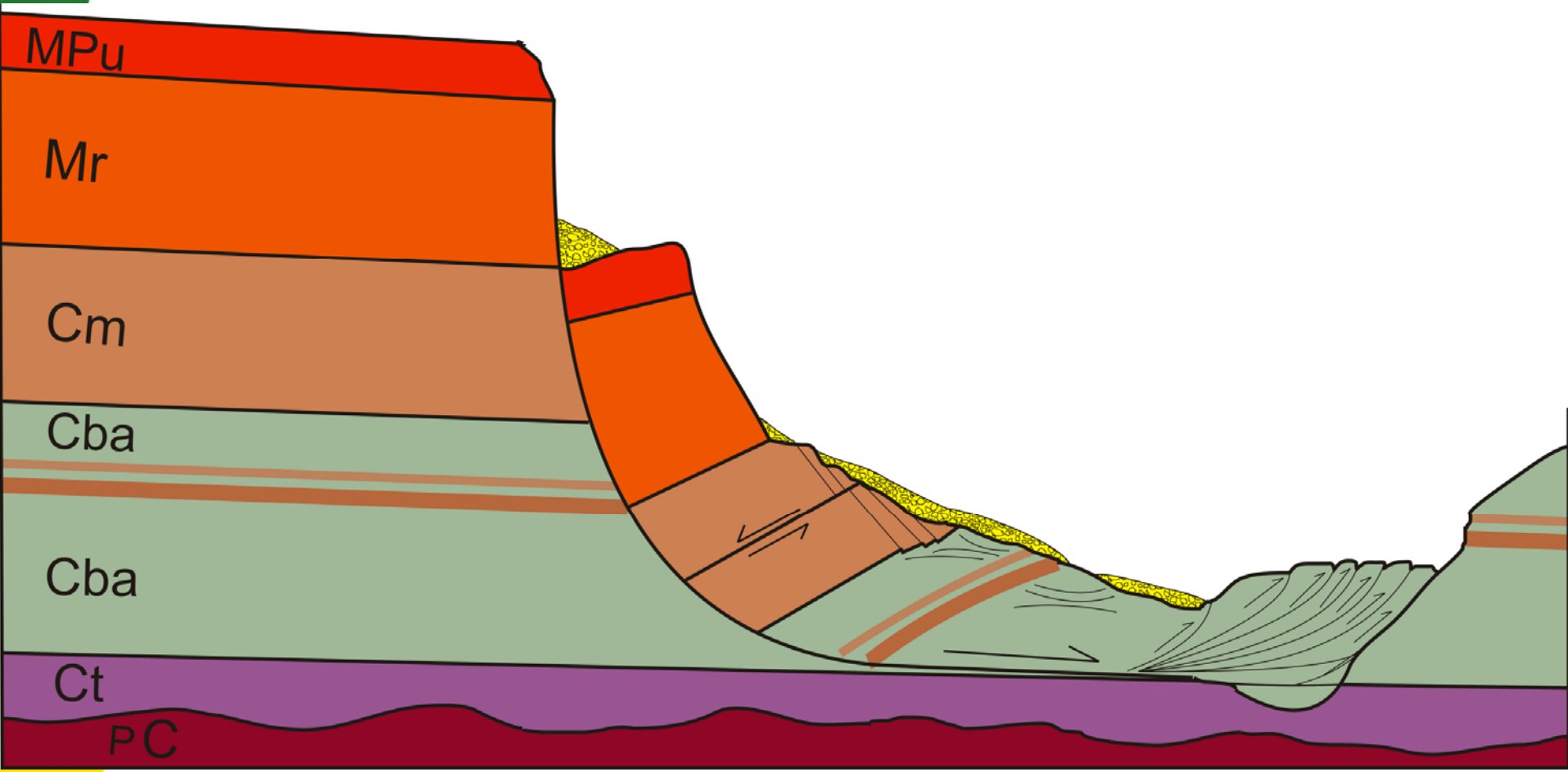

A effective landslide dam is created by all the displaced shale in the passive zone.

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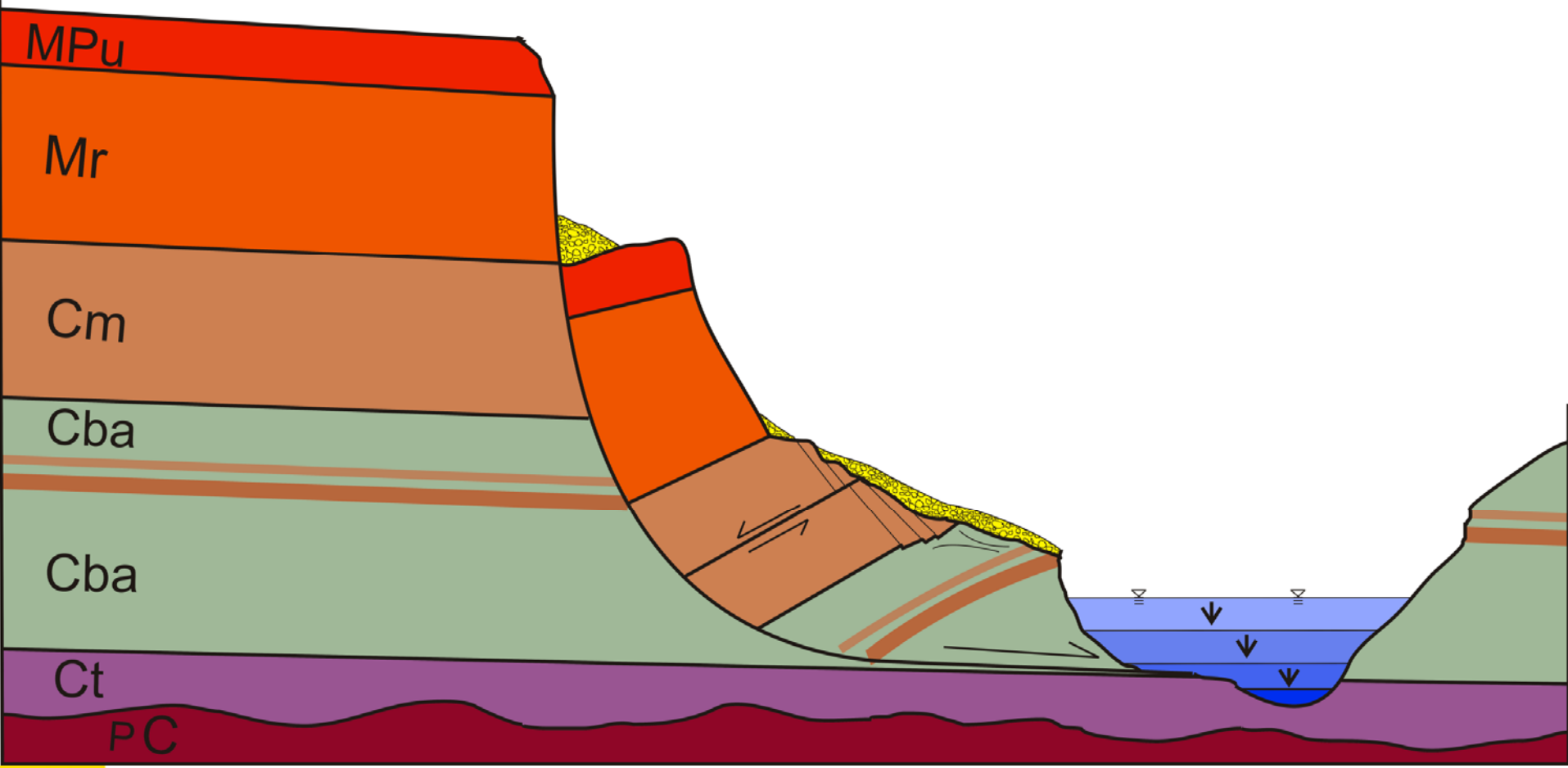
The first landslide dam is eventually breached, near its lowest point



- The landslide dam is rapidly excavated by the outpouring waters, allowing an outbreak flood to rush downstream

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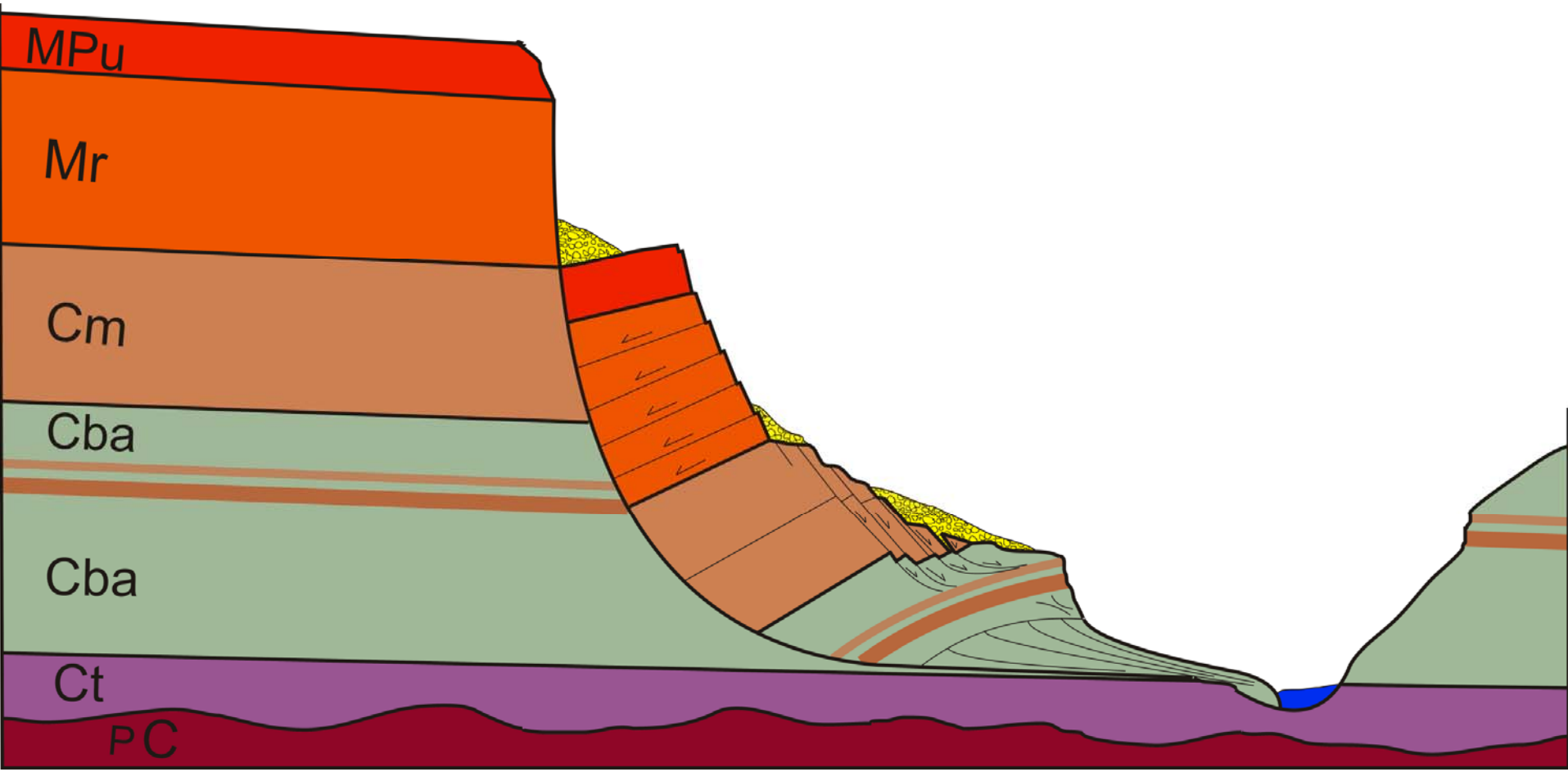
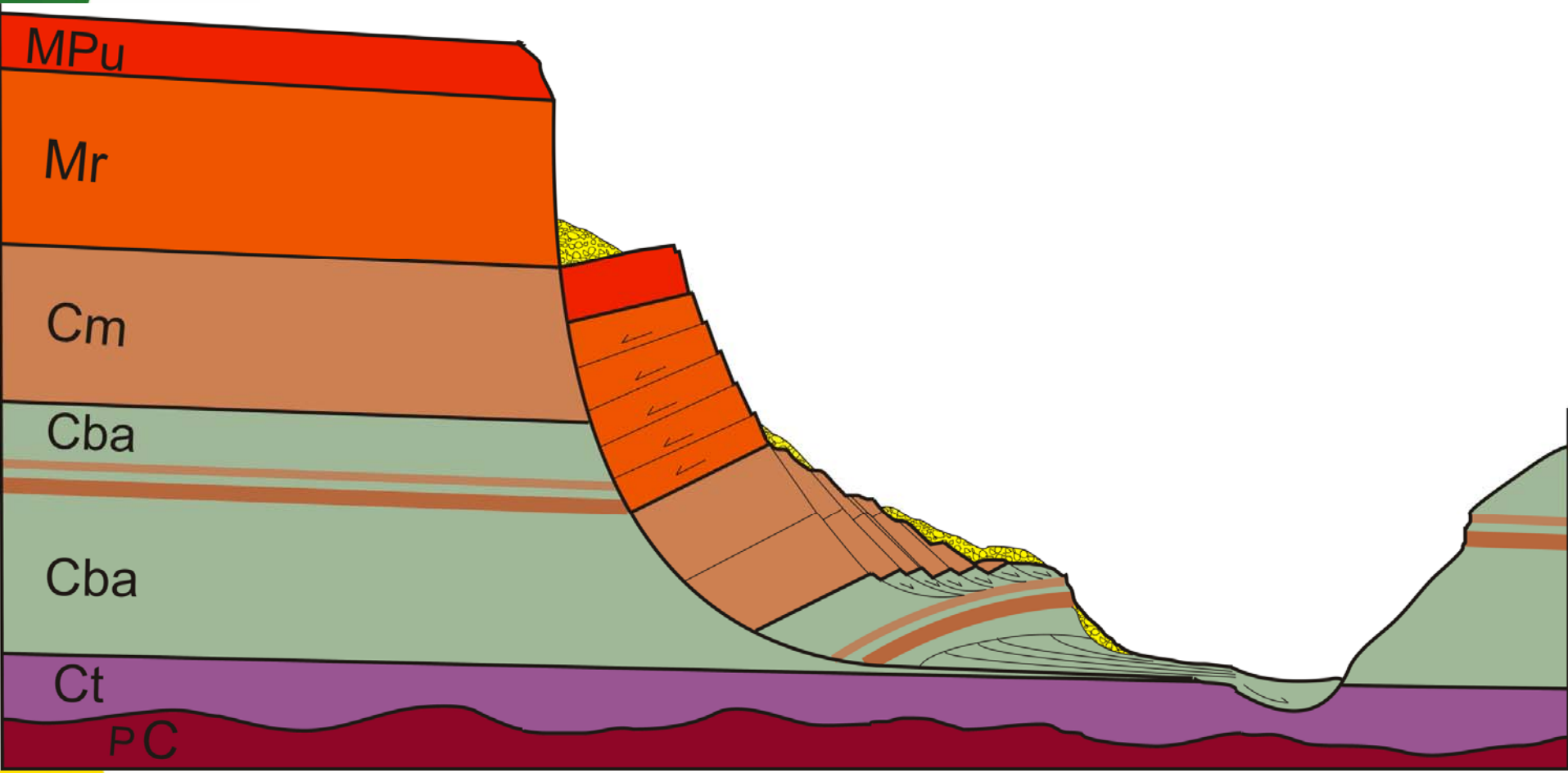


- **Rapid drawdown conditions produce pore pressure imbalance, reducing effective stresses and promoting secondary failures.**



Plastic deformation of the wetted Bright Angel Shale continues until excess pore pressures are dissipated

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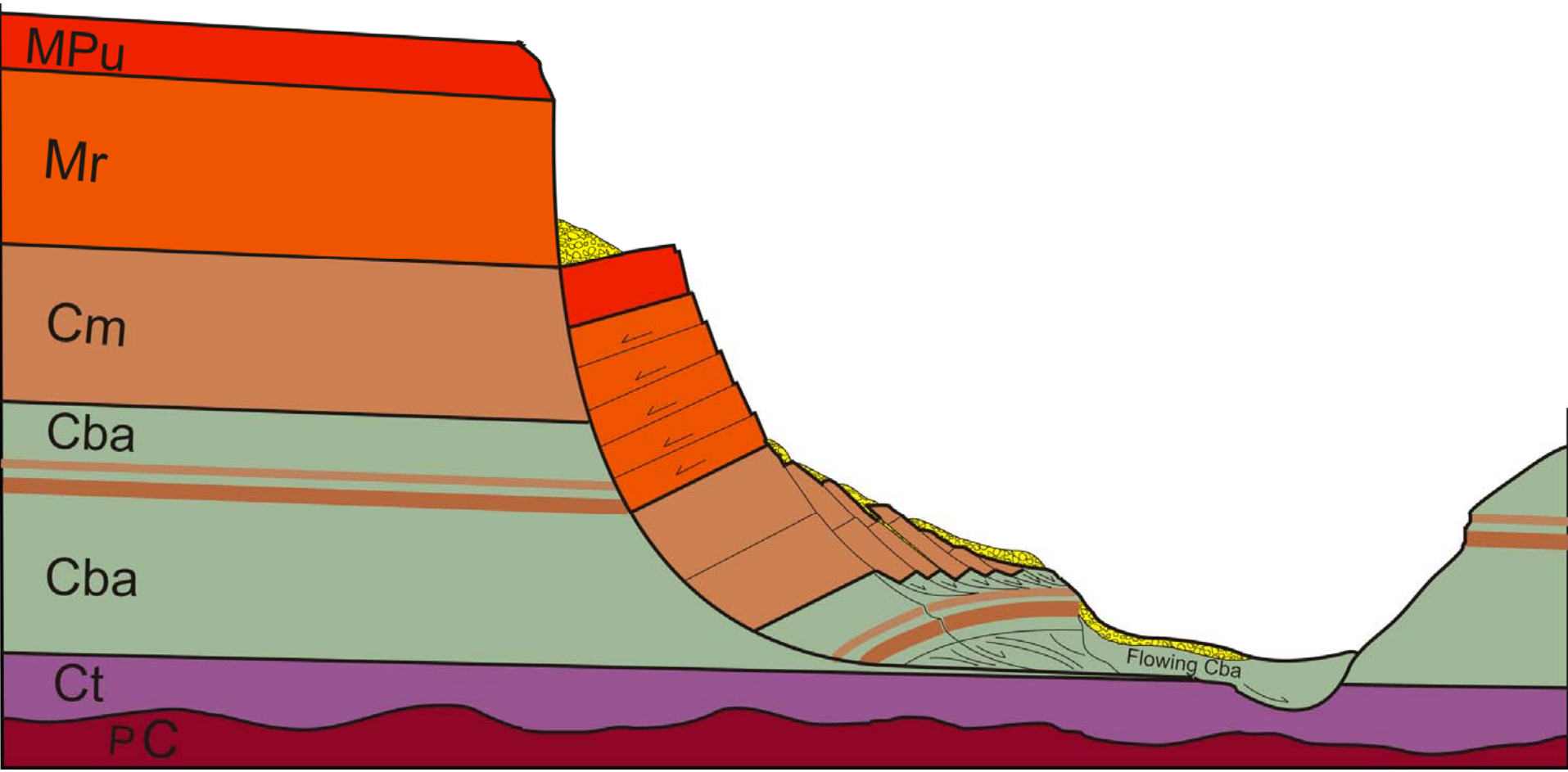
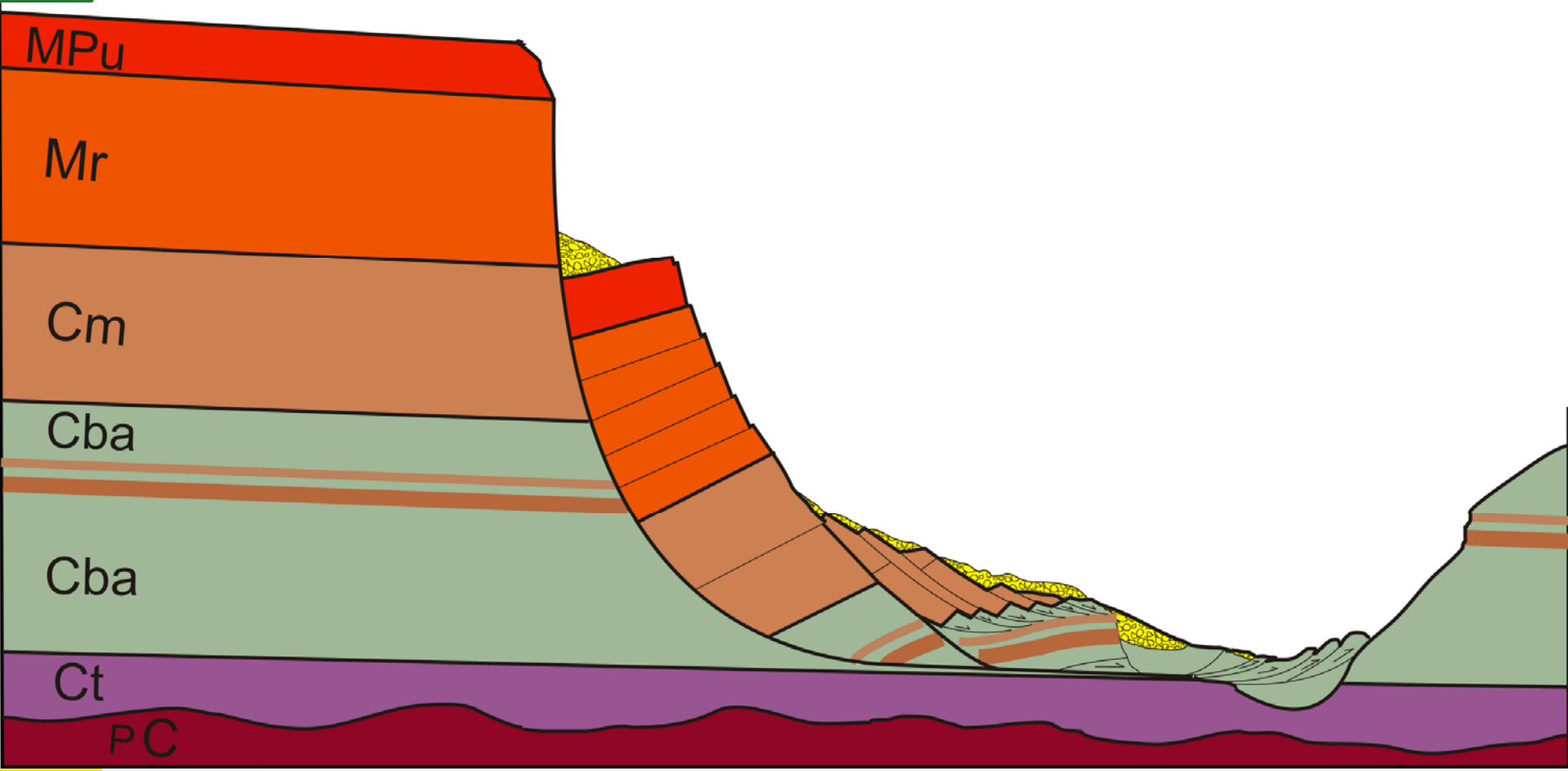


The softened shale continues to flow into the channel as the river removes the obstruction, causing successively smaller blockages



More secondary failures create slightly larger or smaller obstructions

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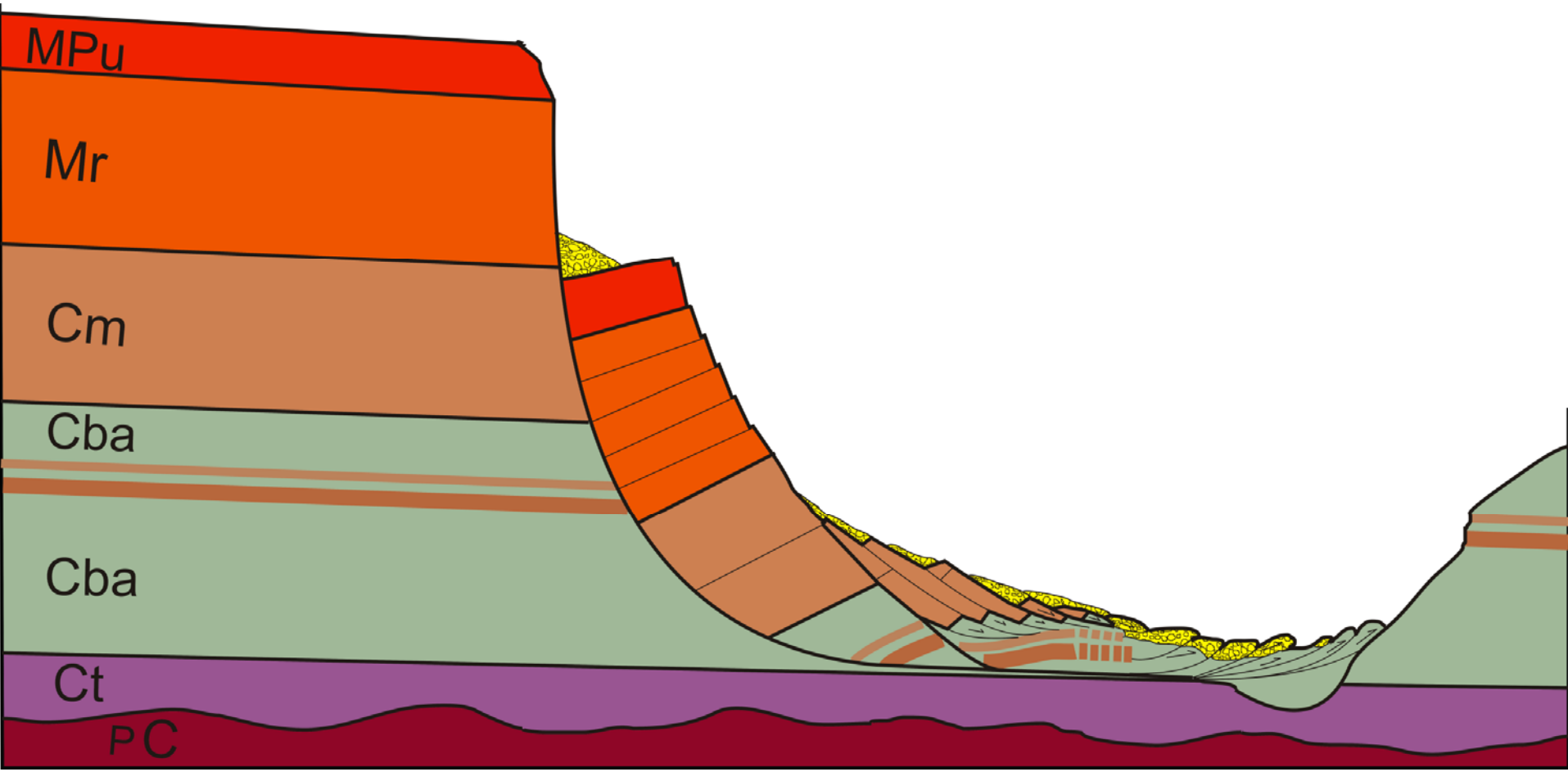
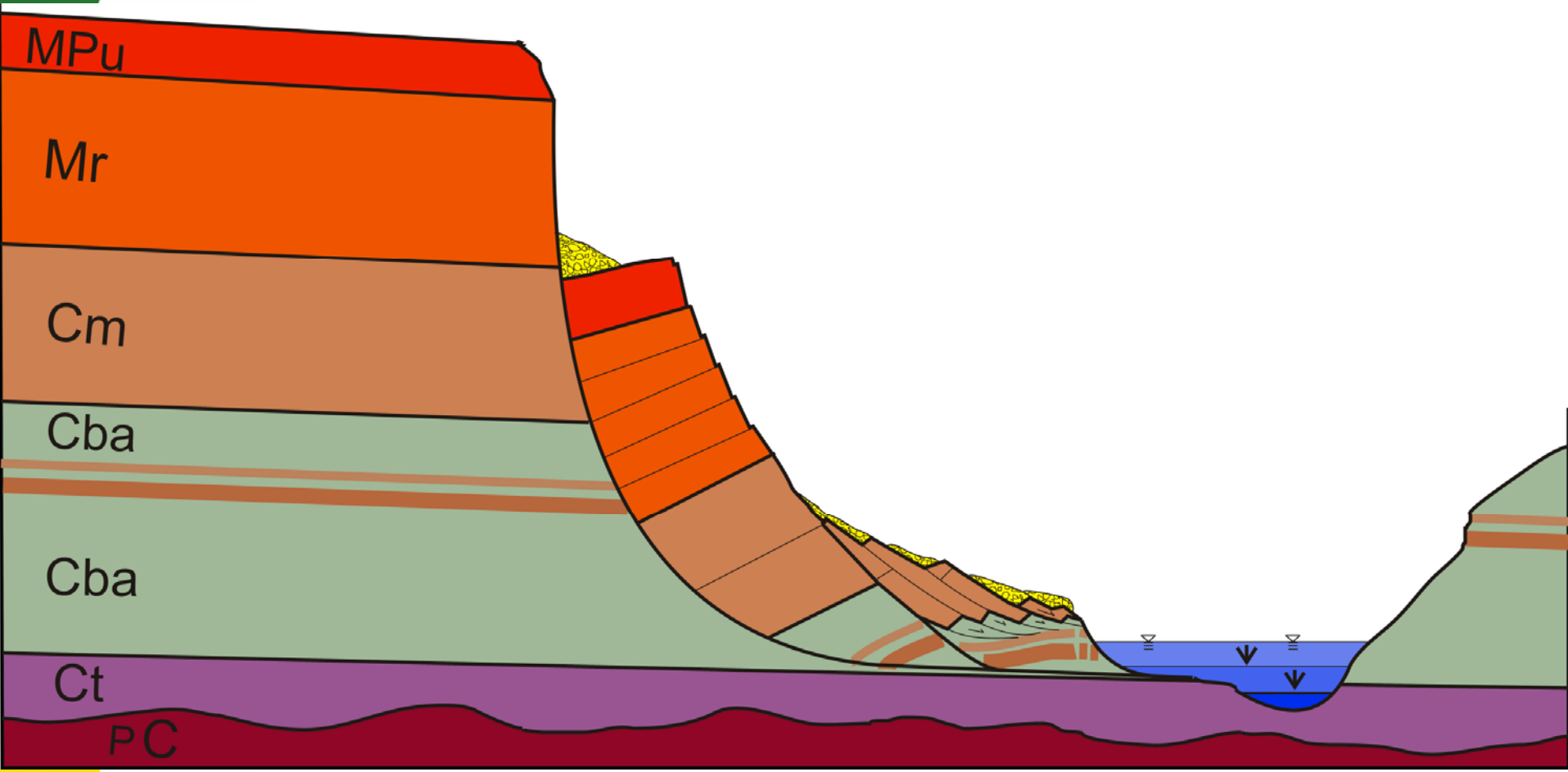


Predicted equilibrium position after rapid the drawdown sequence. A new landslide dam is formed, though much lower than the first.



A new sequence of overtopping rapidly excavates the toe of the slide

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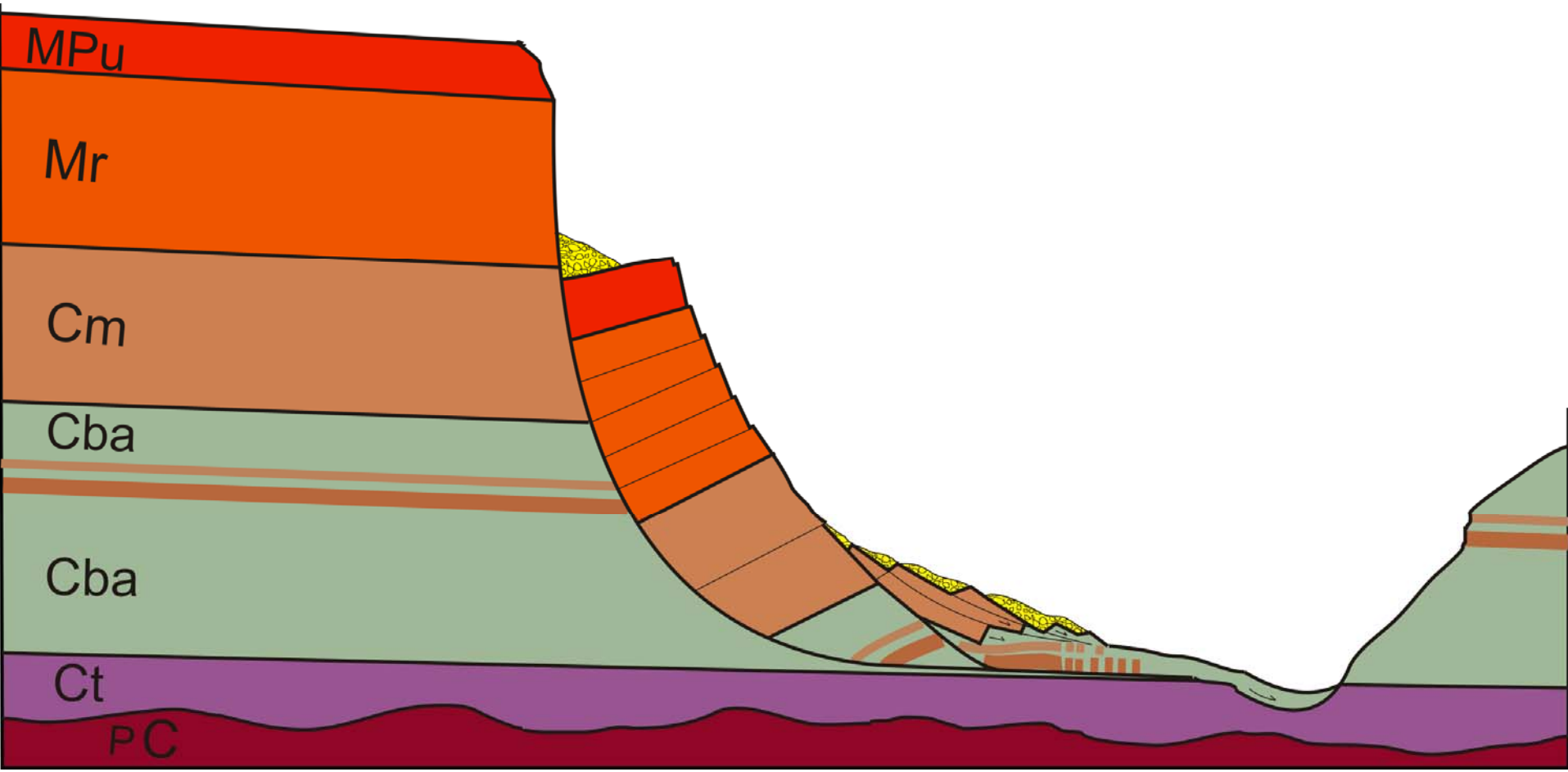
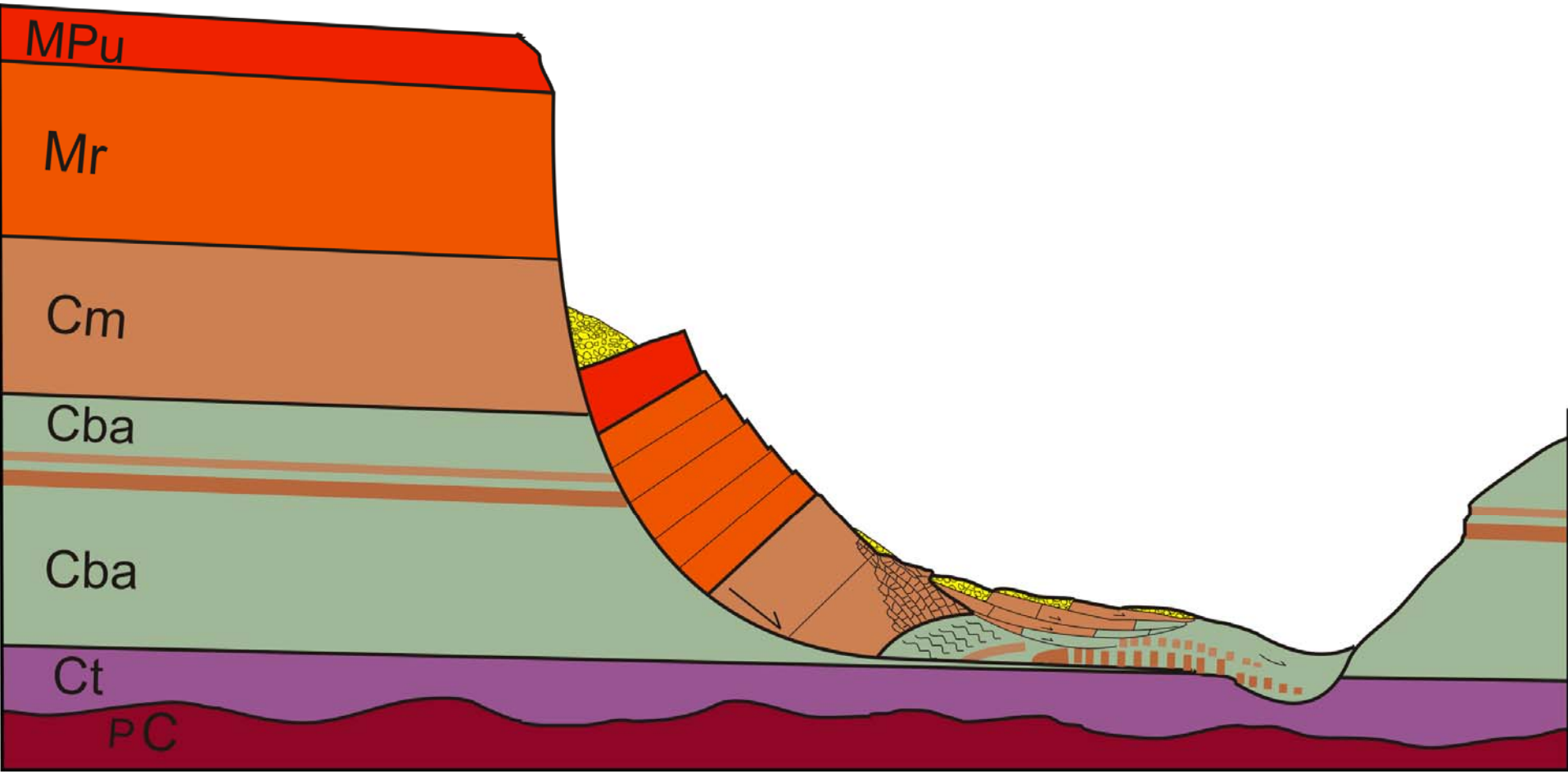
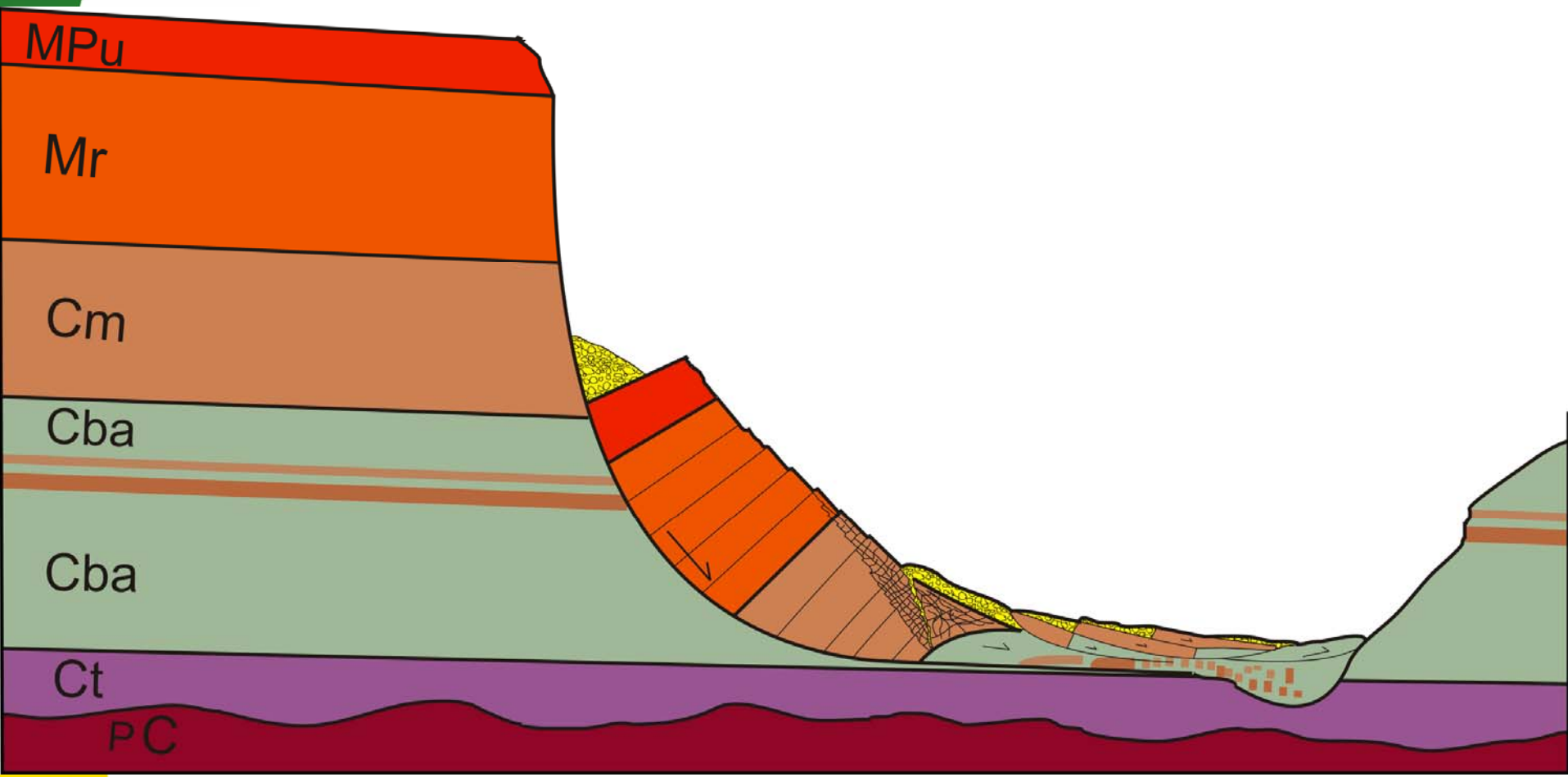


This triggers a new sequence of rapid drawdown-induced movements



Another blockage is created. It is dominated by plastic deformation of the shale



As the toe is overtopped, rapid excavation triggers additional movement

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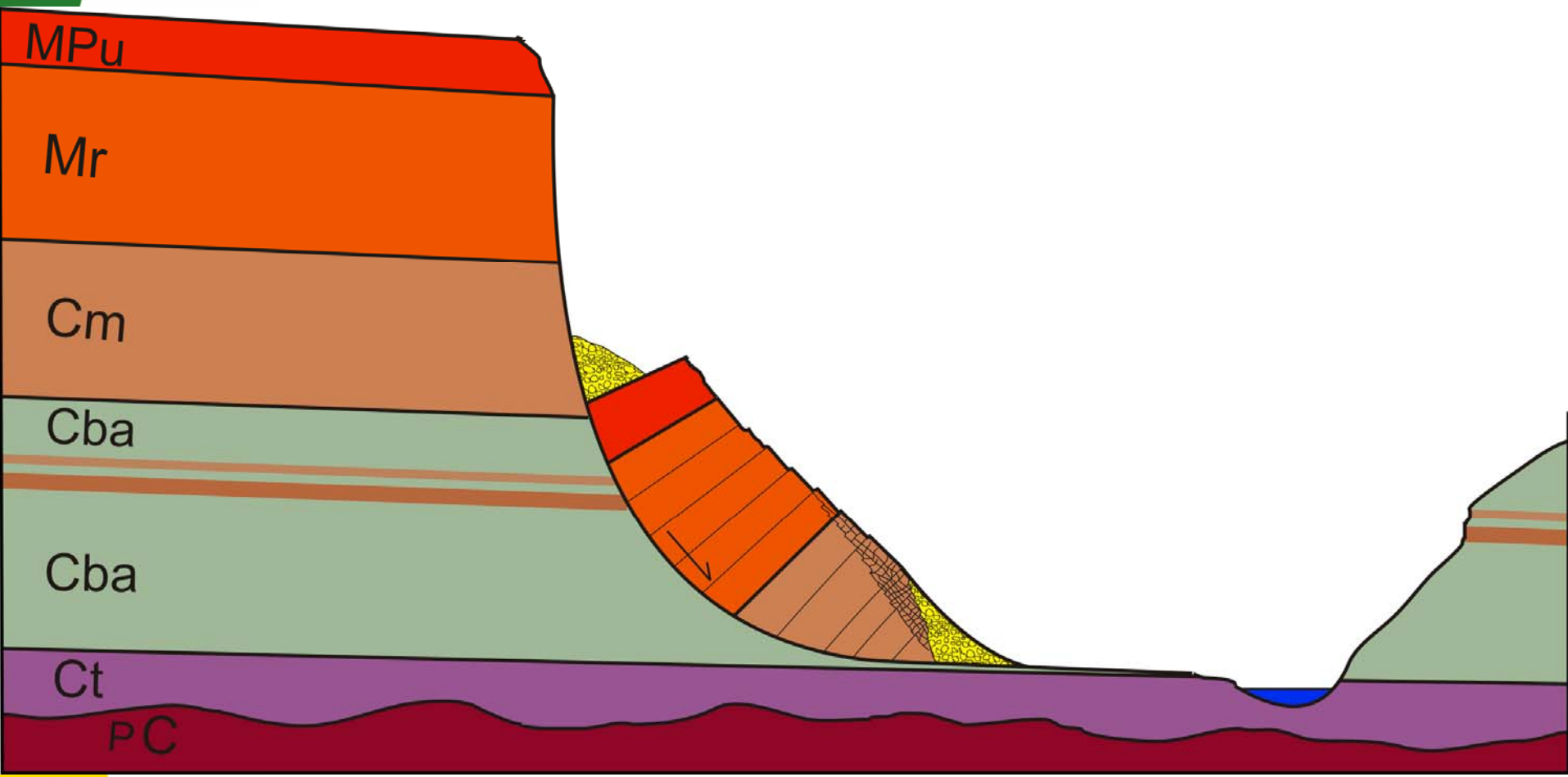

Another outbreak flood excavates the toe of the slump, removing the shale

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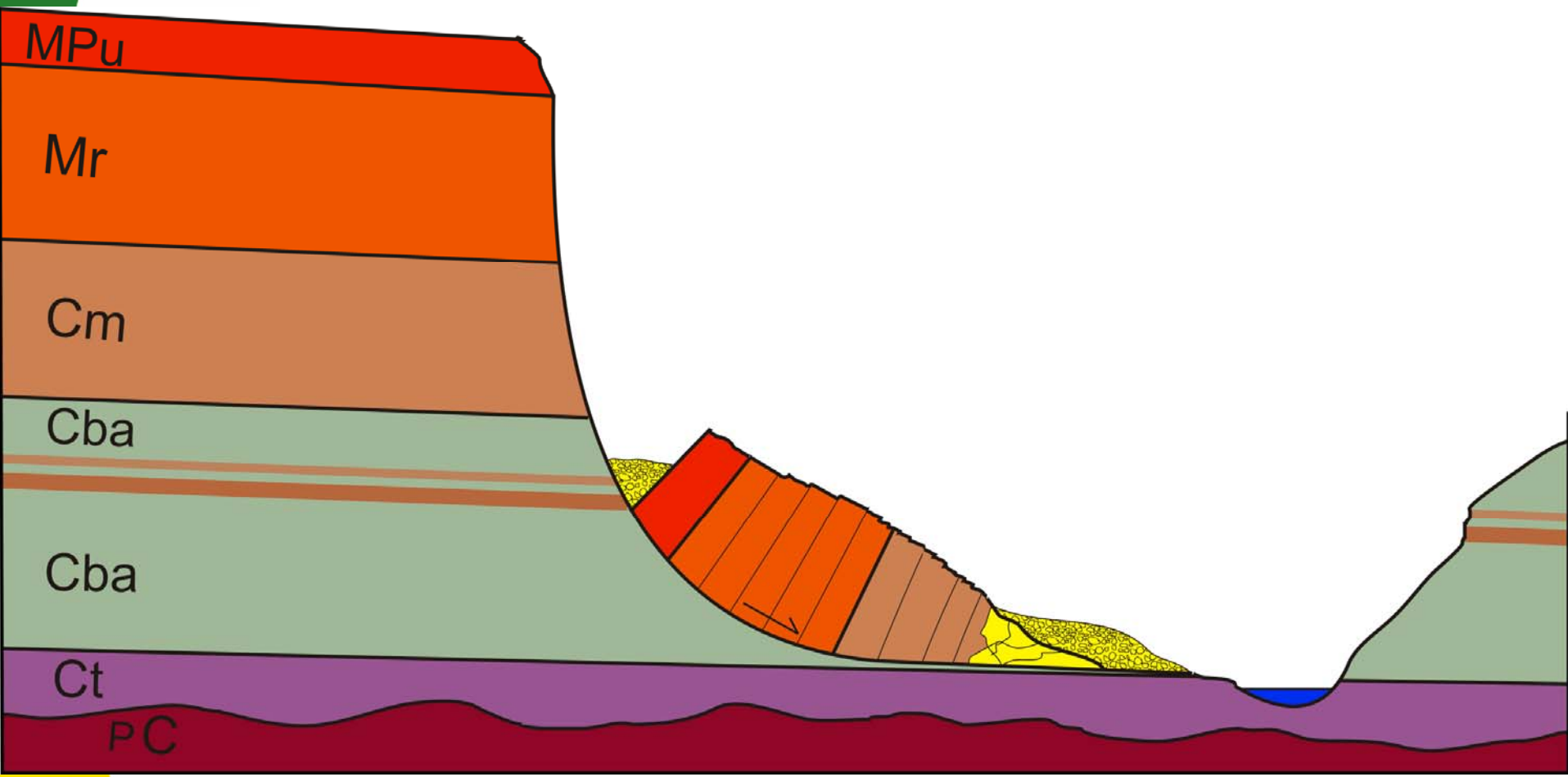

Talus cones create a semi-stable toe buttress

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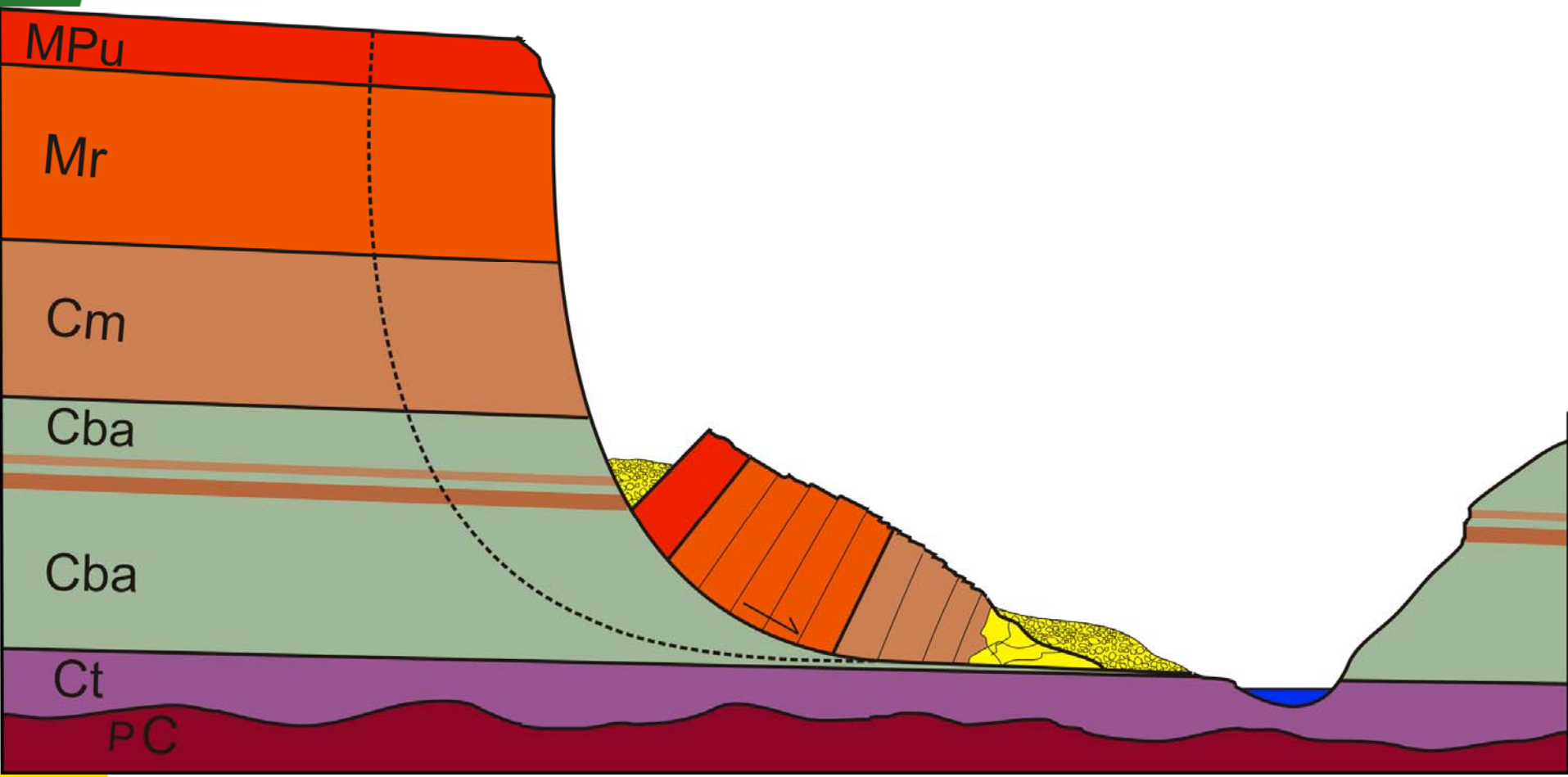

The loss of lateral restraint triggers another sequence of sliding

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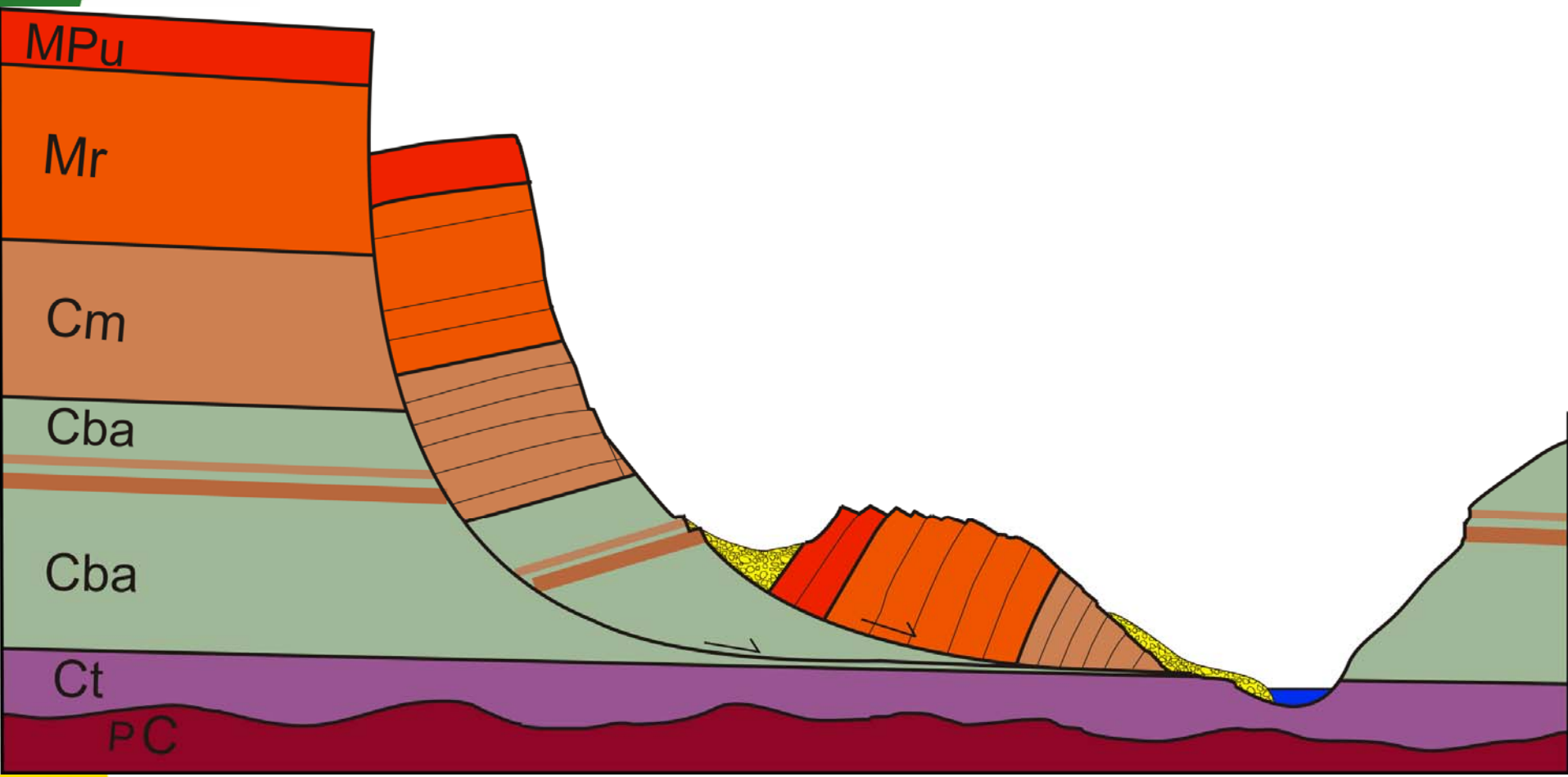

The second Toreva Block starts dropping

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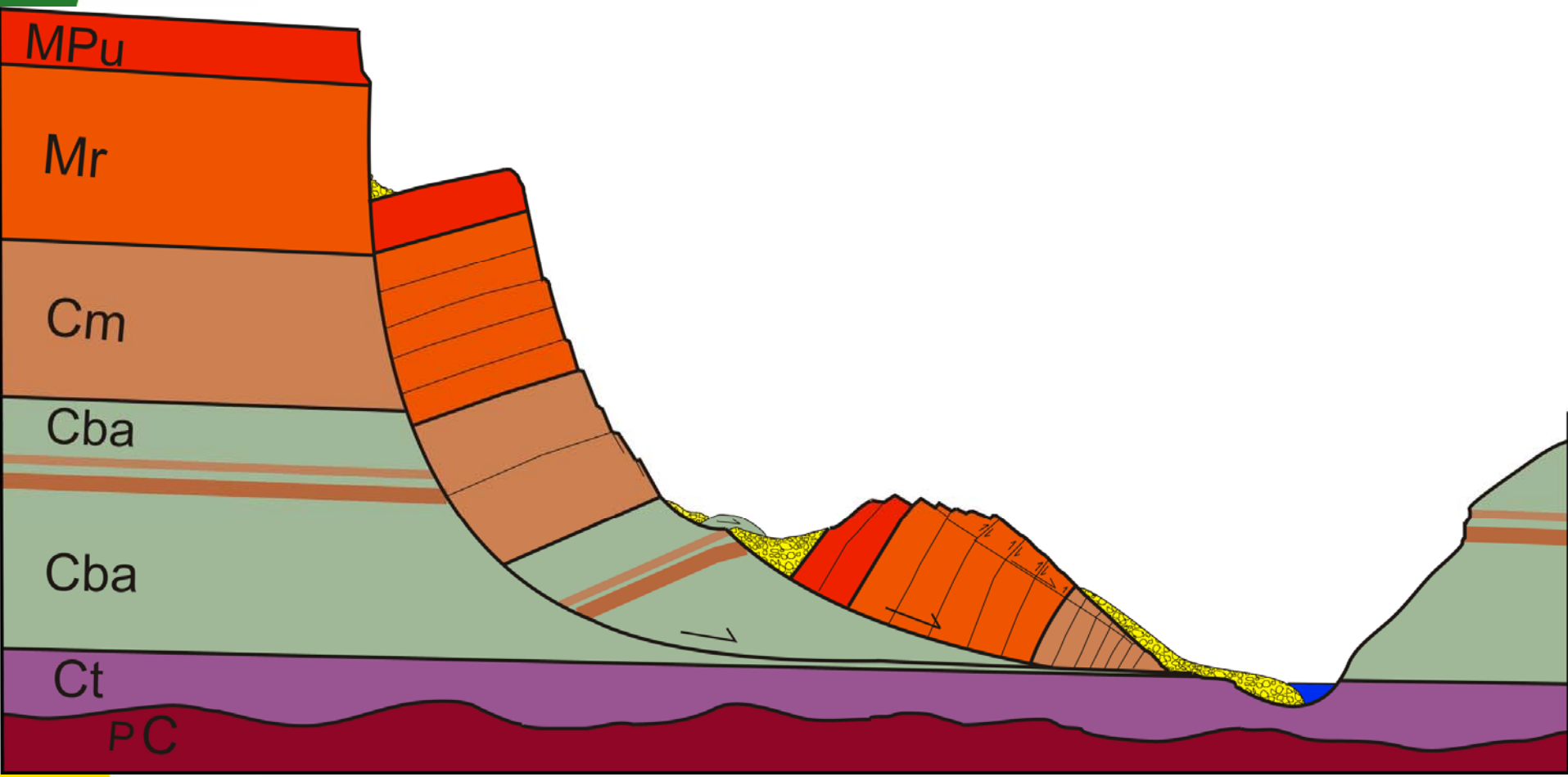

The second block lifts the previous block, steepening its profile

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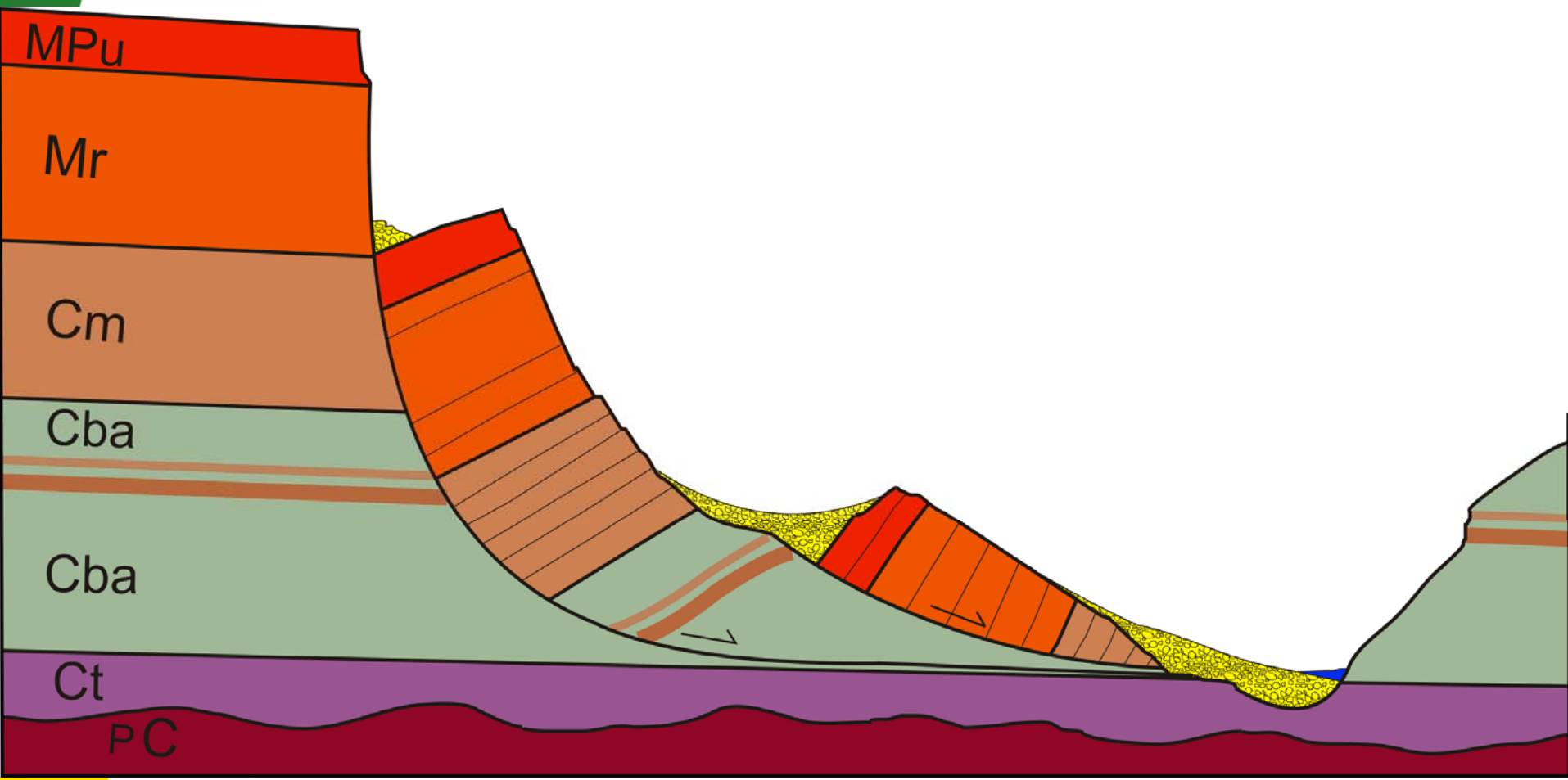

Quasi-equilibrium reached, with talus fan blocking channel

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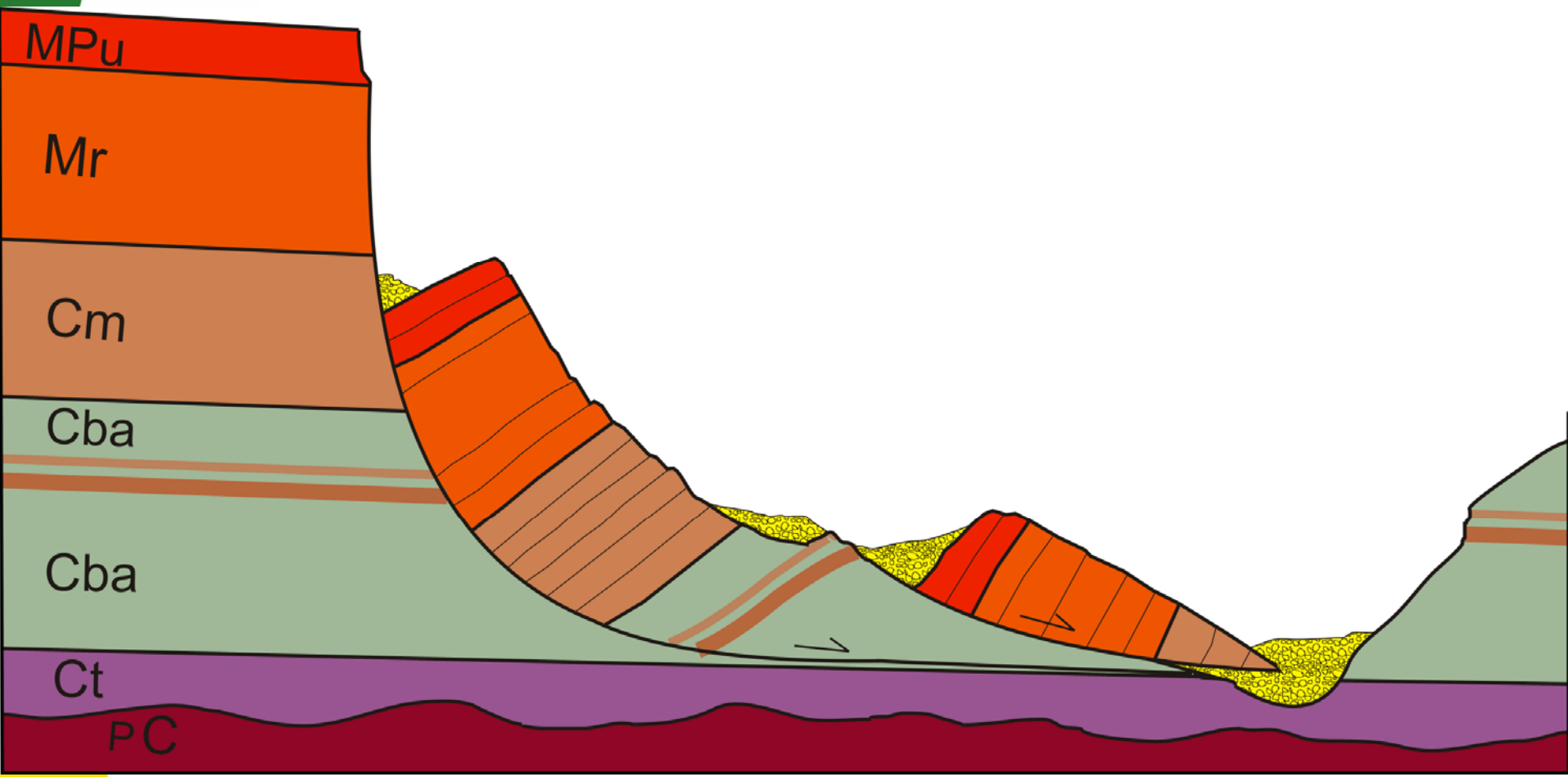

As channel is excavated, the first block moves into channel, creating another blockage

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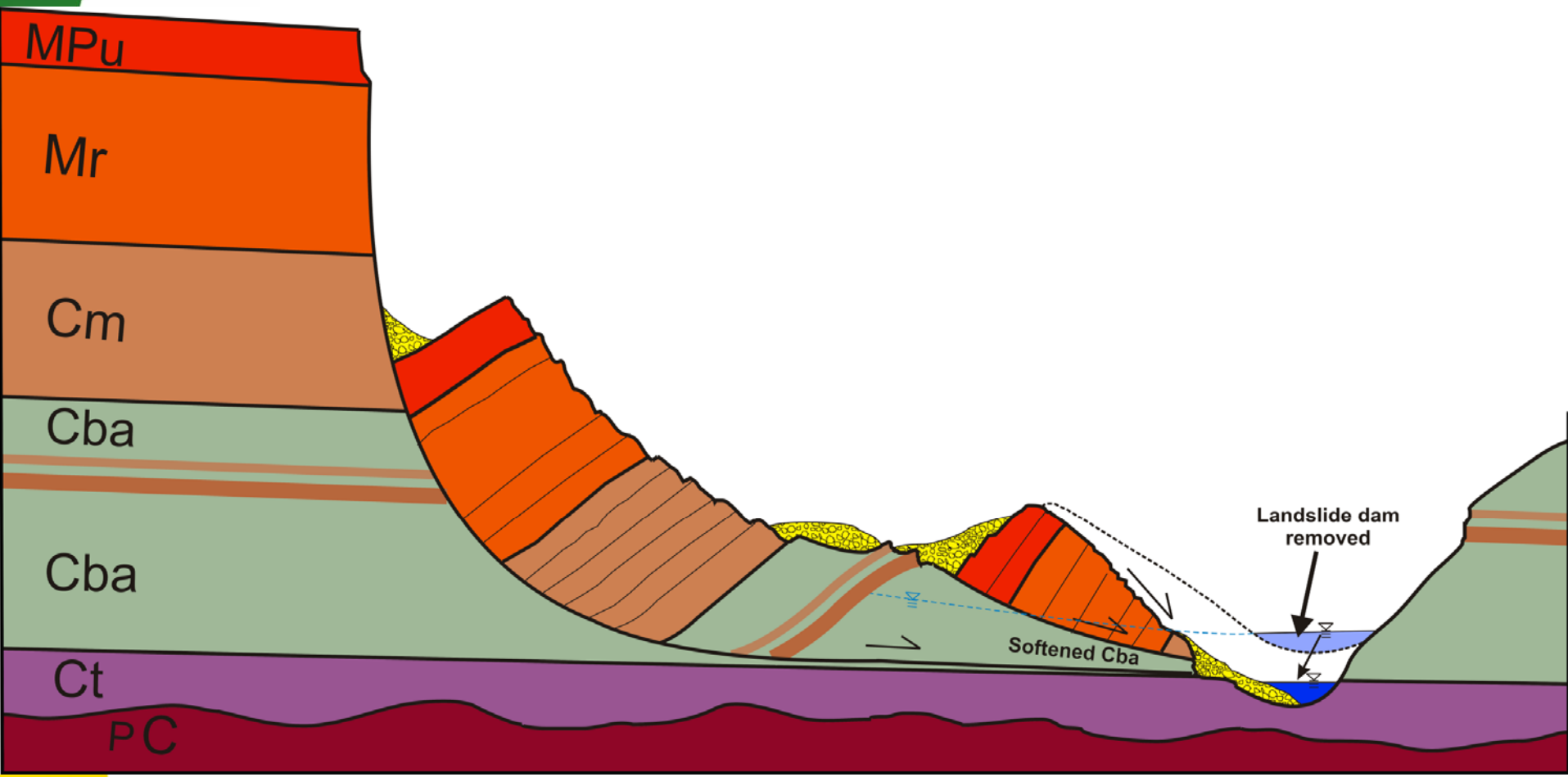

Several blockages are removed. Note softened.

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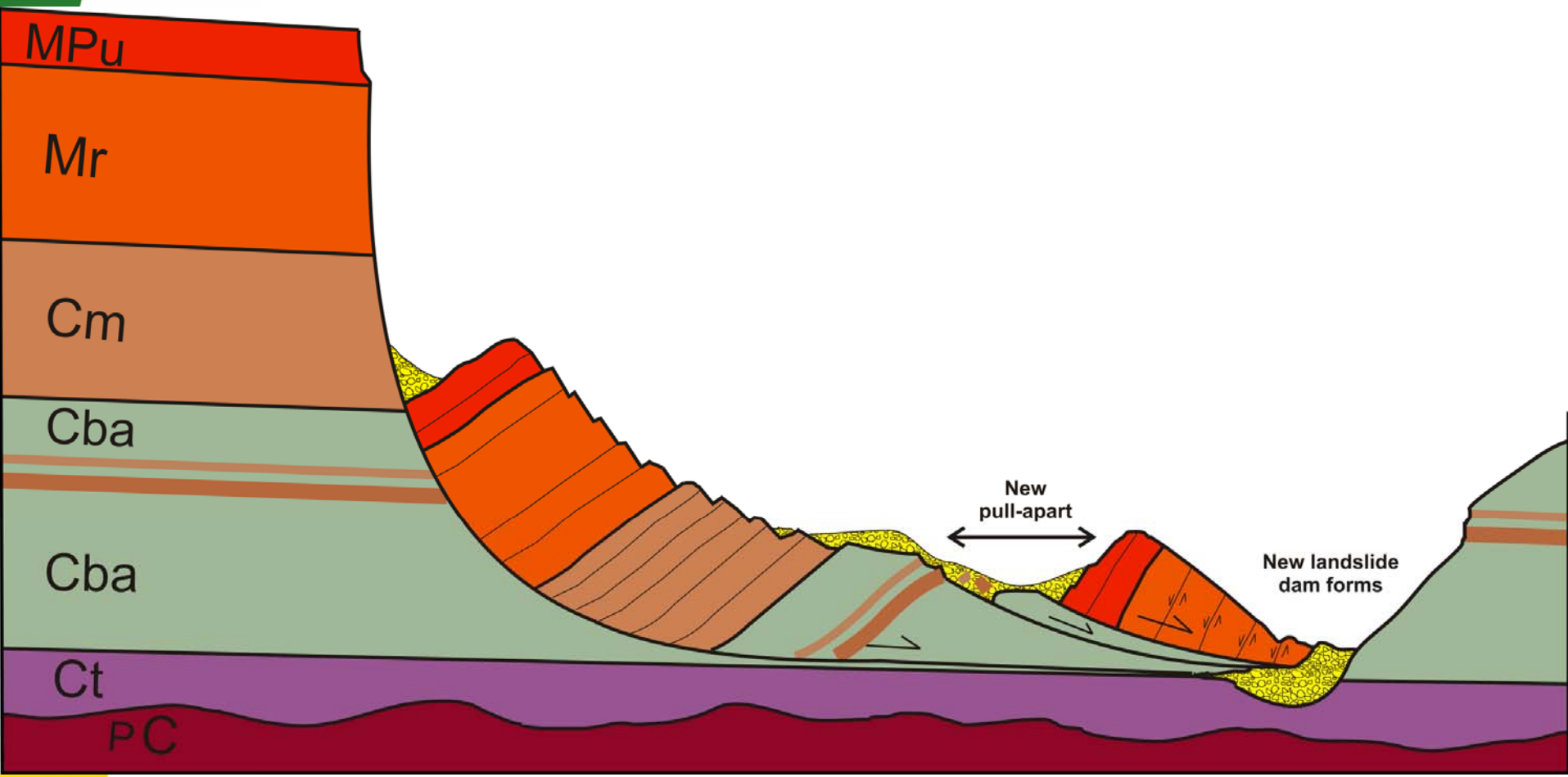

The loss of toe support triggers more movement of the first block, and a pull-apart forms.

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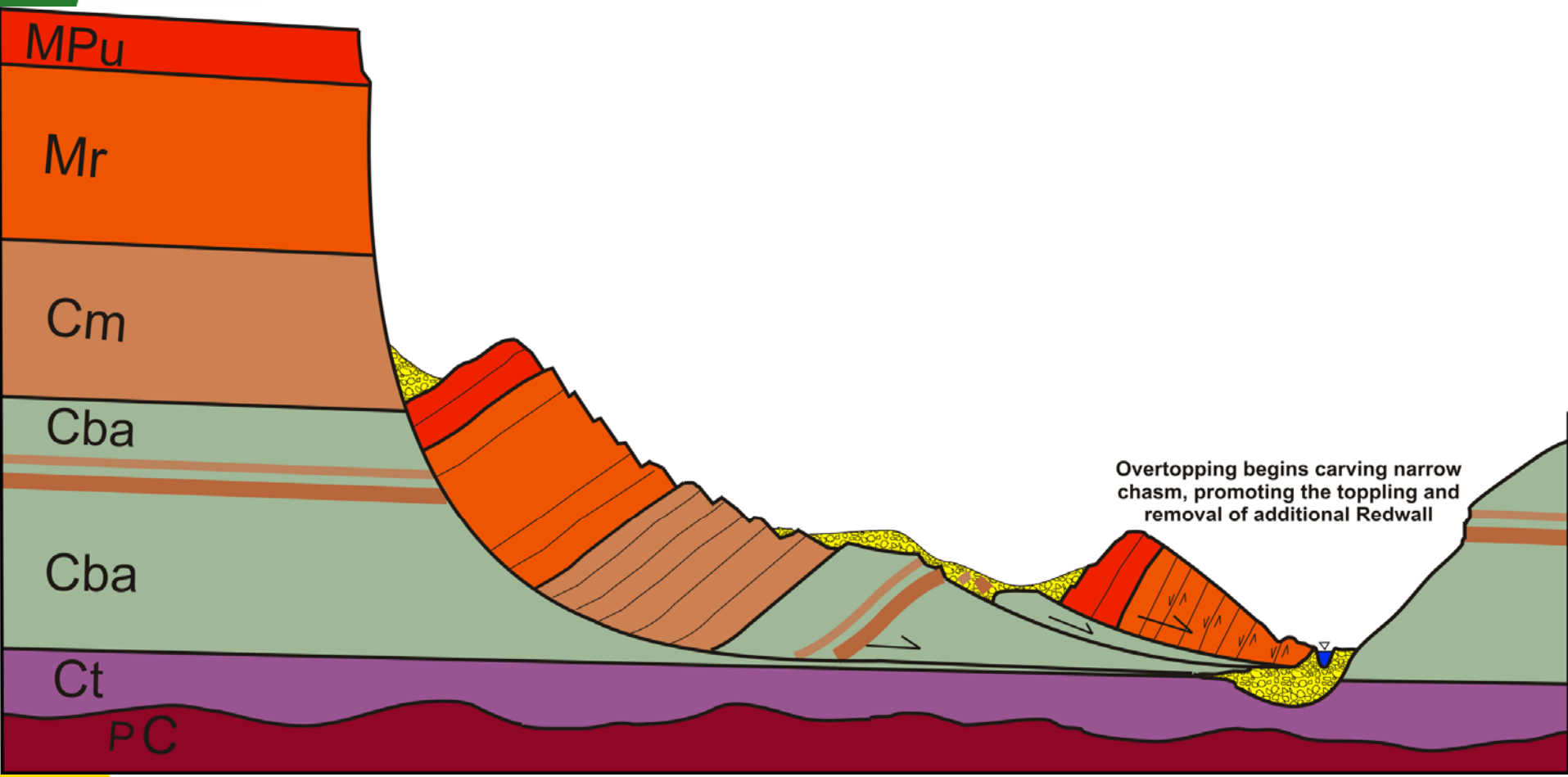
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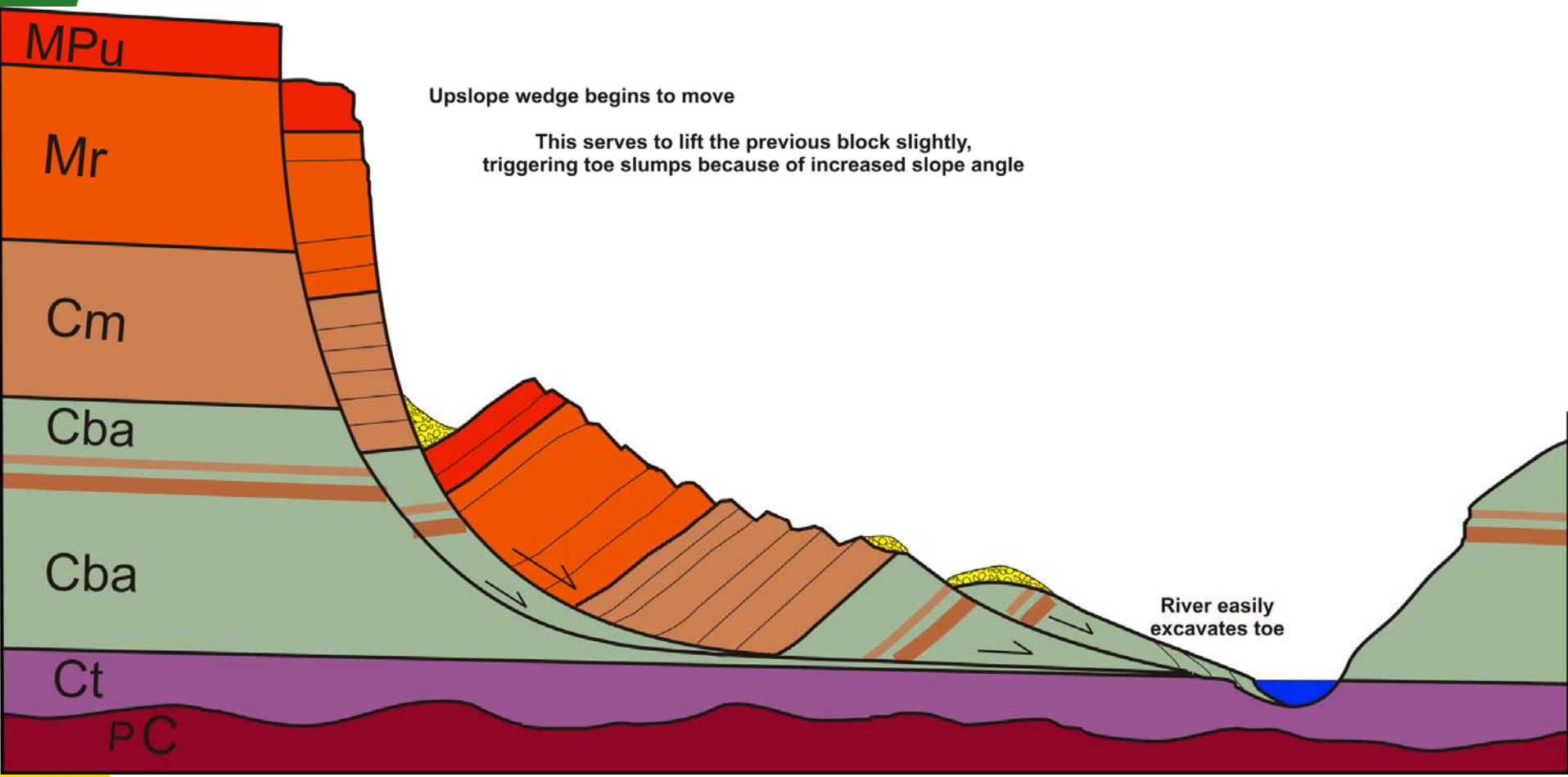
Overtopping begins carving narrow chasm, promoting the toppling and removal of additional Redwall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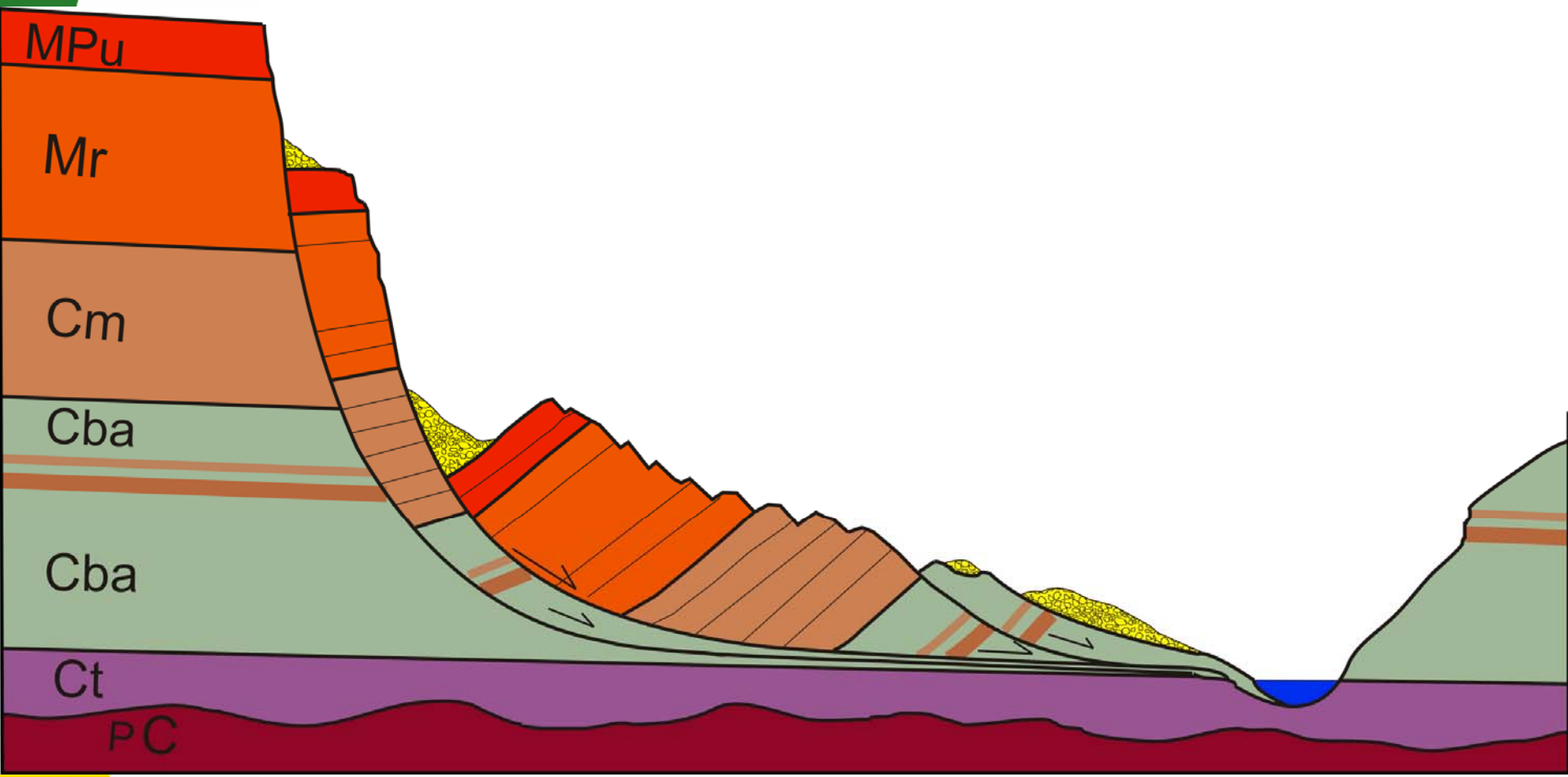
Upslope wedge begins to move
This serves to lift the previous block slightly,
triggering toe slumps because of increased slope angle
River easily
excavates toe



Re-excavation of the channel triggers another retrogressive slump

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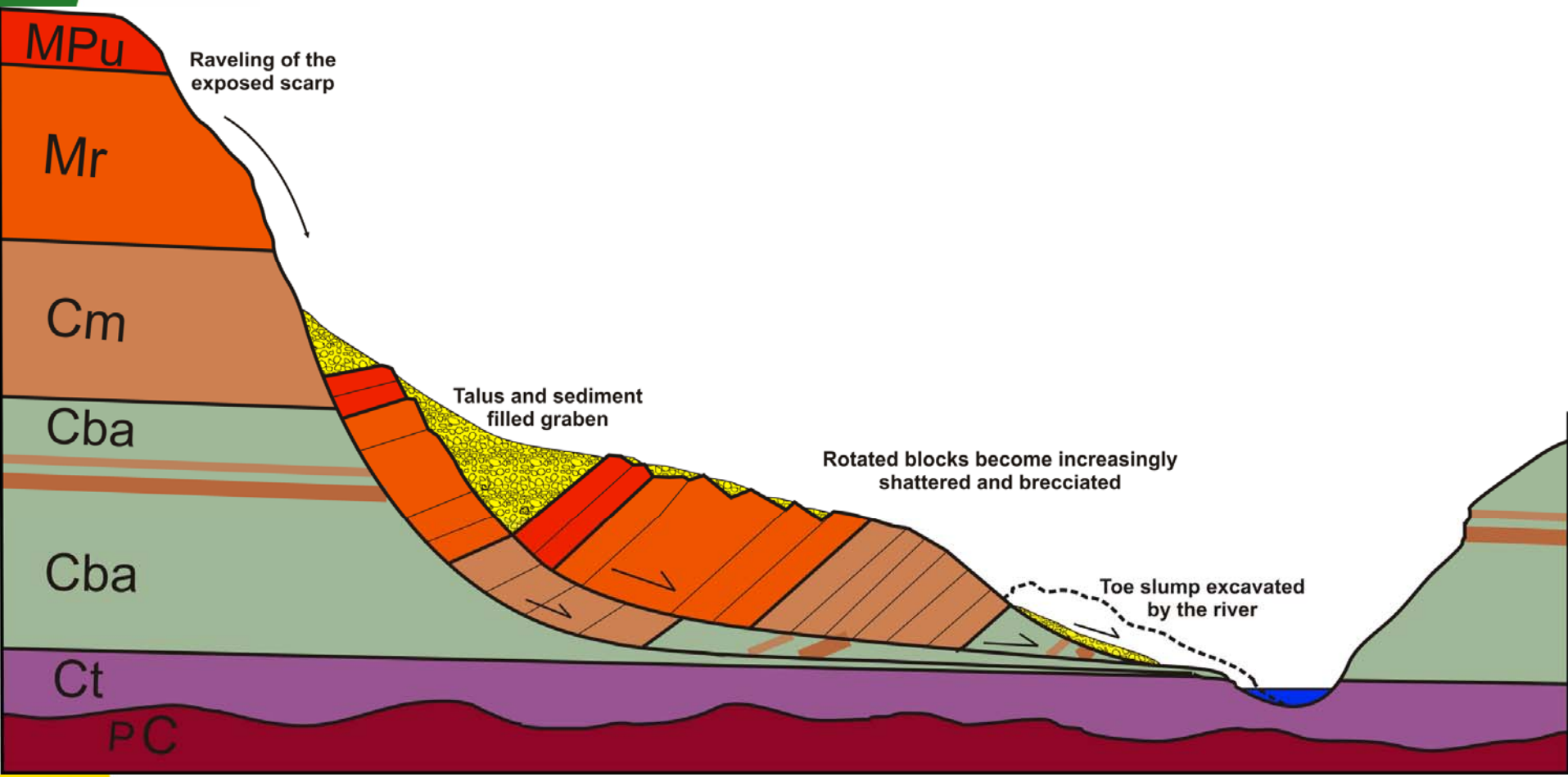
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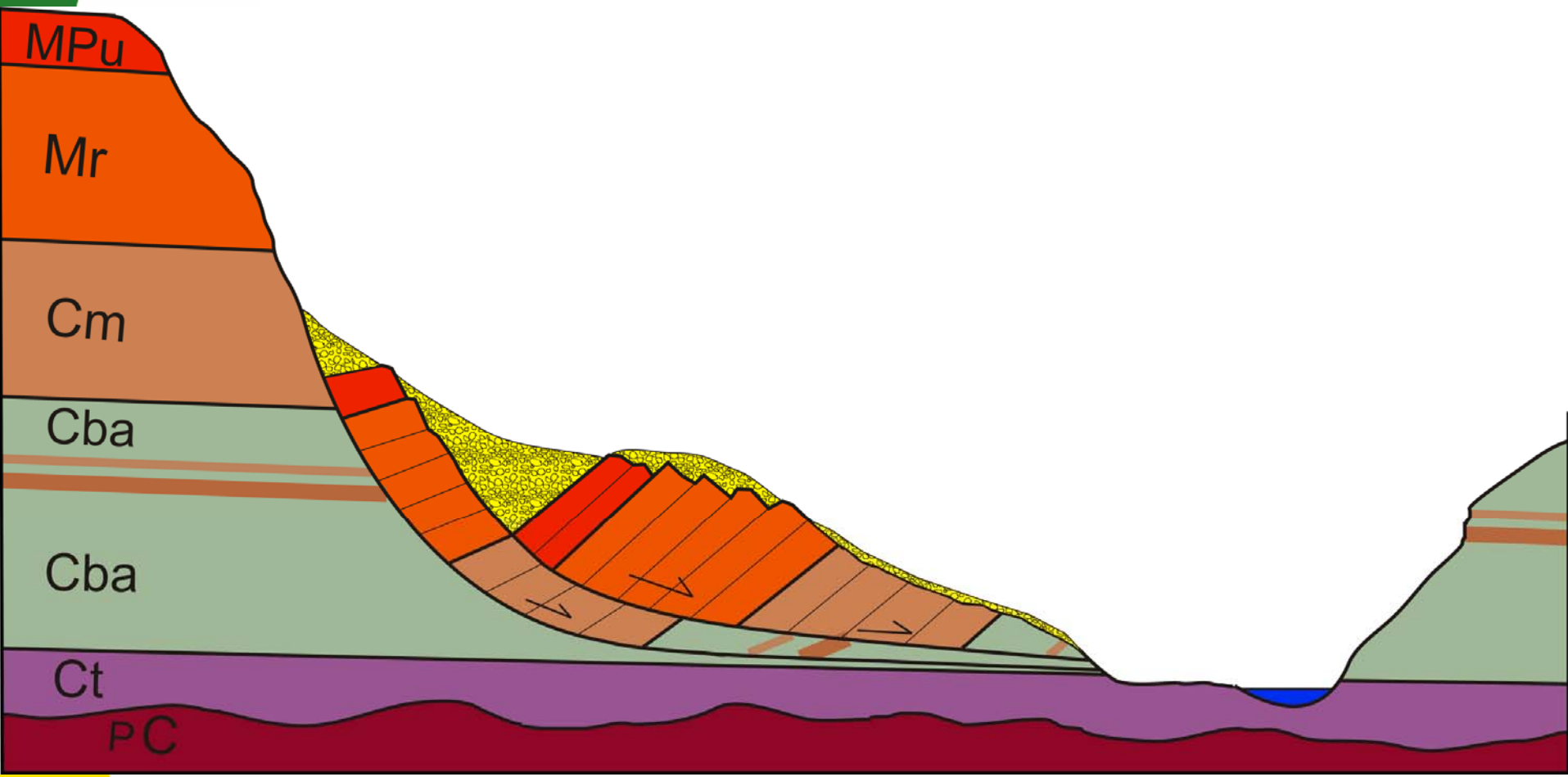
Raveling of the exposed scarp
Talus and sediment filled graben
Rotated blocks become increasingly shattered and brecciated
Toe slump excavated by the river

Present Day Profile of Fishtail Landslide



Regression of Deer Creek Landslide

- The landslide complex just west of Deer Creek also appears to have undergone multiple episodes of regression.
- The modern landslide is only the latest in a series of enormous landslides at this location.
- An ancient canyon profile has been recreated using the canyon profile downstream of Fishtail Canyon, where the Bright Angel Shale hasn't been incised nearly as deep.

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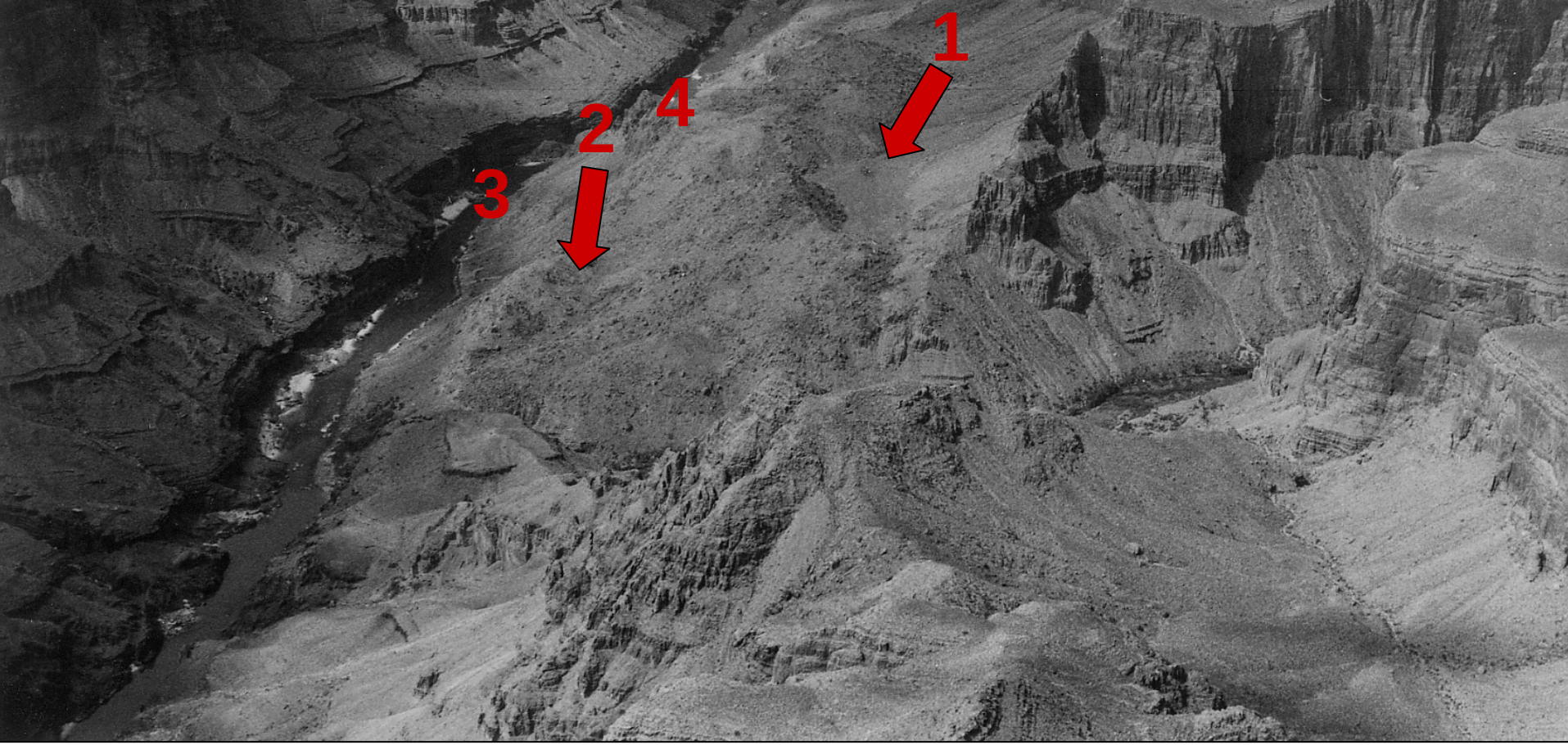
Modern Day Idealized Cross Section At Deer Creek Landslide

The Deer Creek Landslide as viewed from overhead at its eastern end. It extends along the north bank of the Colorado River for 3.7 km. Enclosed depressions are indicated by arrows. (Photo by Alan Herring)



Aerial oblique view of the Deer Creek Landslide Complex showing: 1) headscarp graben; 2) secondary headscarp grabens, and 3) the Colorado River channel, which has been deflected southward. The headscarp graben (1) is about 800 m x 325 m. A buried channel of the Colorado River is exposed above the river's right bank (4). A 52 m thick sequence of lacustrine sediments are located along the river's left bank, in Owl Eyes Canyon, about 3 km upstream. Outwash terraces of cobbles and boulders downstream of this slide were probably deposited by catastrophic breakout floods when the landslide dams overtopped.

Main headscarp graben of the Deer Creek Landslide Complex

This feature is over 800 m long, 320 m wide, and is likely around 100 m deep beneath the sediments (based on our models).

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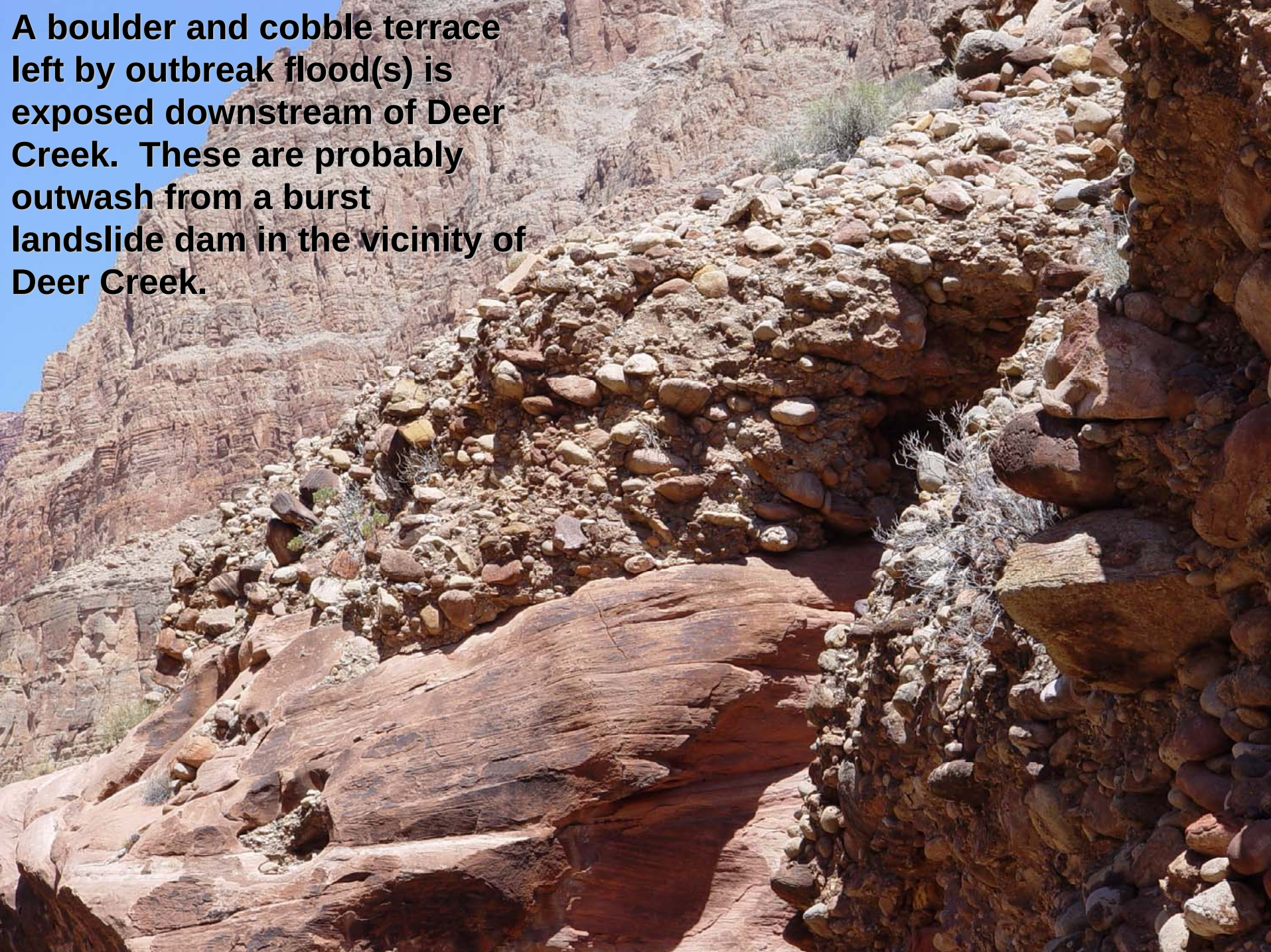
A 52 m thick sequence of fine-grained lake sediments is present at Owl Eyes Canyon on river left just upstream of the Granite Narrows. These sediments are thought to have been deposited behind an old landslide dam, probably at Deer Creek, that has since burst.


A boulder and cobble terrace left by outbreak flood(s) is exposed downstream of Deer Creek. These are probably outwash from a burst landslide dam in the vicinity of Deer Creek.

Poncho's Radical Runup

- This feature was originally recognized by prior researchers, but they assumed it was part of the modern day Deer Creek Slide
- John Warme and Jill Savage of the Colorado School of Mines recognized that the feature probably predates the modern Deer Creek Slides.
- A run up occurred and ran over 900 ft (275 m) up the opposing slopes, making this the largest recognized landslide run-up in the continental U.S.
- This likely dammed the Colorado River to a similar elevation.

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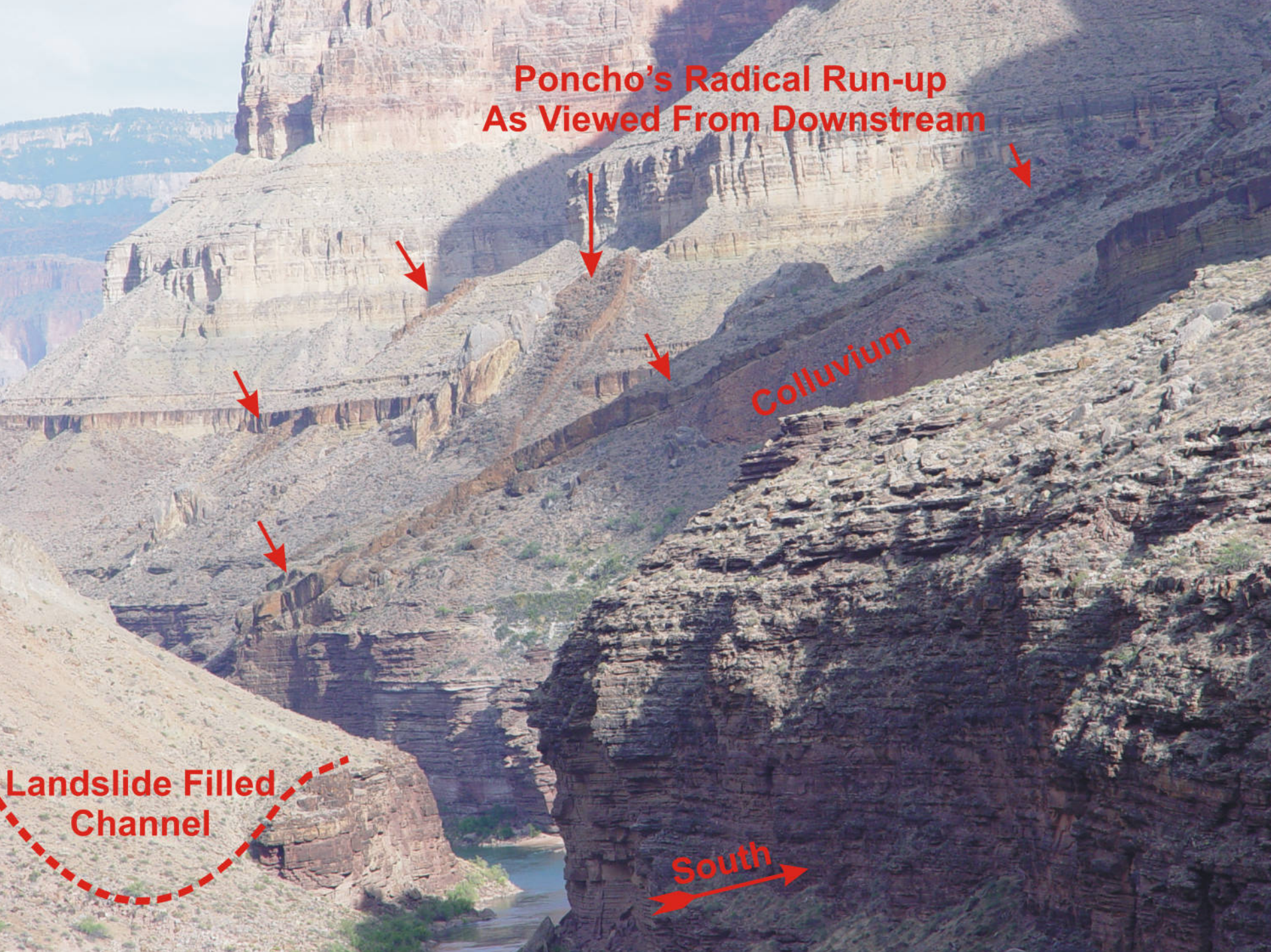
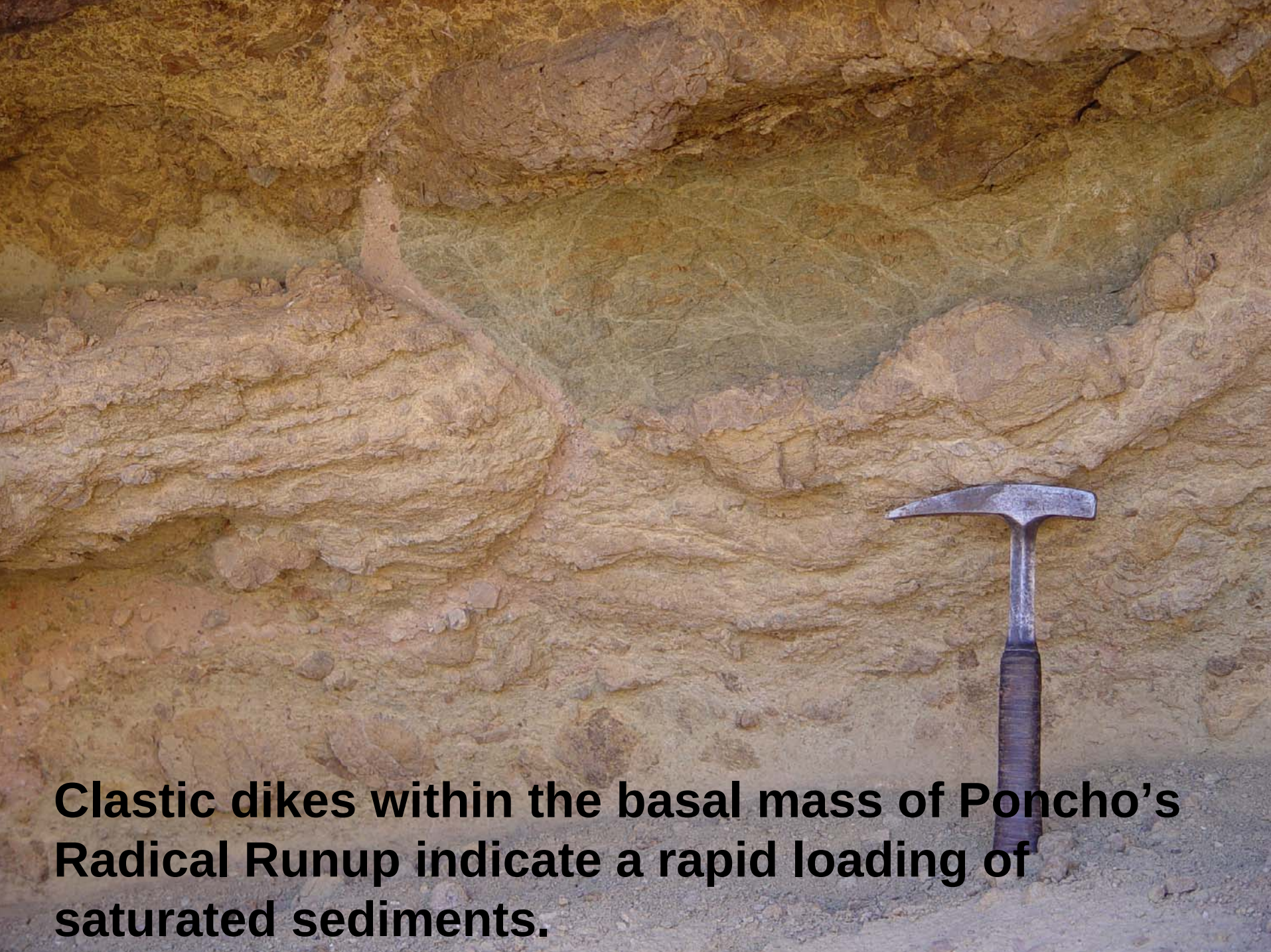
Poncho's Radical Runup - John Warme


Poncho's Radical Run-up
As Viewed From Downstream
Colluvium
Landslide Filled
Channel
South



Clastic dikes within the basal mass of Poncho's Radical Runup indicate a rapid loading of saturated sediments.

Kinematic Model of Poncho's Radical Run-up

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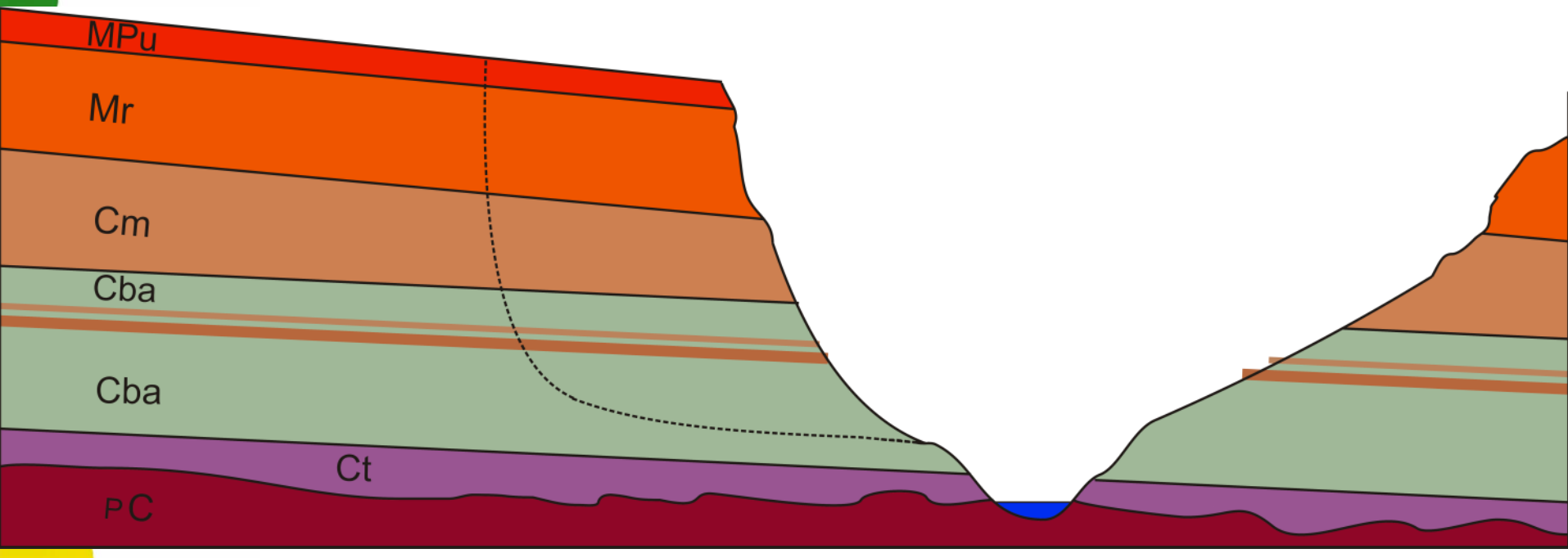
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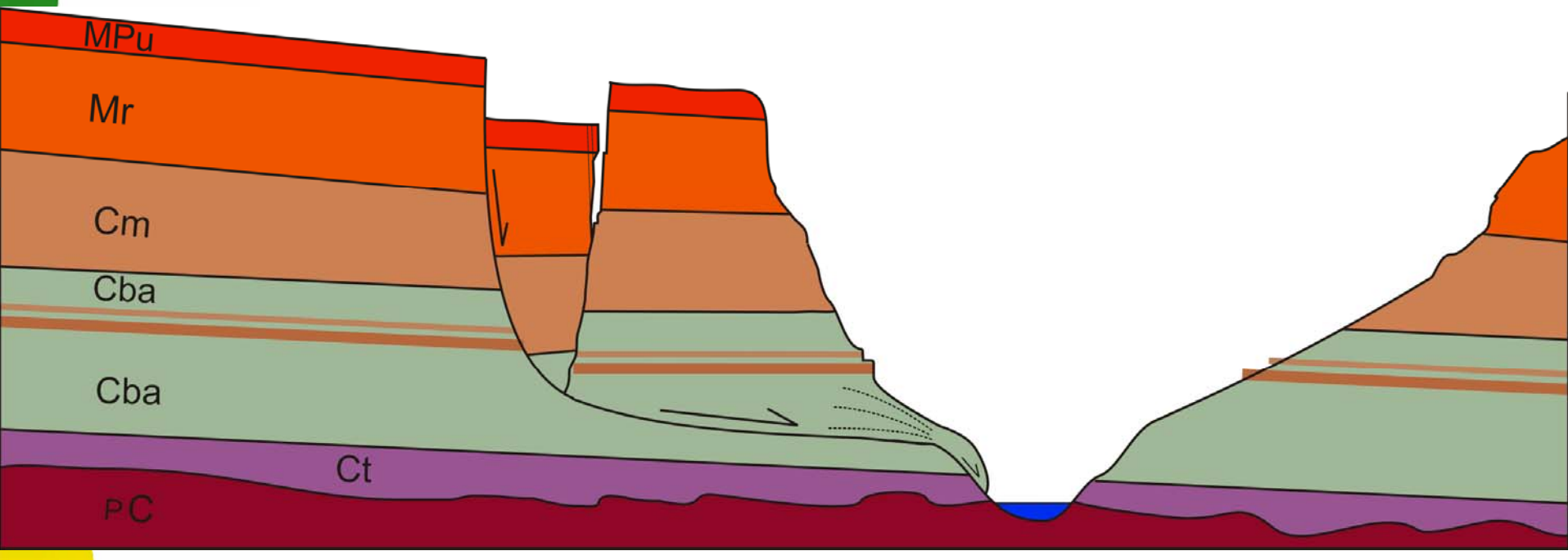
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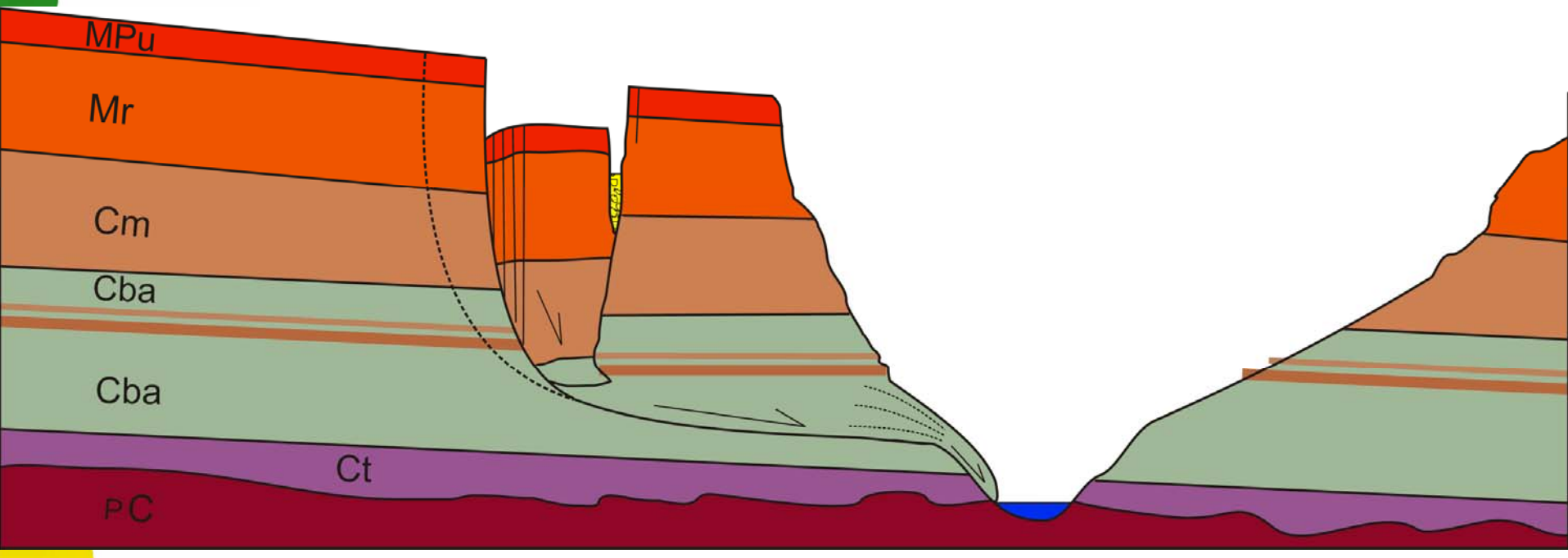
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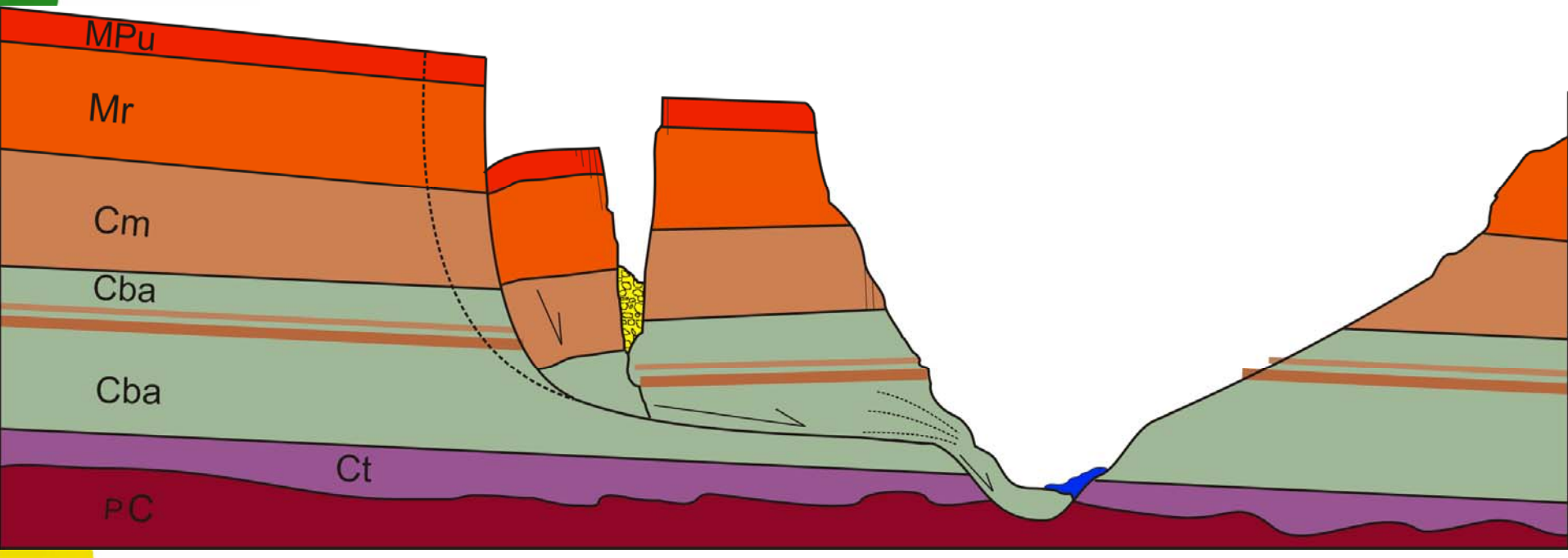
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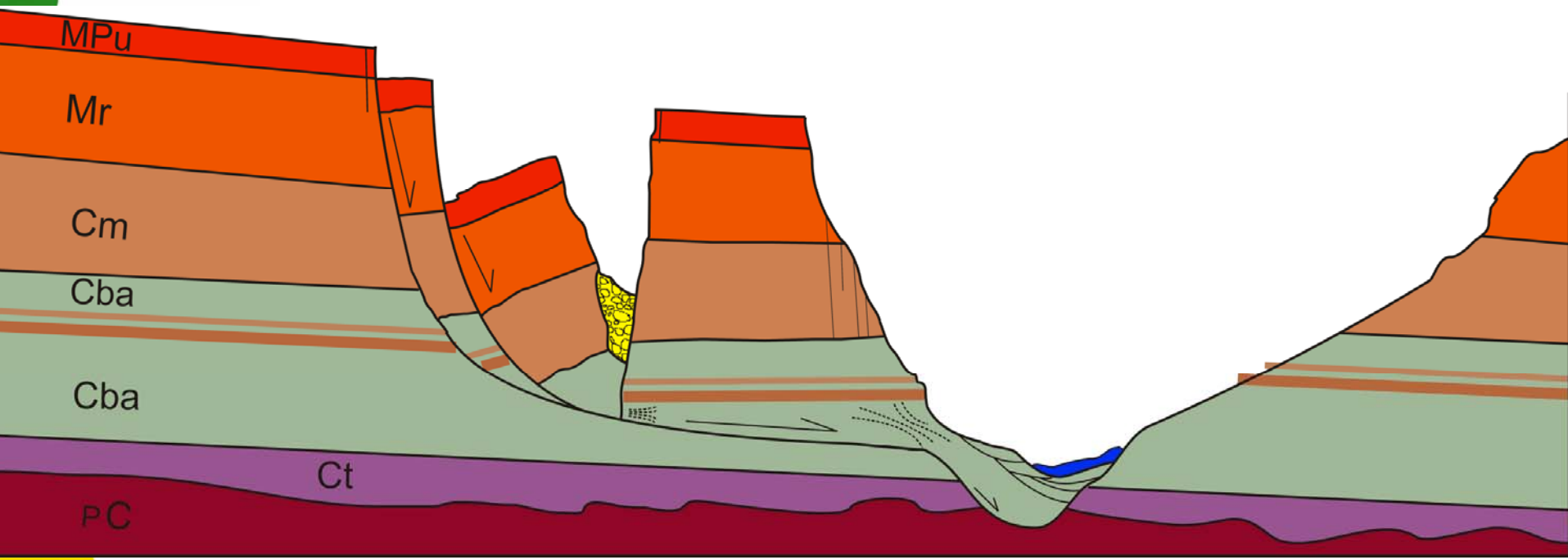

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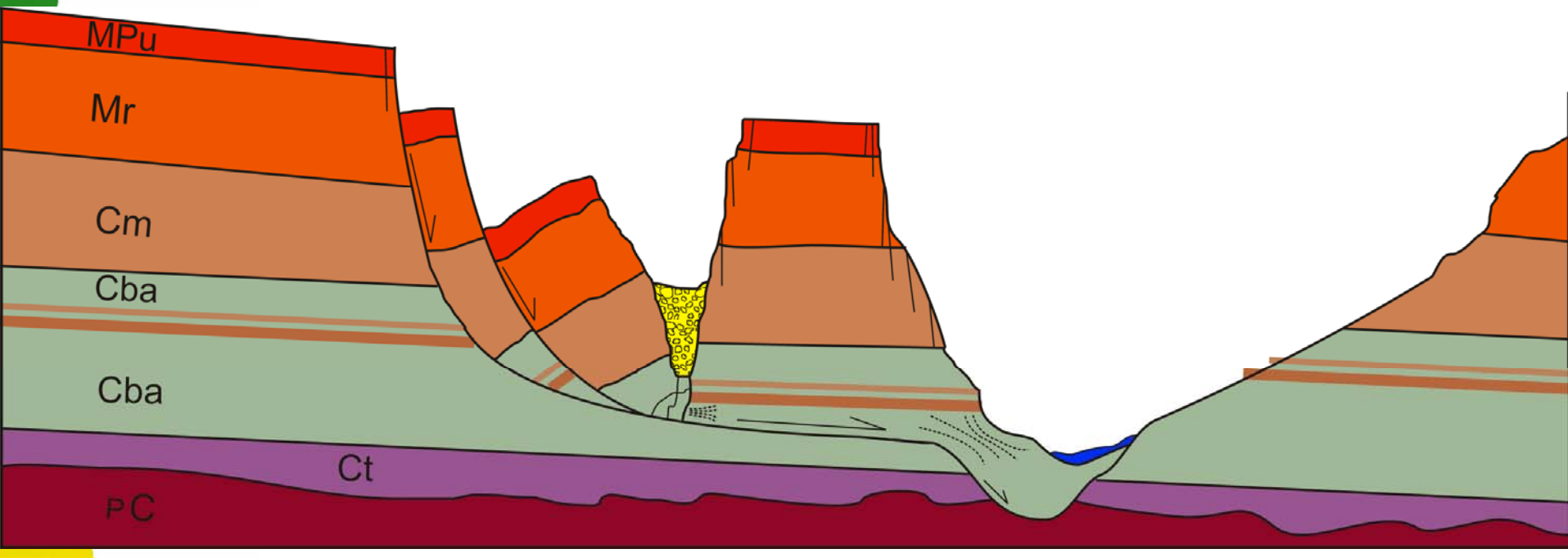
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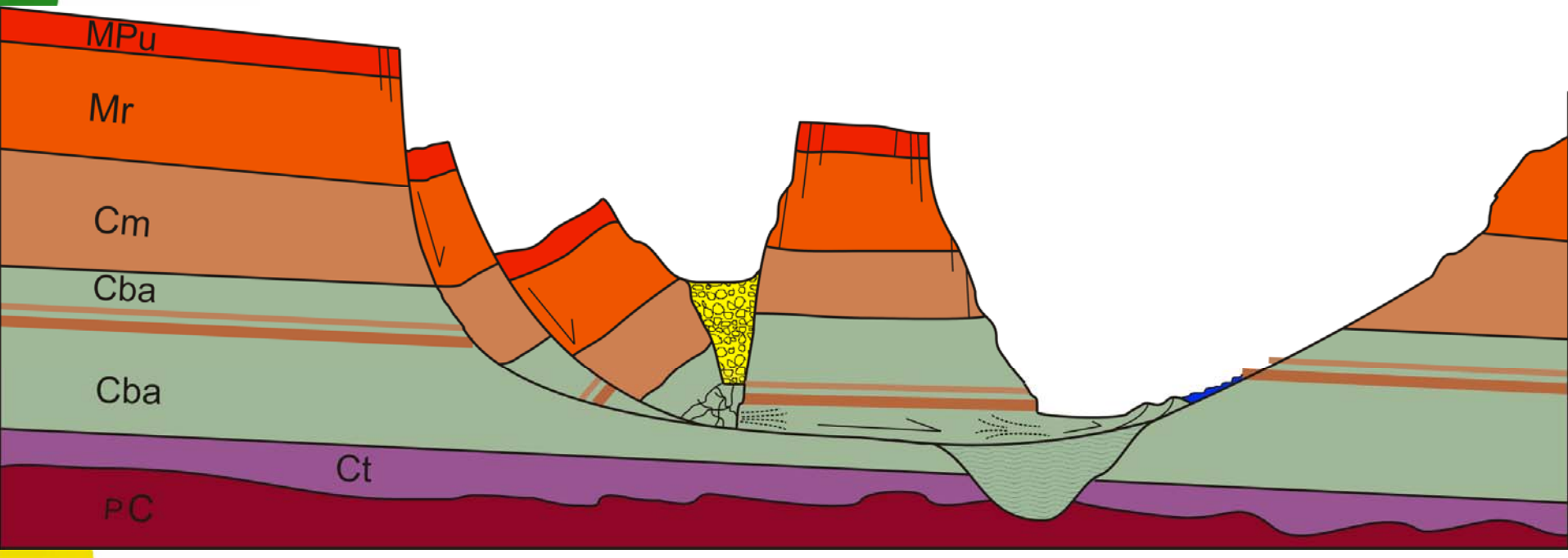
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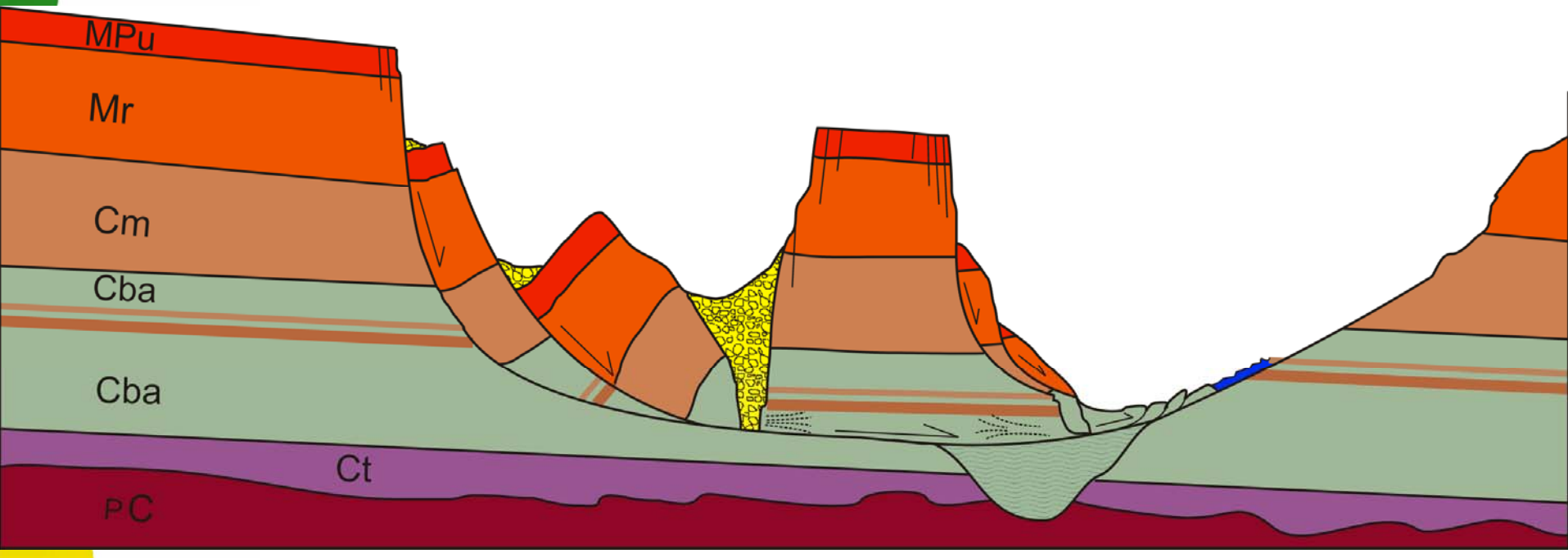
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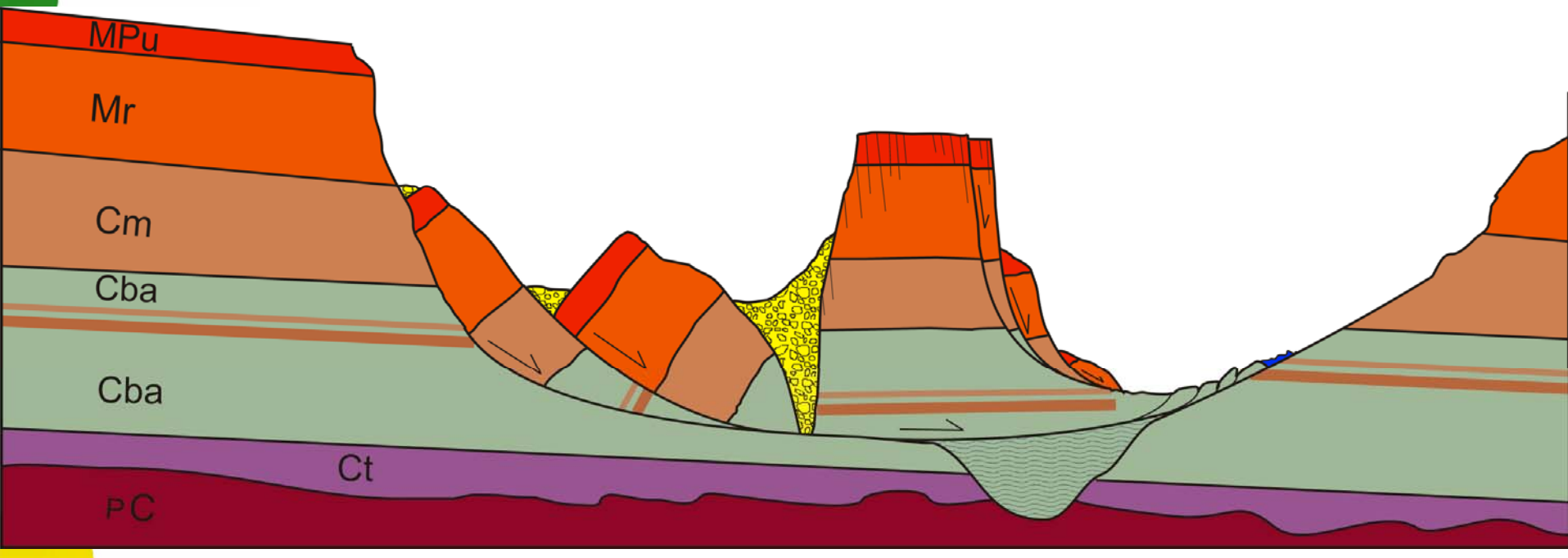
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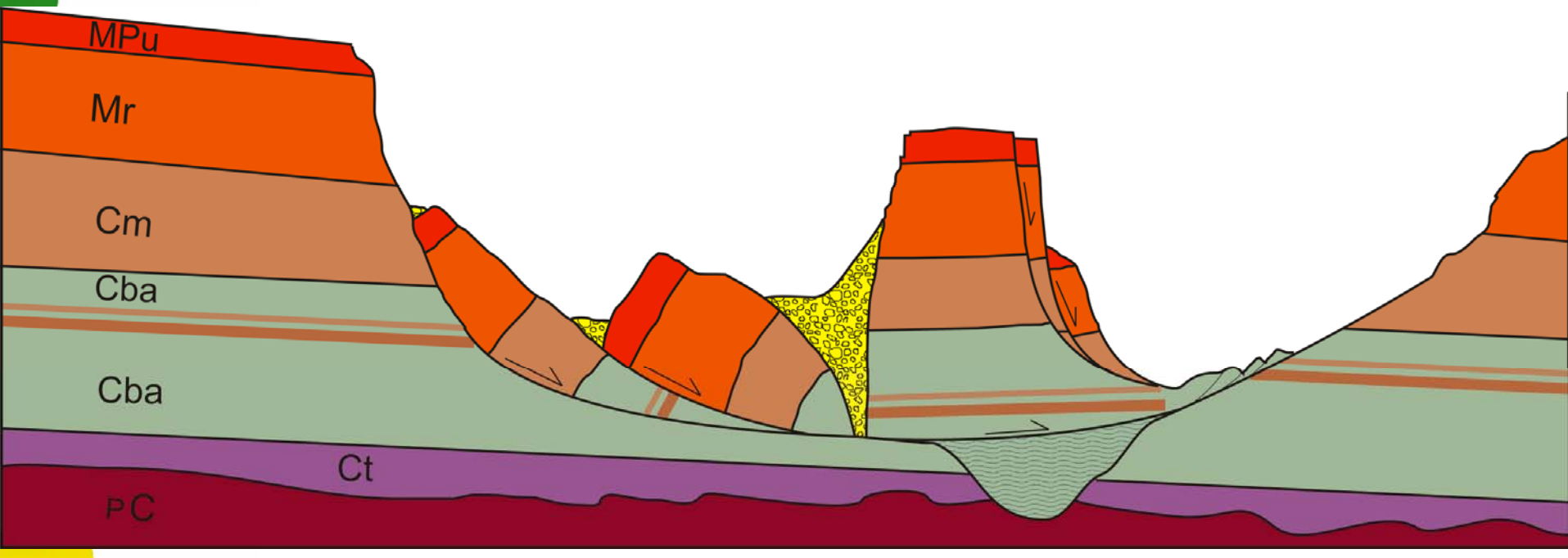
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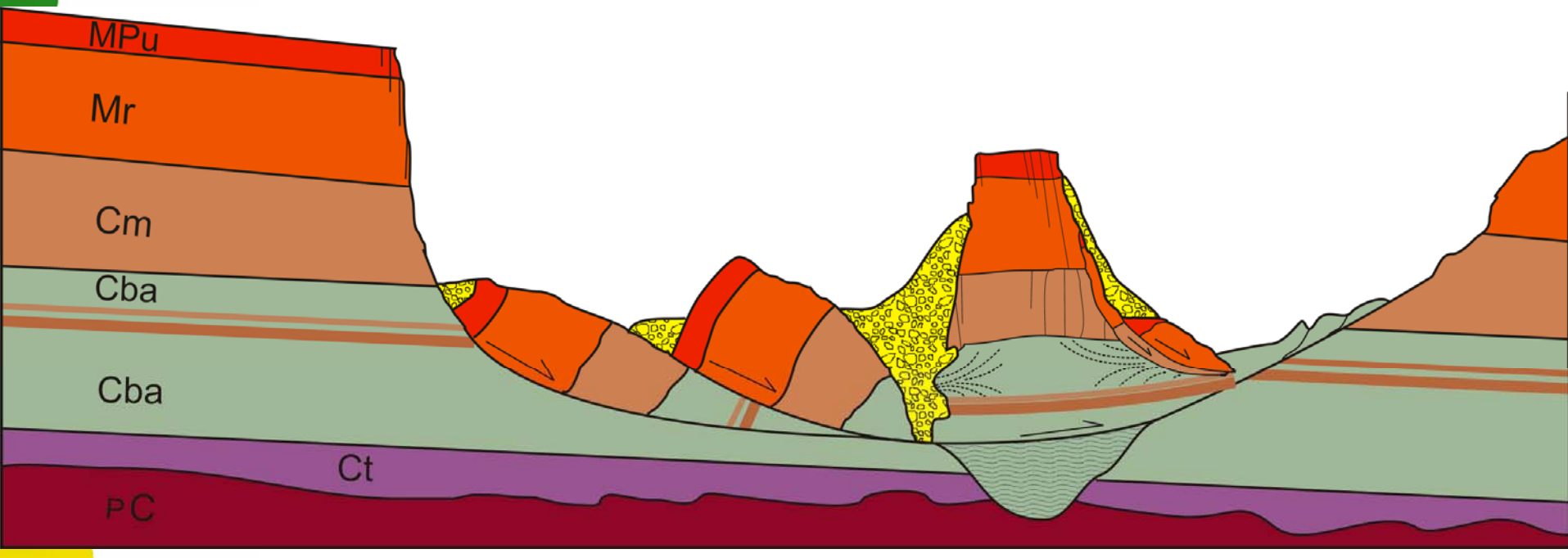
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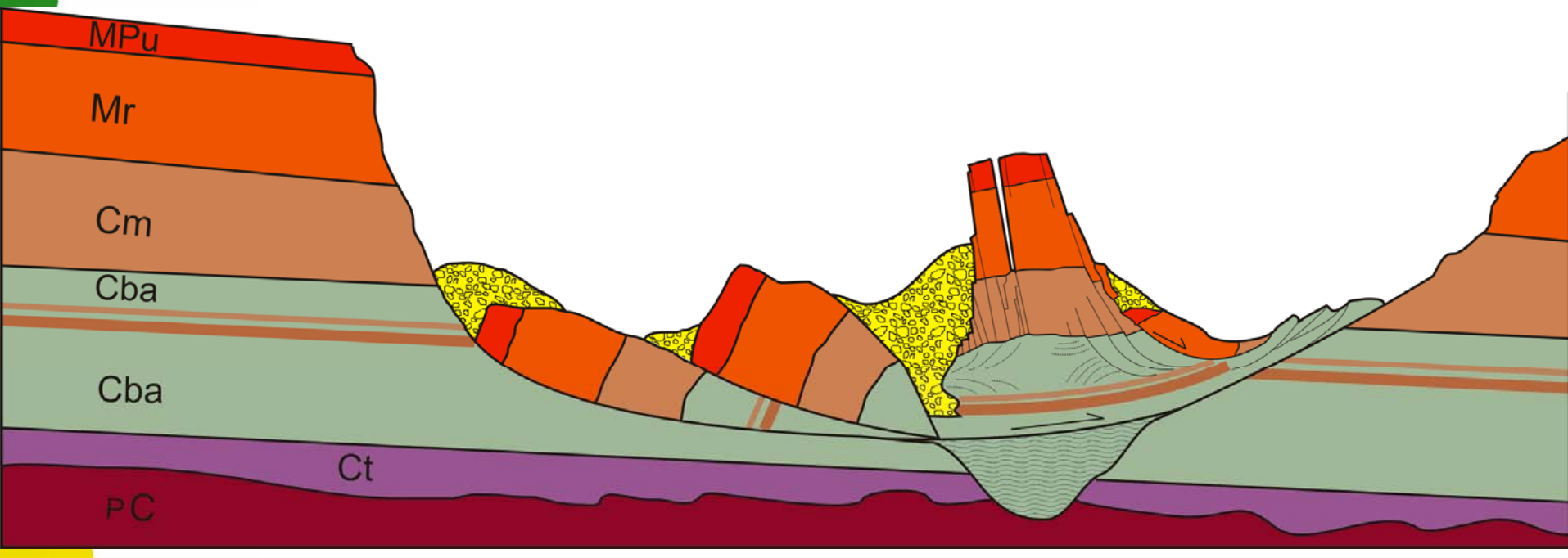
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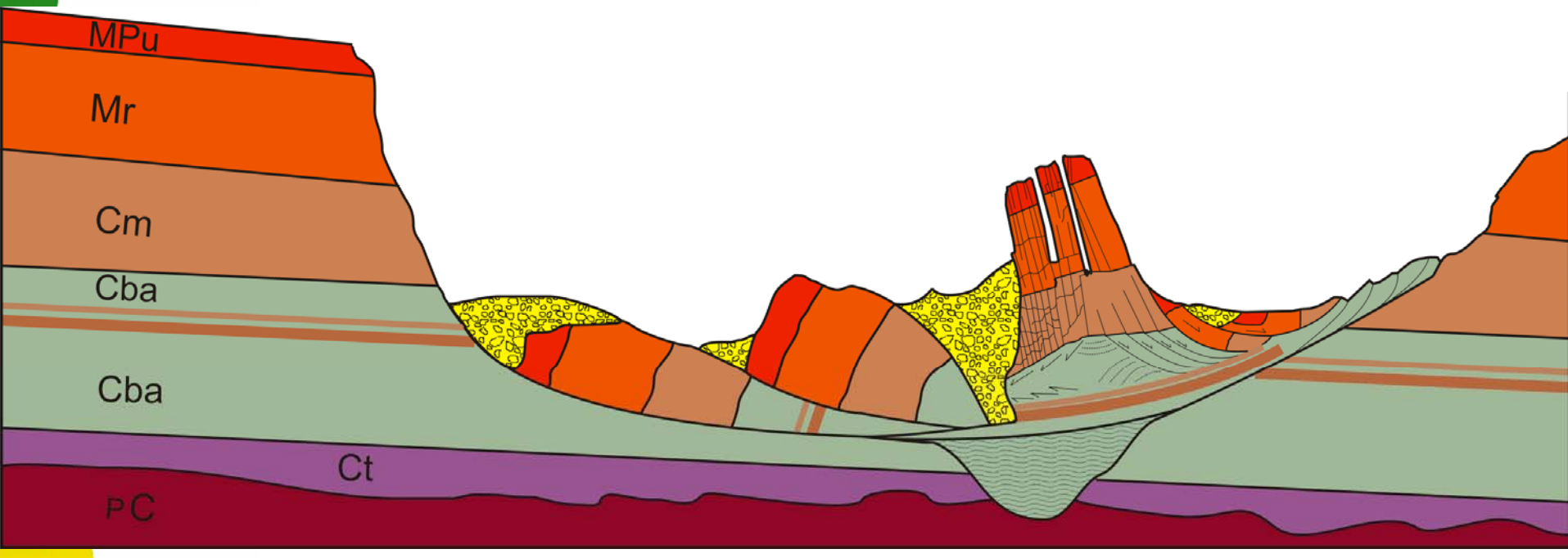
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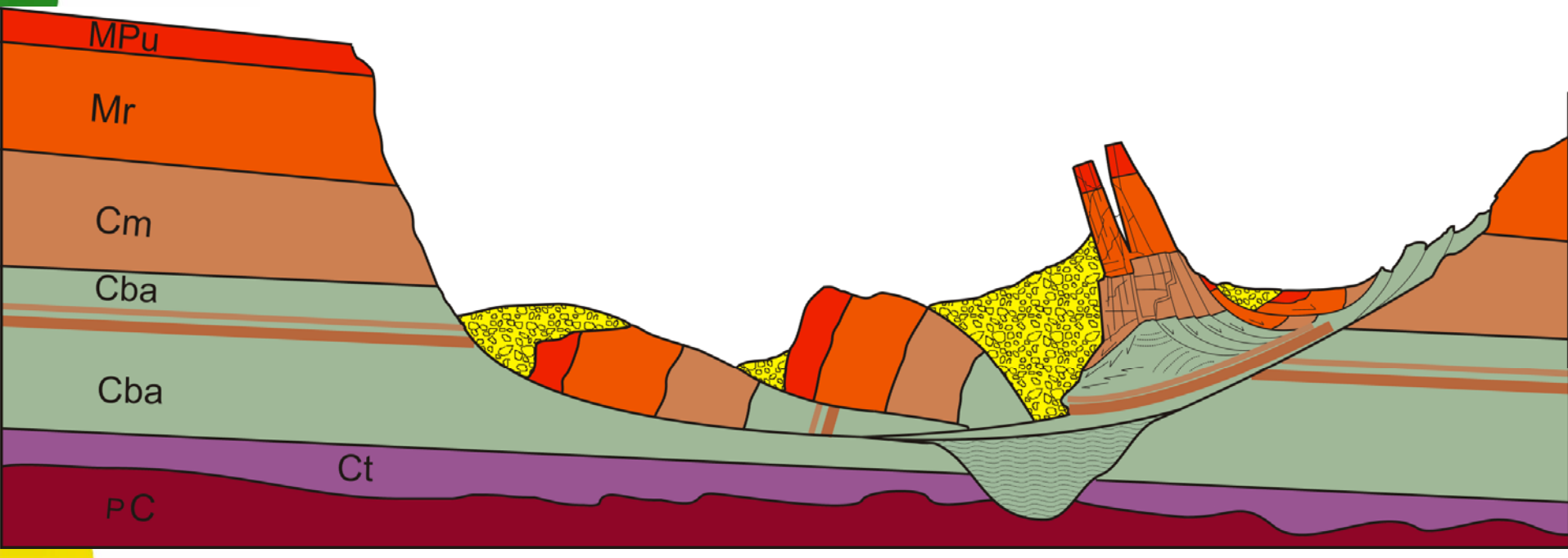
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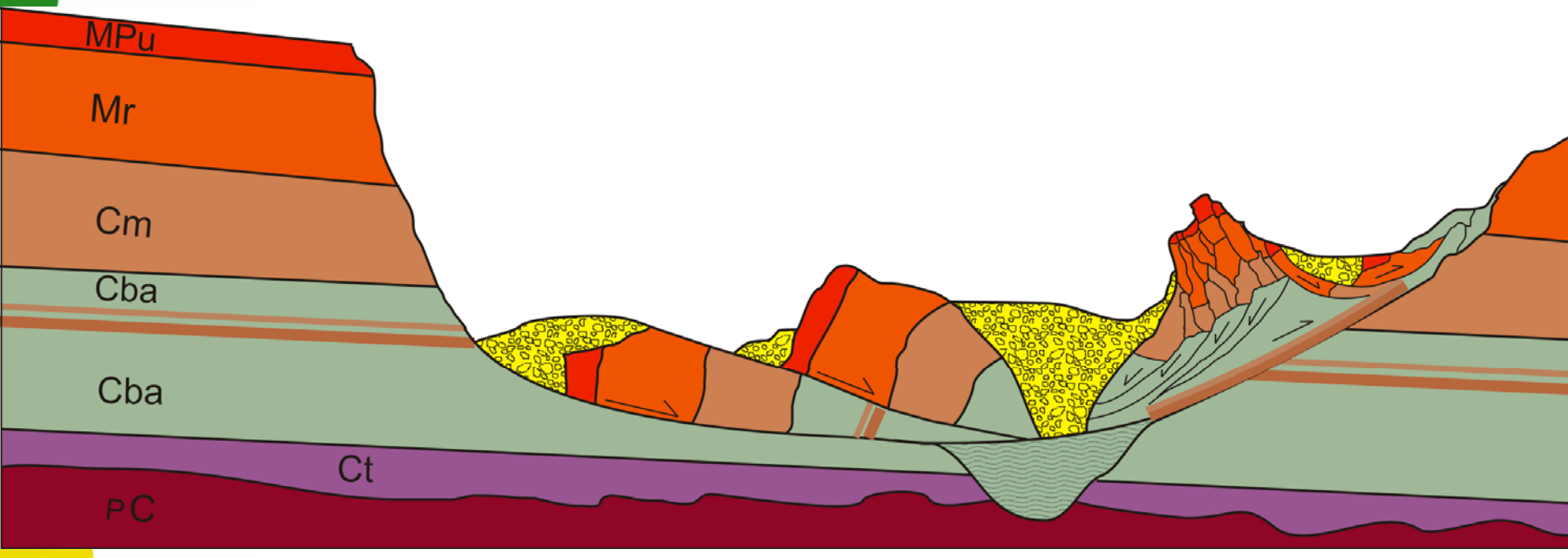
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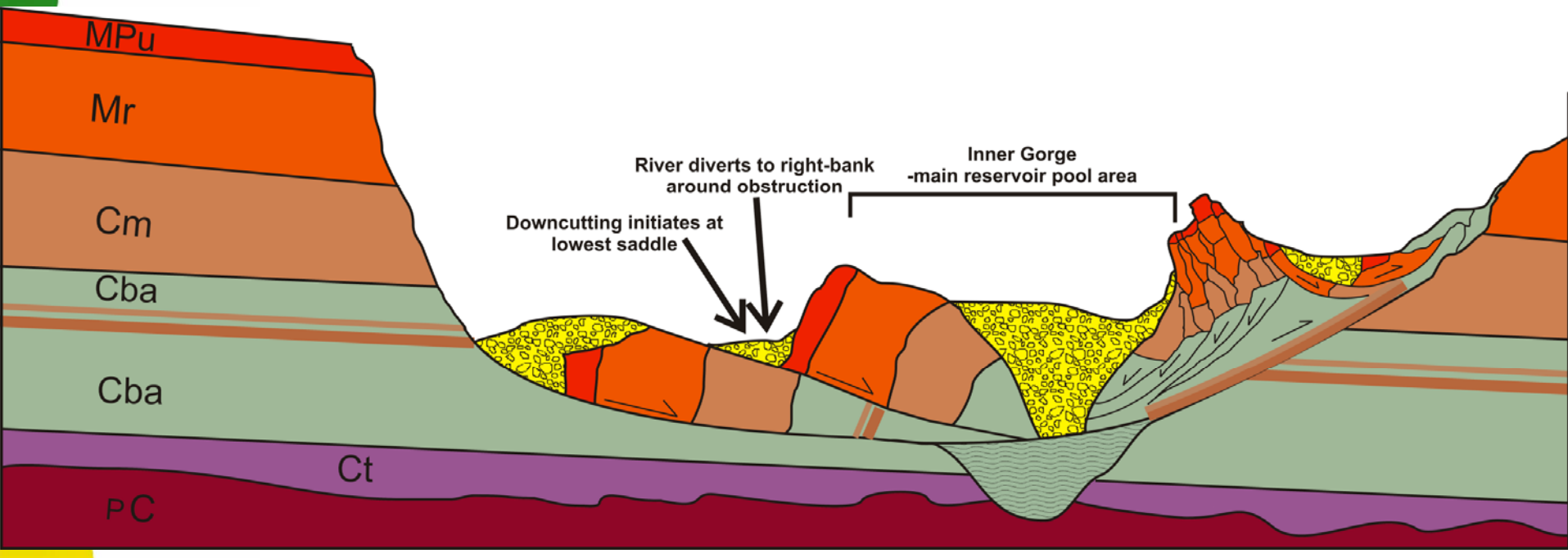
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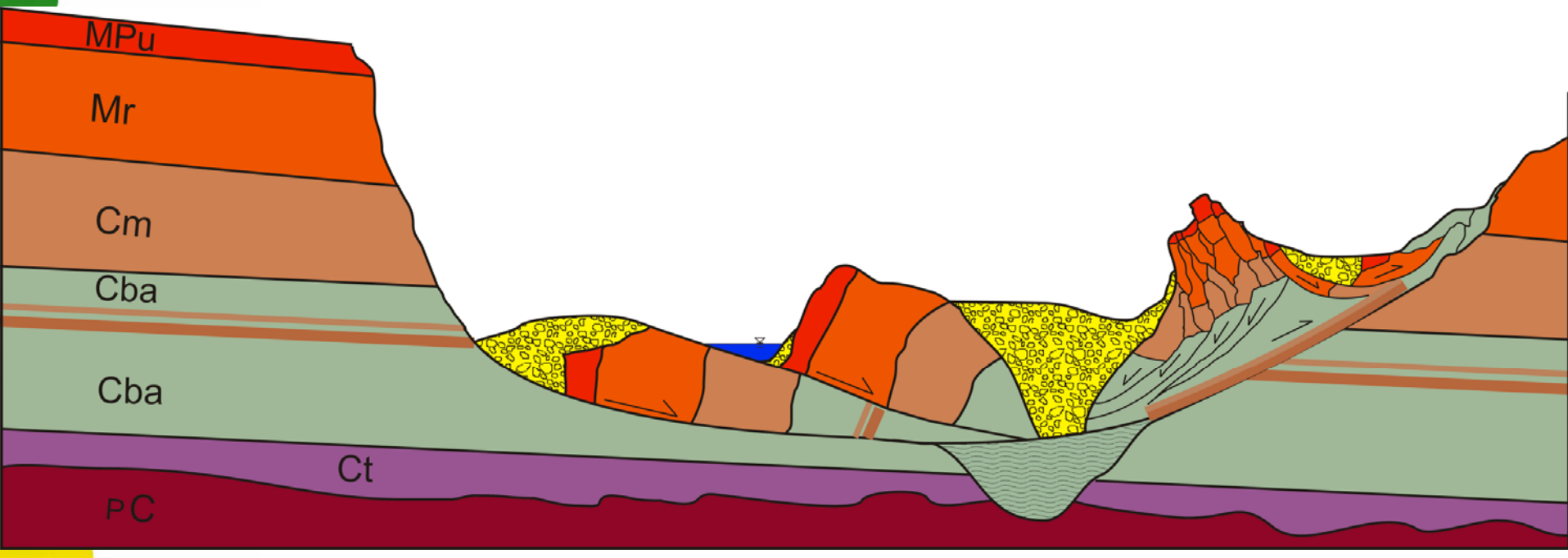
River diverts to right-bank
around obstruction
Downcutting initiates at
lowest saddle
Inner Gorge
-main reservoir pool area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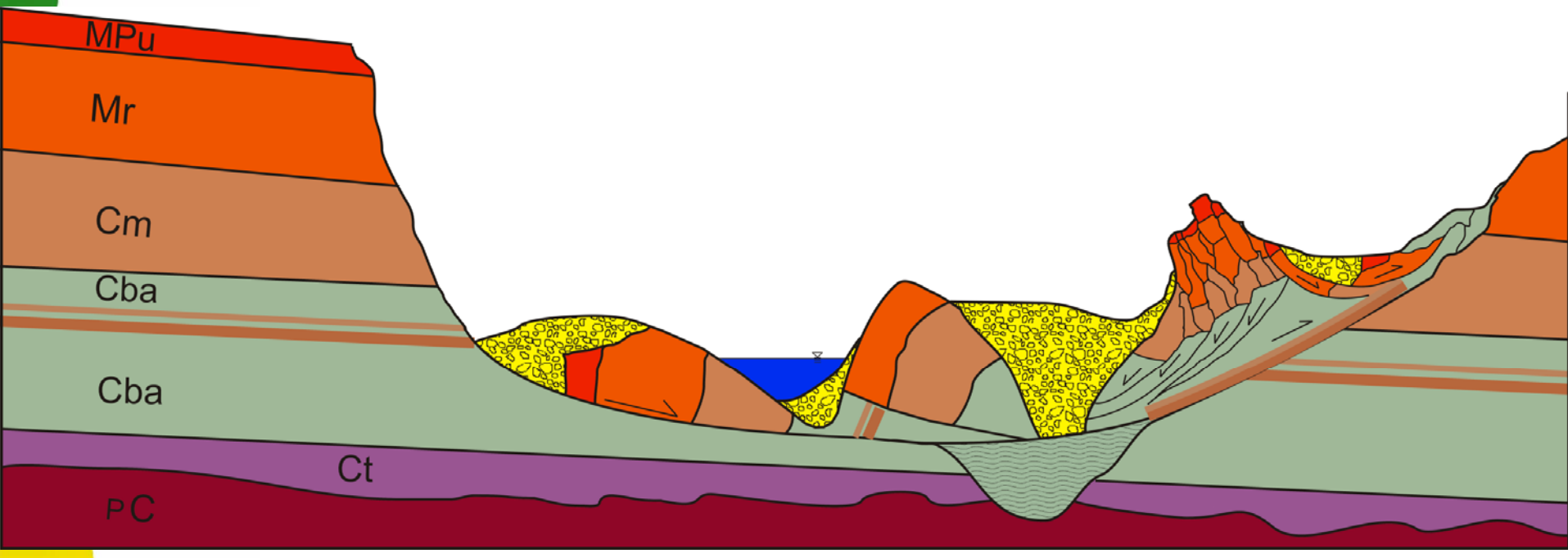
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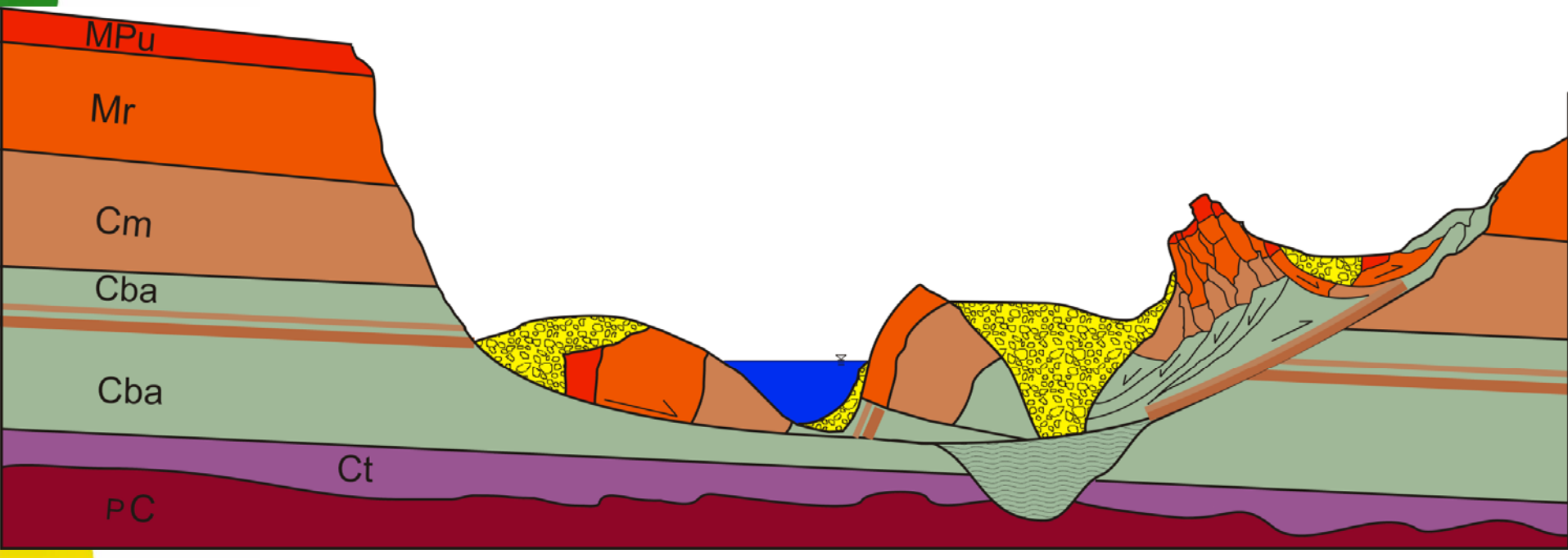
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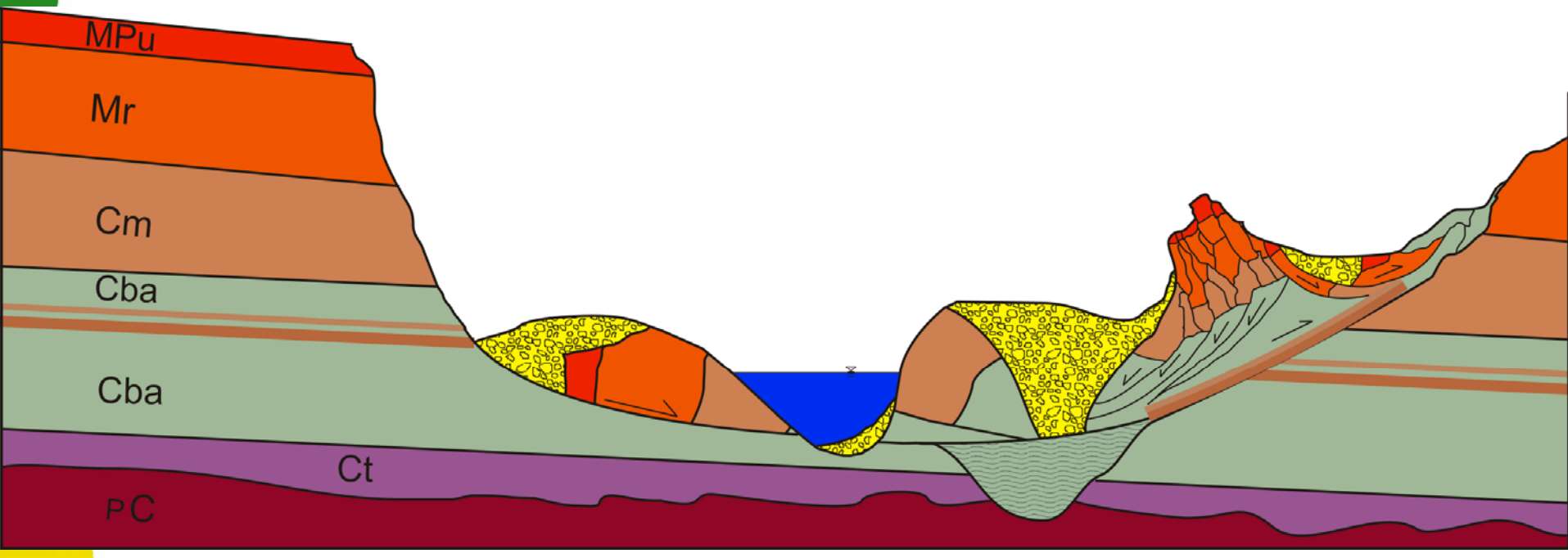
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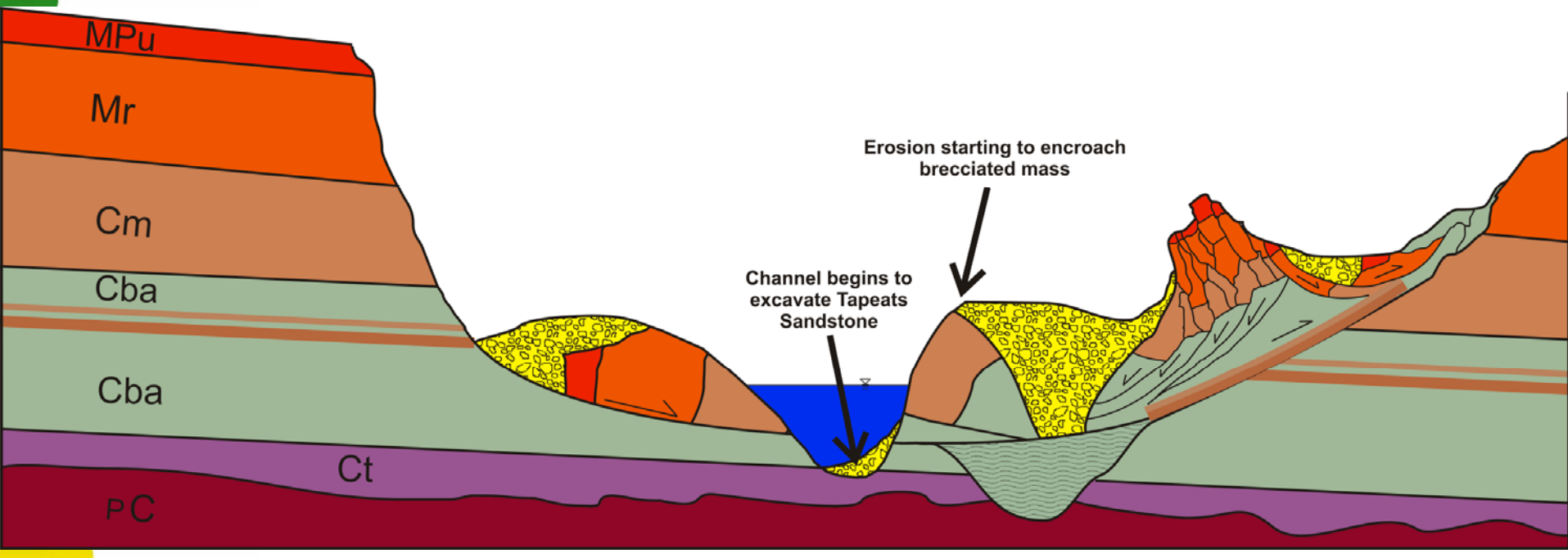
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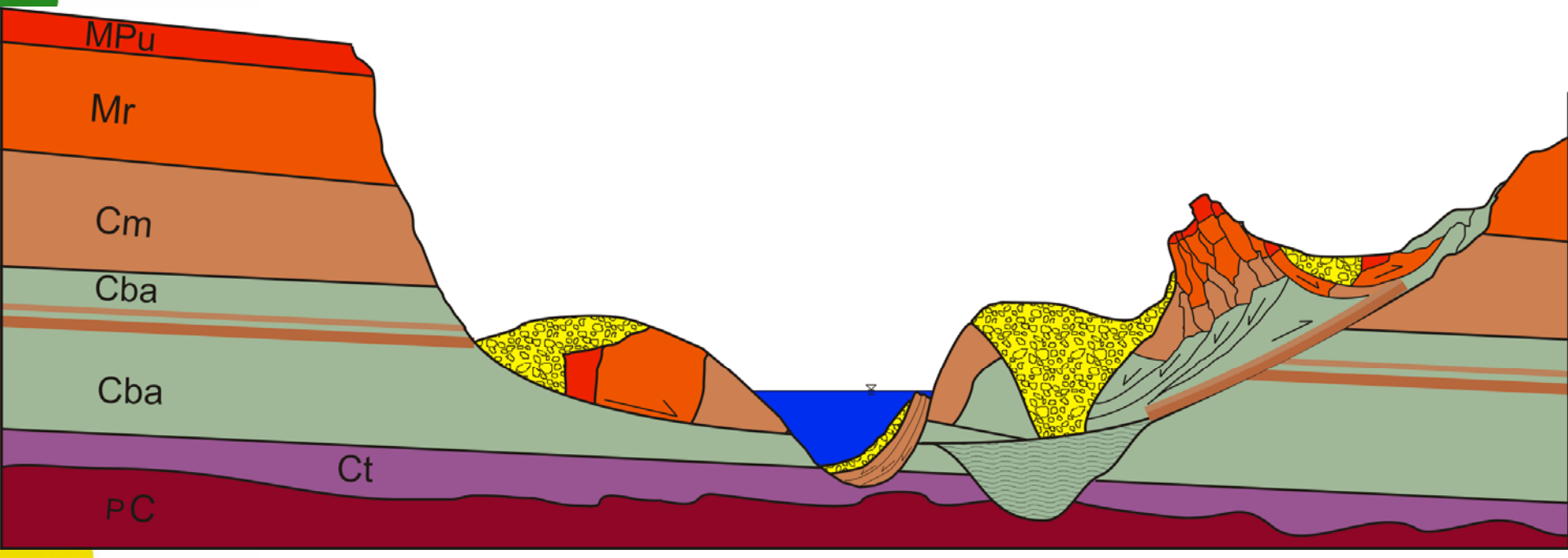
Erosion starting to encroach brecciated mass
Channel begins to excavate Tapeats Sandstone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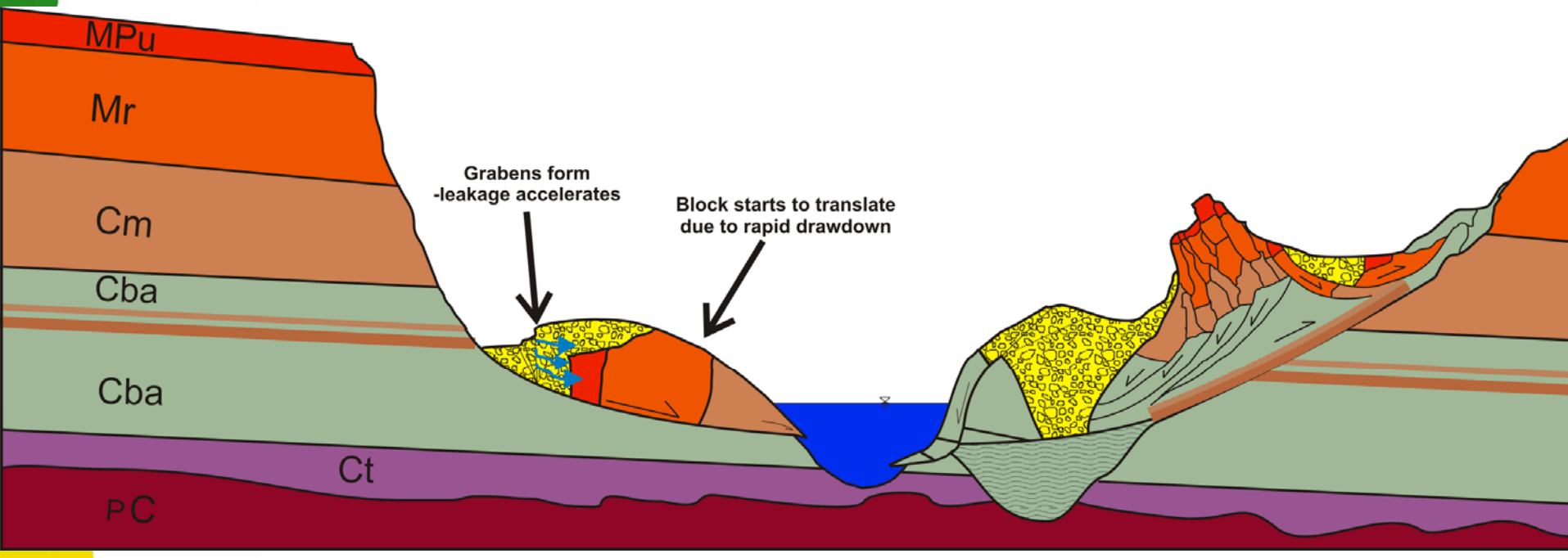
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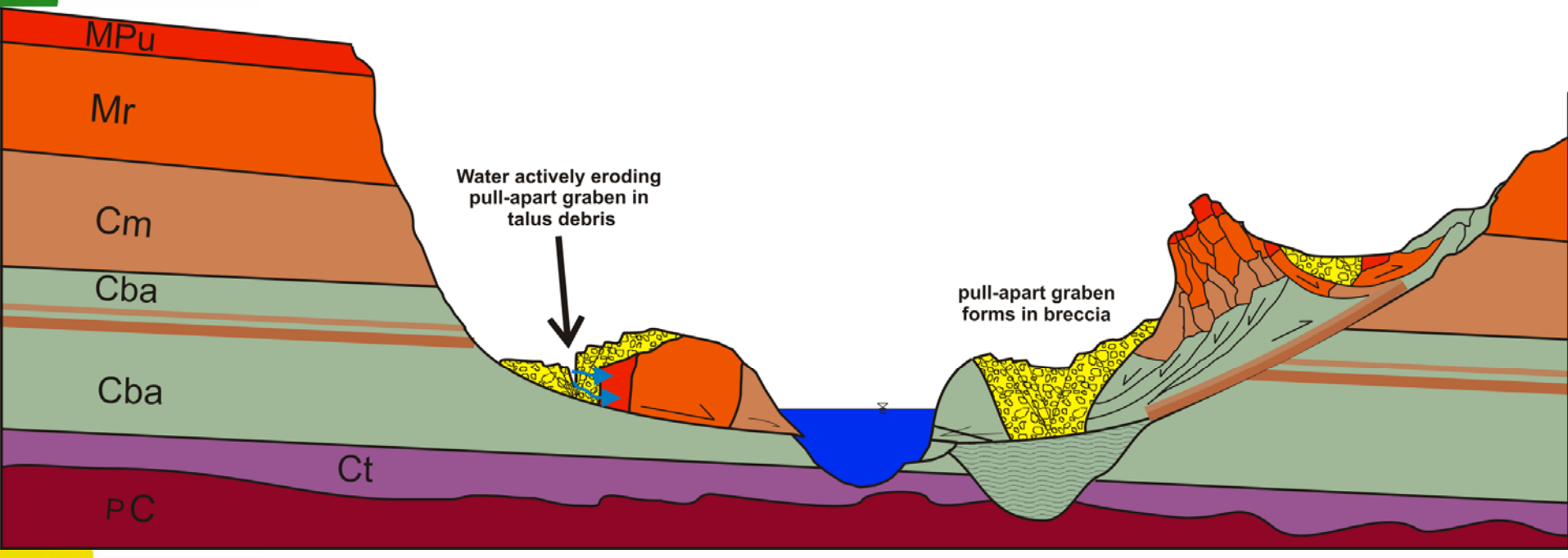
Grabens form
-leakage accelerates
Block starts to translate
due to rapid drawdown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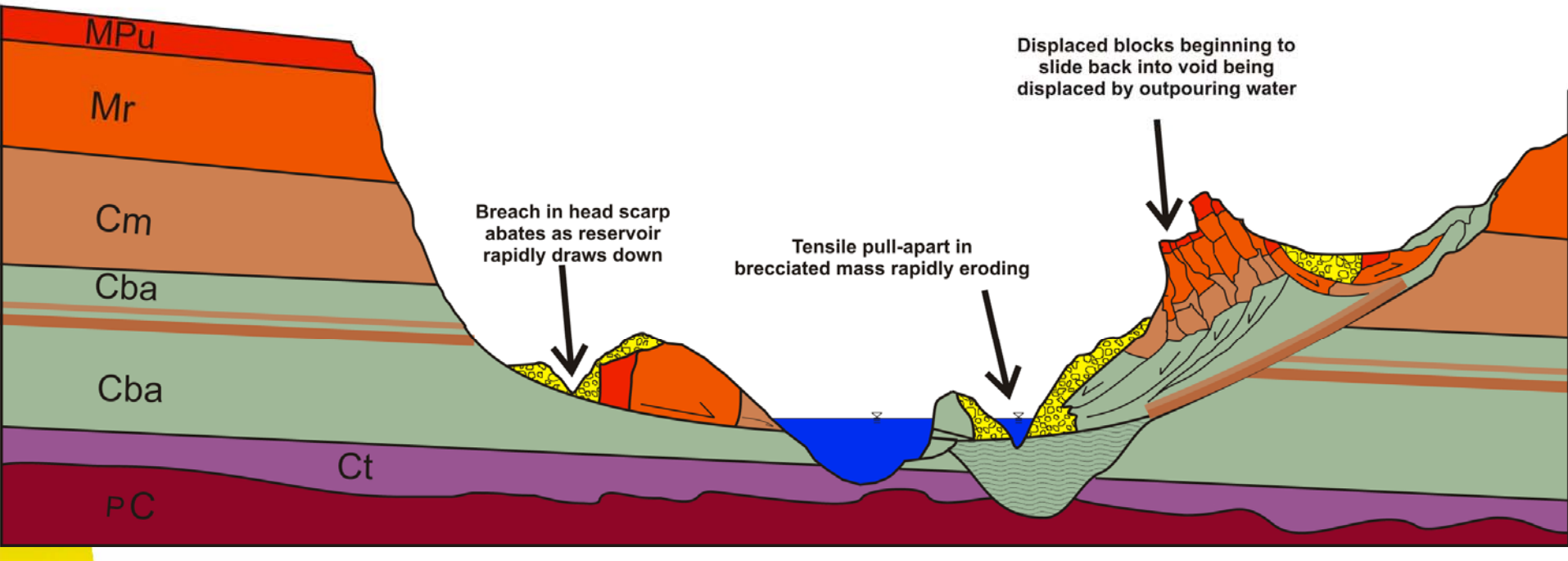
Water actively eroding pull-apart graben in talus debris
pull-apart graben forms in breccia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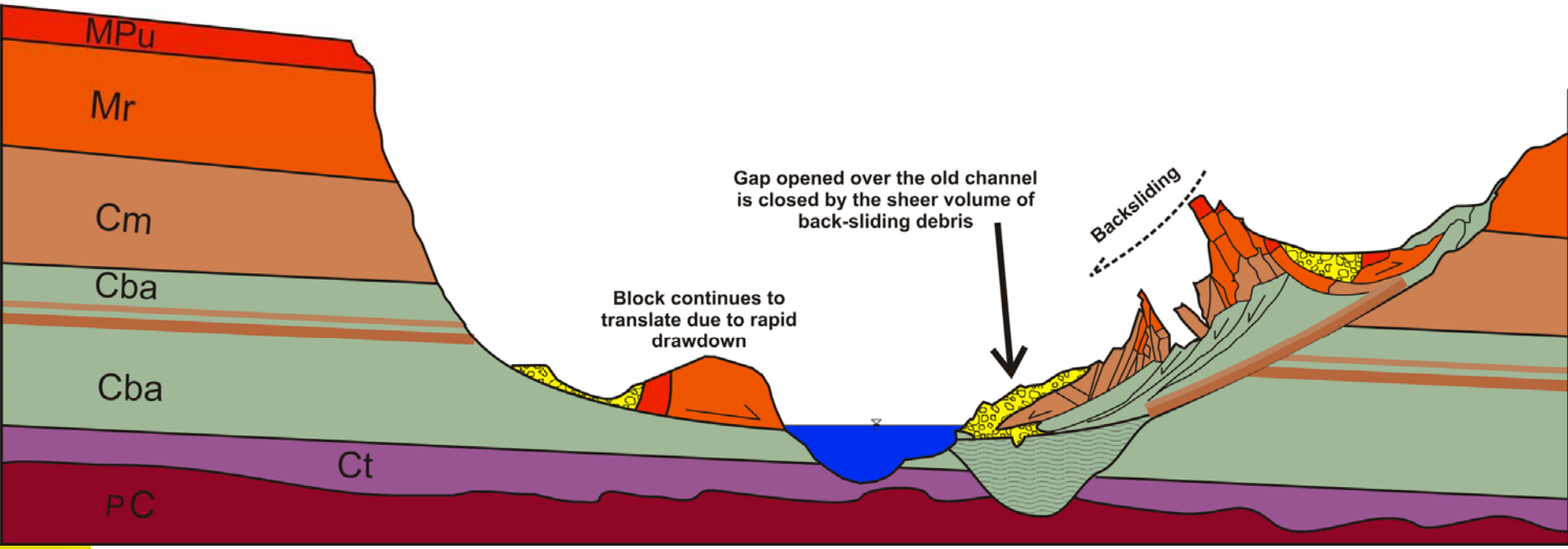
Breach in head scarp abates as reservoir rapidly draws down
Tensile pull-apart in brecciated mass rapidly eroding
Displaced blocks beginning to slide back into void being displaced by outpouring water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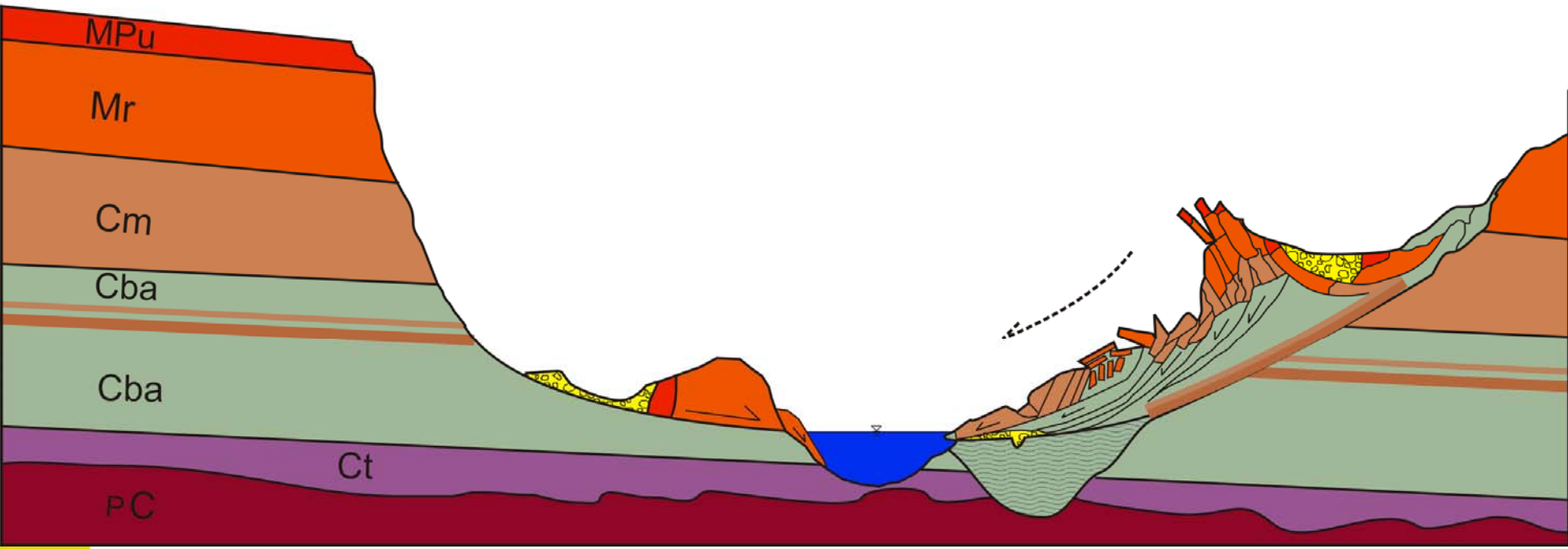
Gap opened over the old channel is closed by the sheer volume of back-sliding debris
Backsliding
Block continues to translate due to rapid drawdown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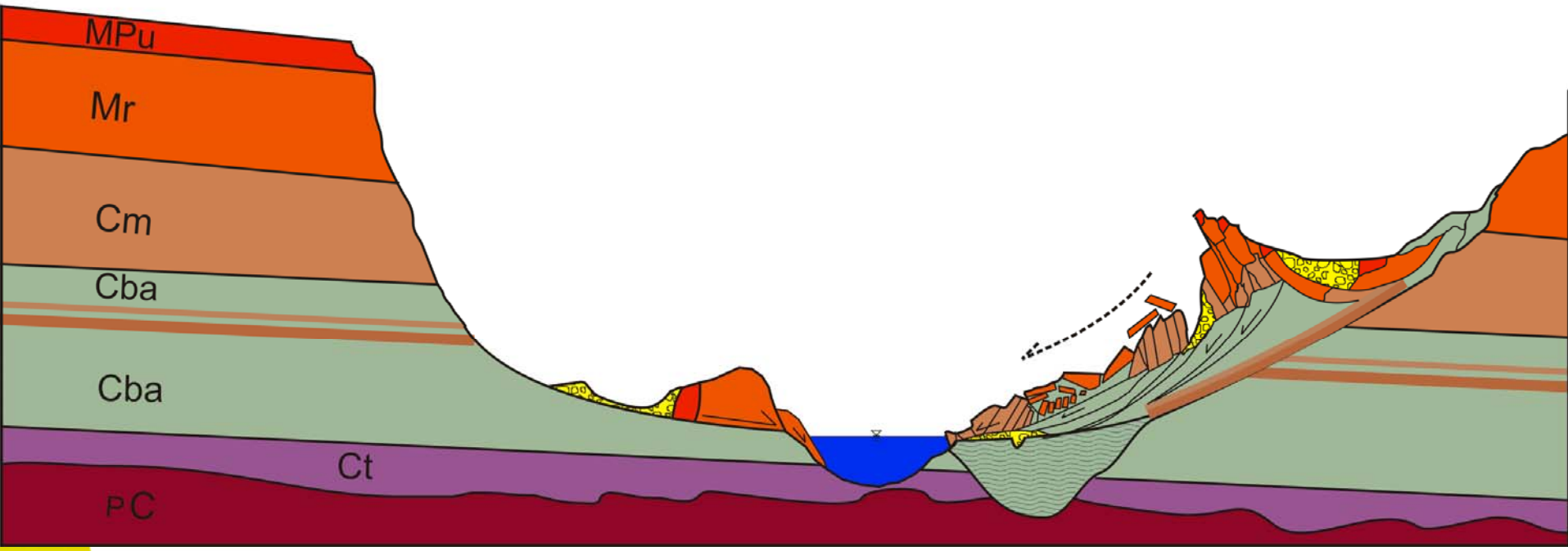
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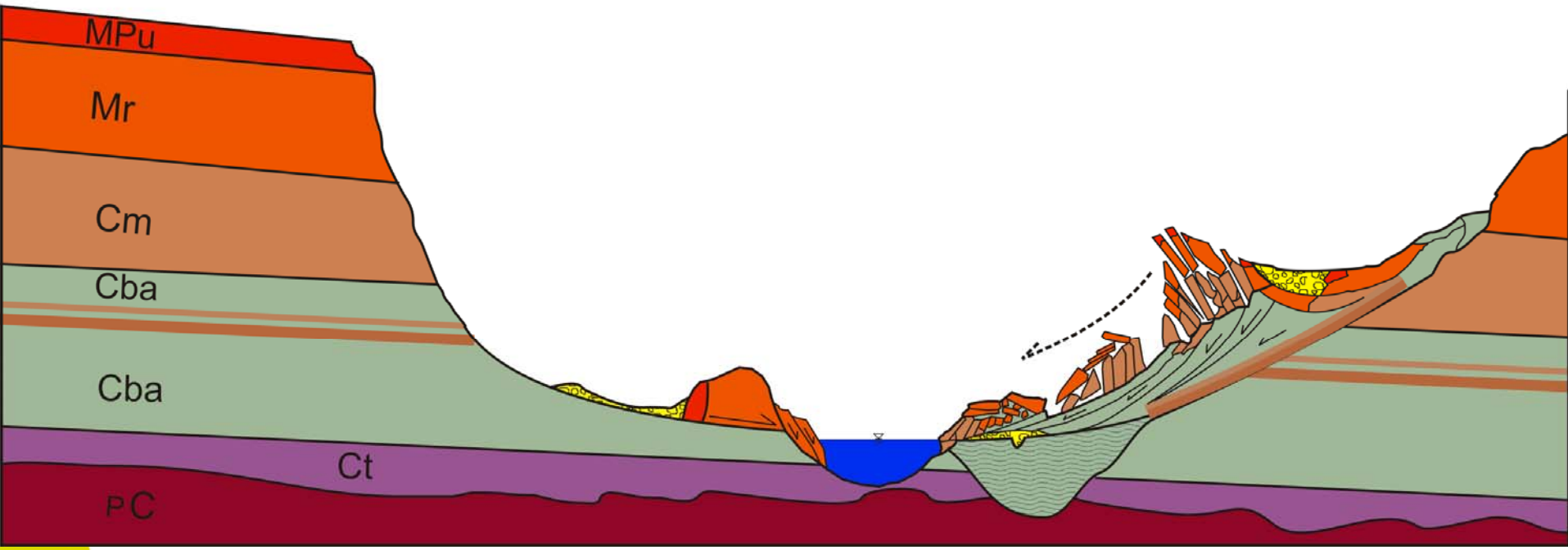
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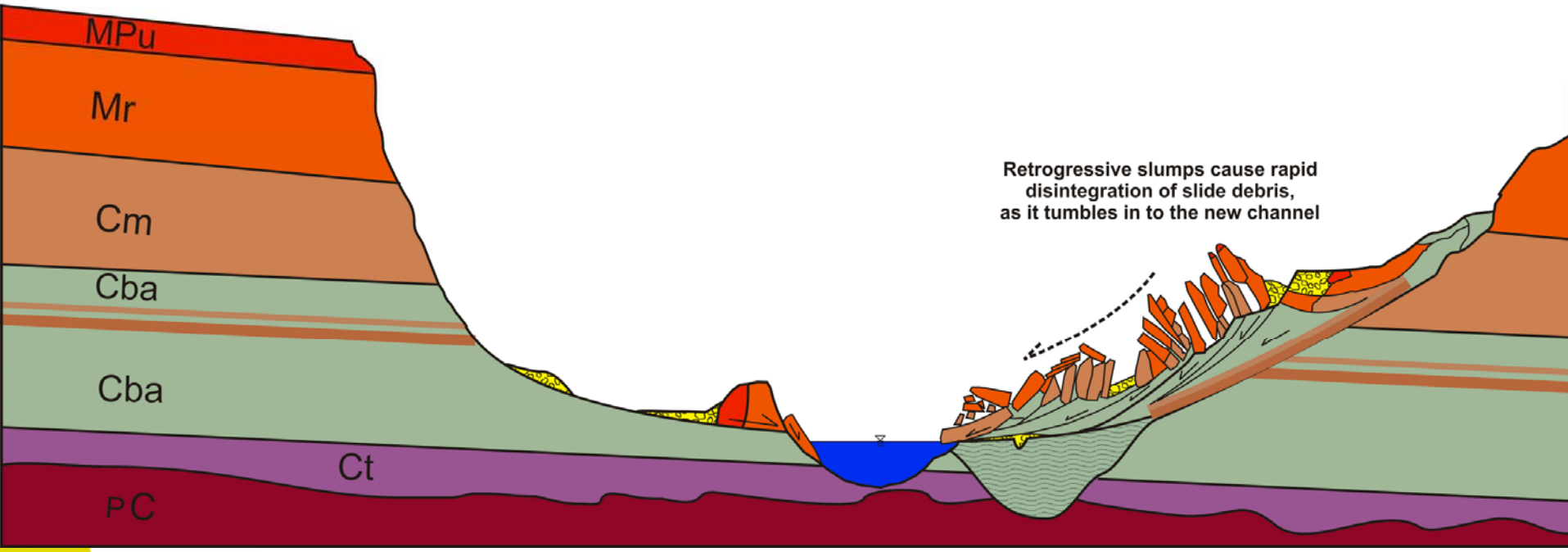
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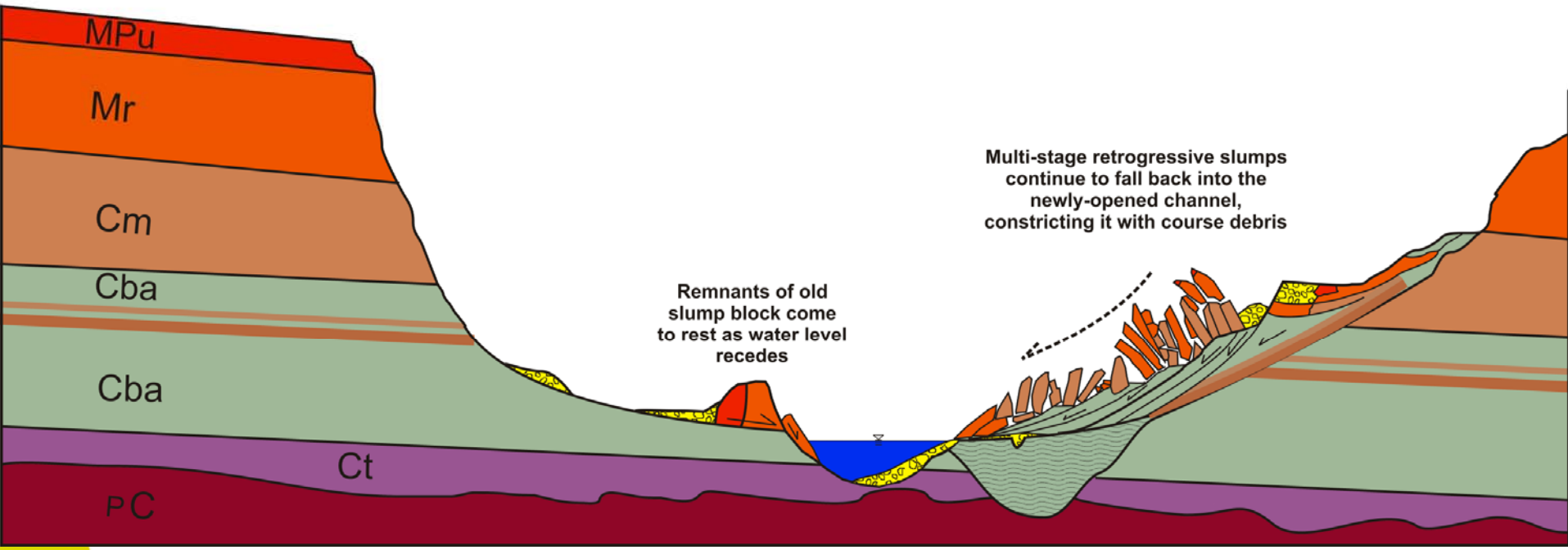
Retrogressive slumps cause rapid
disintegration of slide debris,
as it tumbles in to the new channel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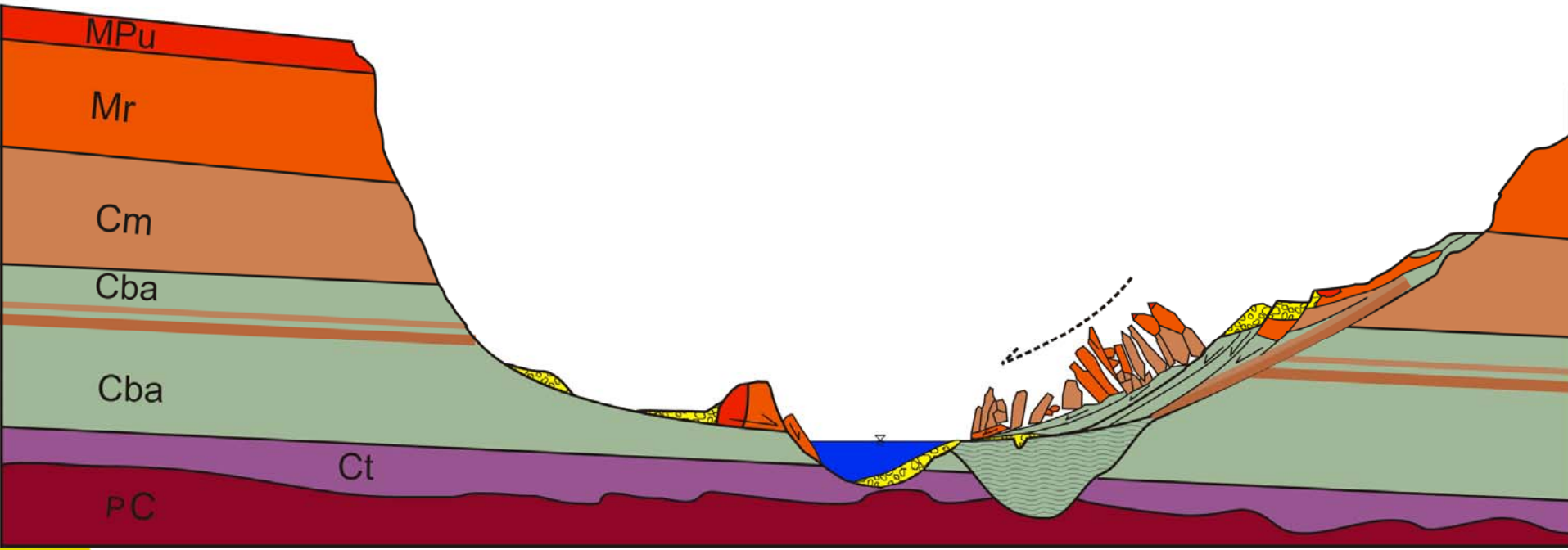
Remnants of old slump block come to rest as water level recedes
Multi-stage retrogressive slumps continue to fall back into the newly-opened channel, constricting it with course debris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Poncho's Radical Runup – A Prehistoric Vaiont?

Vaiont Section Before Failure

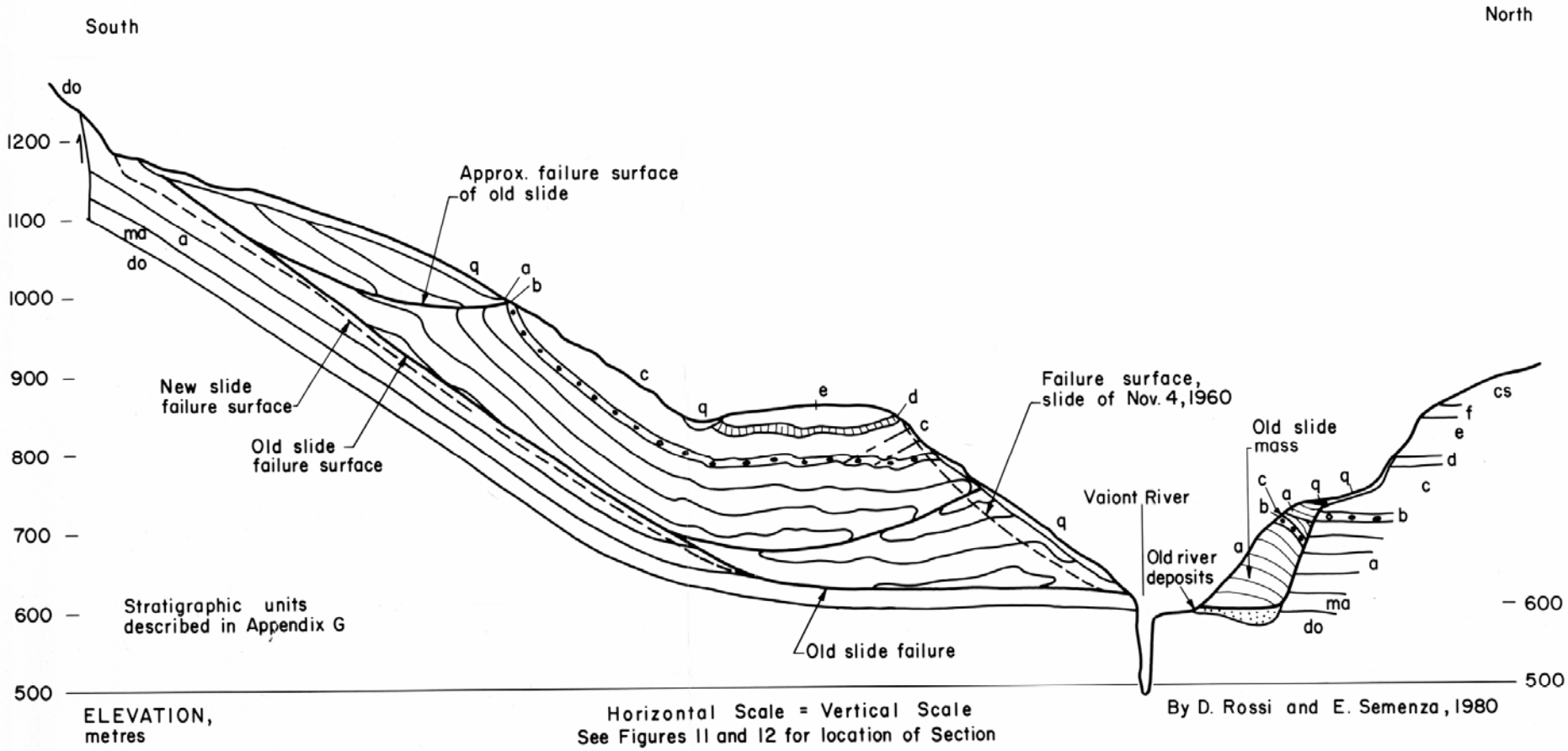


FIGURE 15
Geologic Section 2, Vaiont Slide
Before October 9, 1963

From Patton and Hendron (1985)

Vaiont Section After Failure

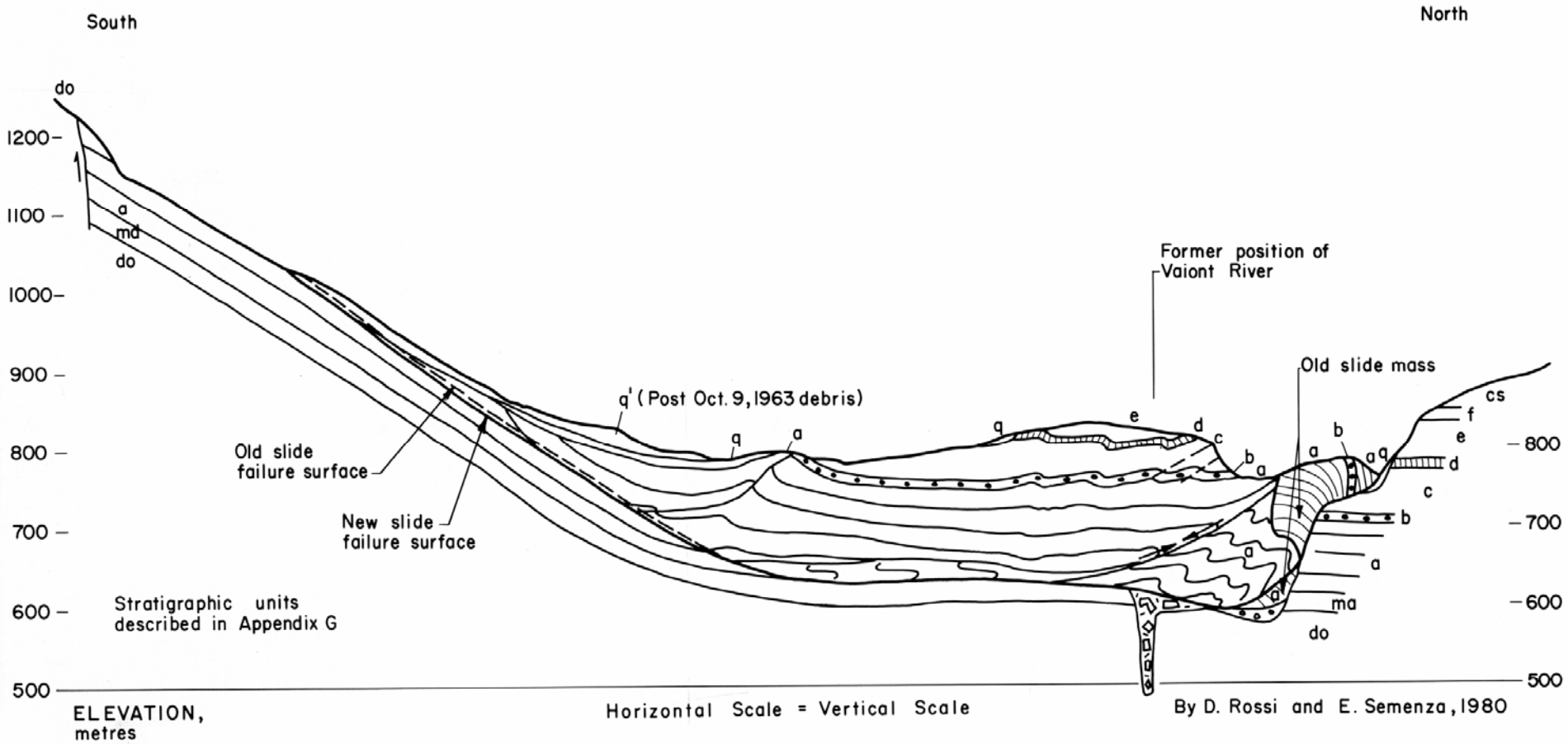
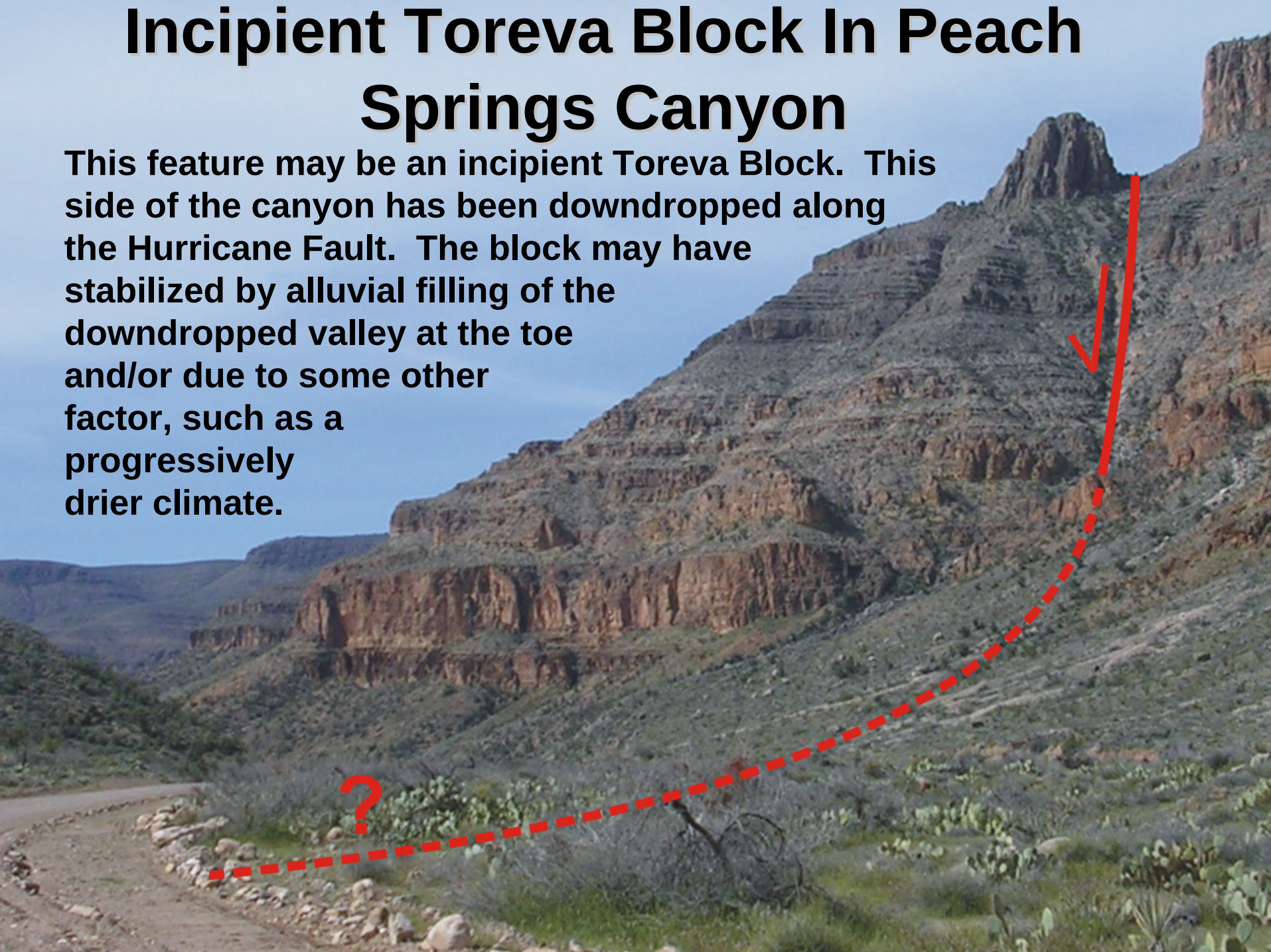


FIGURE 16
Geologic Section 2, Vaiont Slide
After October 9, 1963

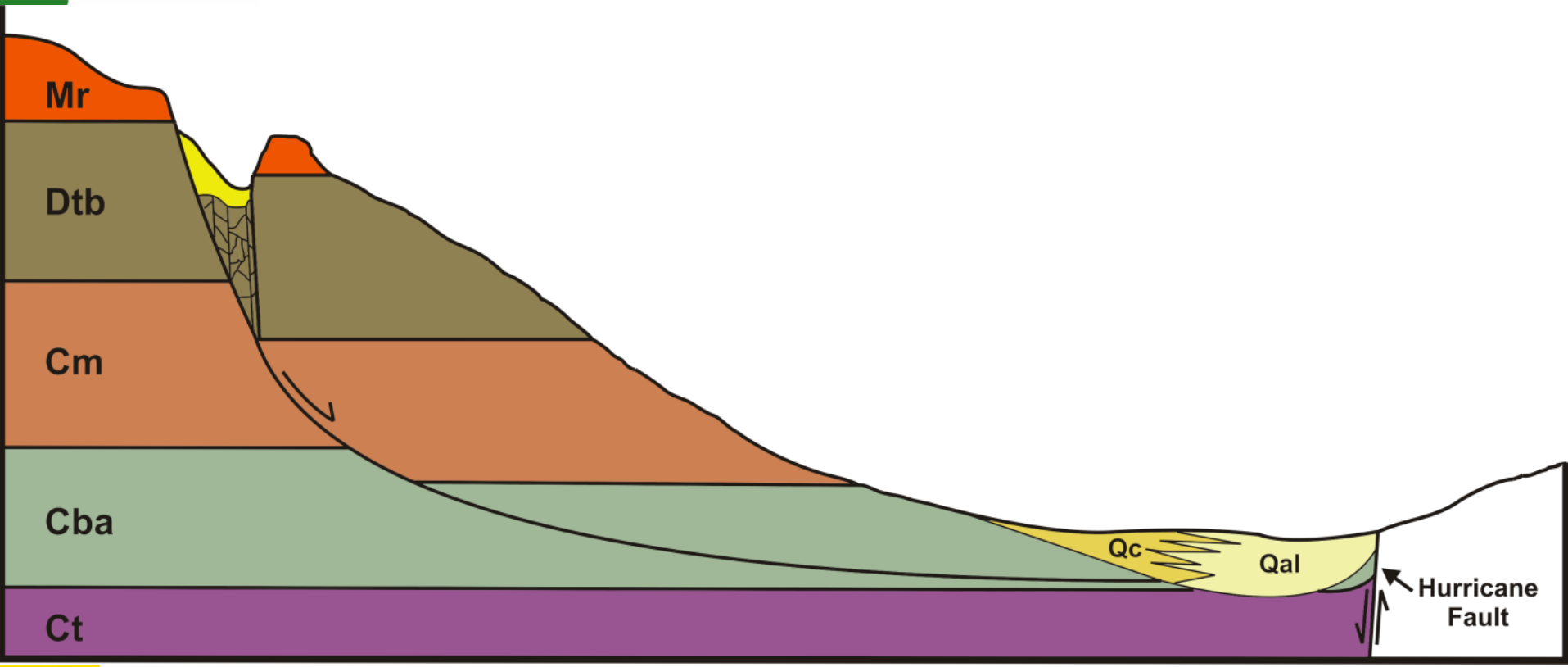
From Patton and Hendron (1985)

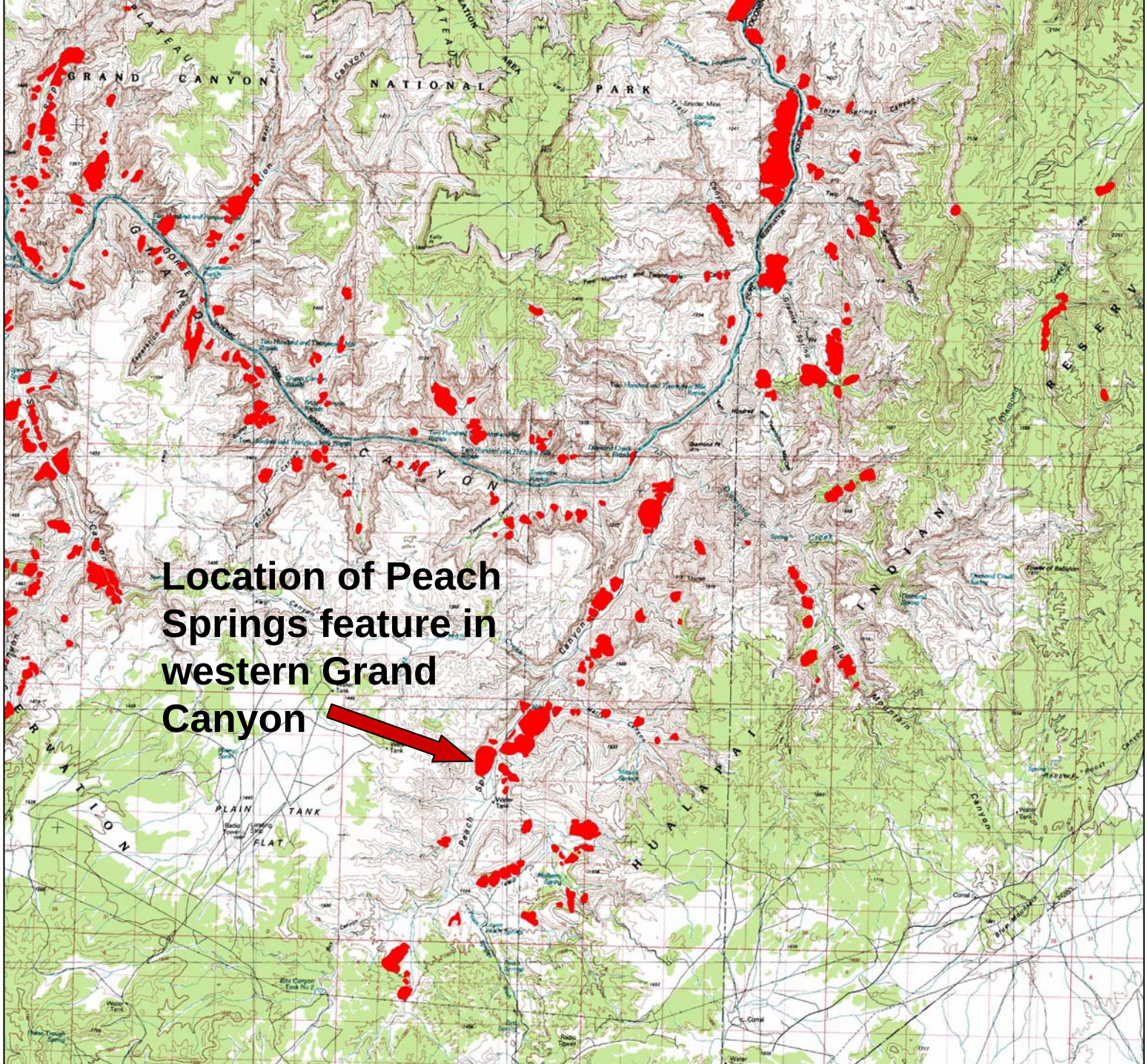
Incipient Toreva Block In Peach Springs Canyon



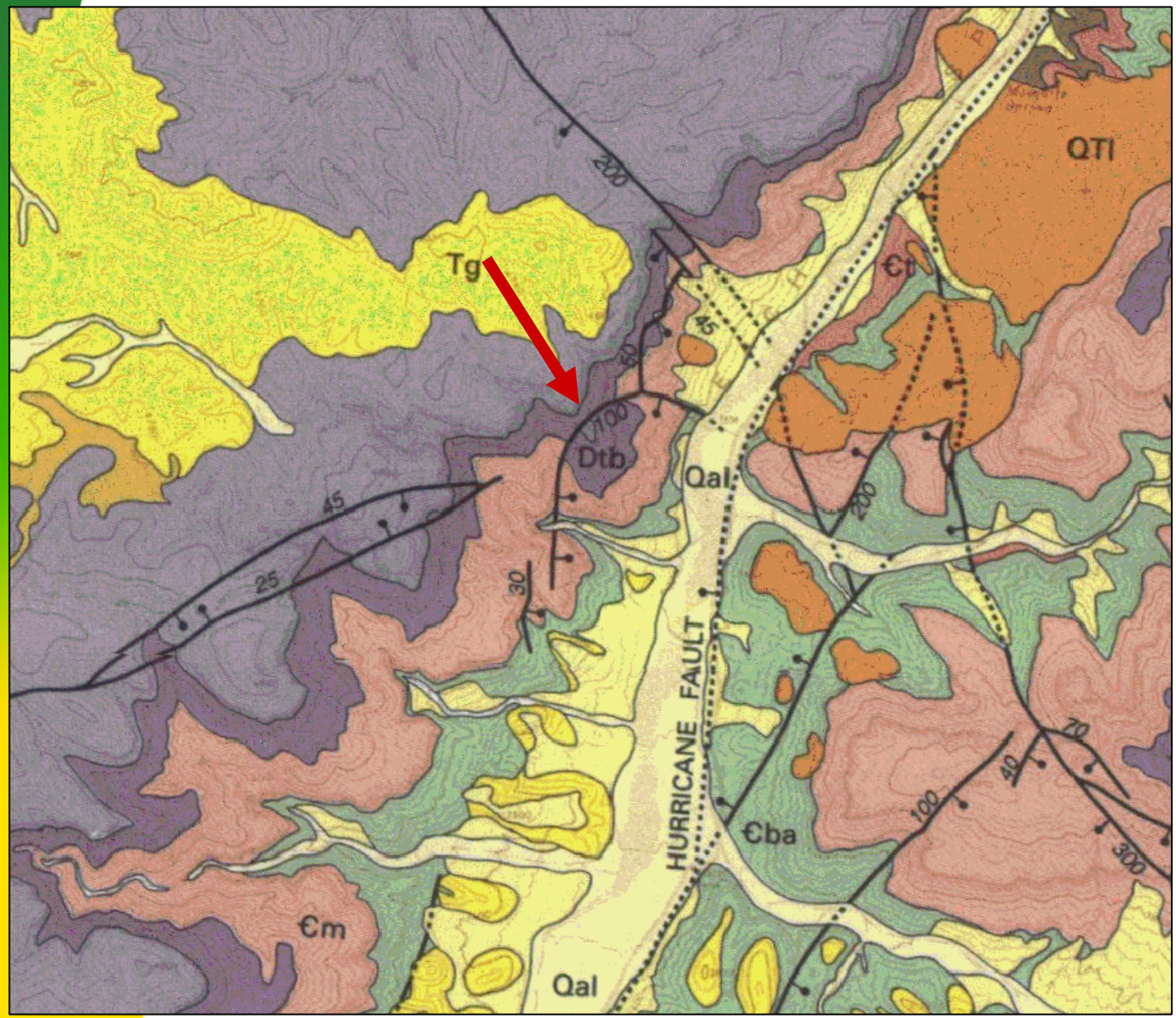
This feature may be an incipient Toreva Block. This side of the canyon has been downdropped along the Hurricane Fault. The block may have stabilized by alluvial filling of the downdropped valley at the toe and/or due to some other factor, such as a progressively drier climate.

Incipient Toreva Block In Peach Springs Canyon




Location of Peach Springs feature in western Grand Canyon

Incipient Toreva Block In Peach Springs Canyon



The feature is presently mapped as a crescent shaped fault on geologic maps of the Hualapi Reservation. The arcuate shape is typical of landslide headscarps.

Conclusions

- Method provides a visually appealing way to show the hypothesized genesis of large landslides.
- One can work towards a known geometry to re-create present day conditions. This method predicts the subsurface locations of displaced formations and failure surfaces.
- Human judgment is used, often avoiding errors made by computer applications.
- The downside to this method is that it is not automated and requires much human input. The models for Fishtail and Poncho's Radical Runup took more than two months to create.
- Each model created using this method is only ONE possibility of how the landslide formed.
- The method has presently not been adapted for 3D situations as it would be exponentially more time consuming.

UMR


This talk will be online soon at...
www.umr.edu/~rogersda/cp_megalandslides