# LESSONS ON SITE CHARACTERIZATION GLEANED FROM FORENSIC STUDIES

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# KARL TERZAGHI

- Austrian engineer 1883-1963
- Graduate training in geomorphology
- World traveler and astute observer of nature
- Fathered soil mechanics
- Awarded 4 Norman Medals
- Promoted appreciation of engineering geology by civil engineering profession

# TERZAGHI'S METHOD

- Study geology and geomorphology of region surrounding project site
- Gather all forms of existing data, including geologic, soils, hydrologic, meteorlogic
- Identify "missing gaps" in geo information
- Make on-the-ground reconnaissance of the site; note dominant erosional processes
- Formulate a working hypothesis regarding the nature of likely subsurface conditions
- Develop plan of site exploration, designed to fill missing gaps

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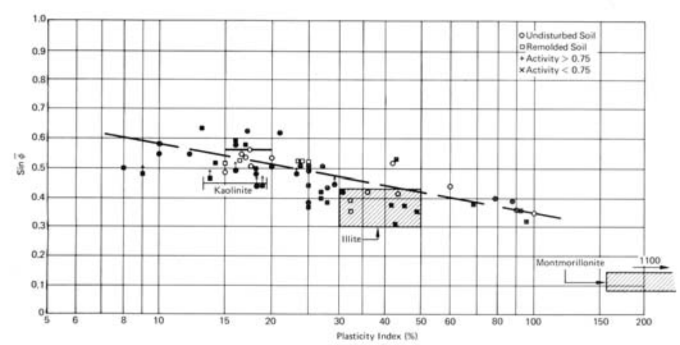
# TERZAGHI'S REPORTS

His first report was a summary of site geology and what he perceived to be the data gaps

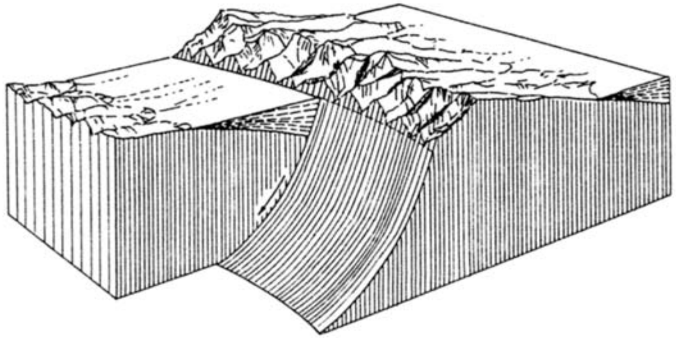
The second report summarized the site specific investigation and either characterized site conditions or demanded additional work

Terzaghi made thorough use of ongoing construction observations to verify assumed site conditions




Always made provisions for changing plans whenever different conditions were observed

# EXPERIENCE

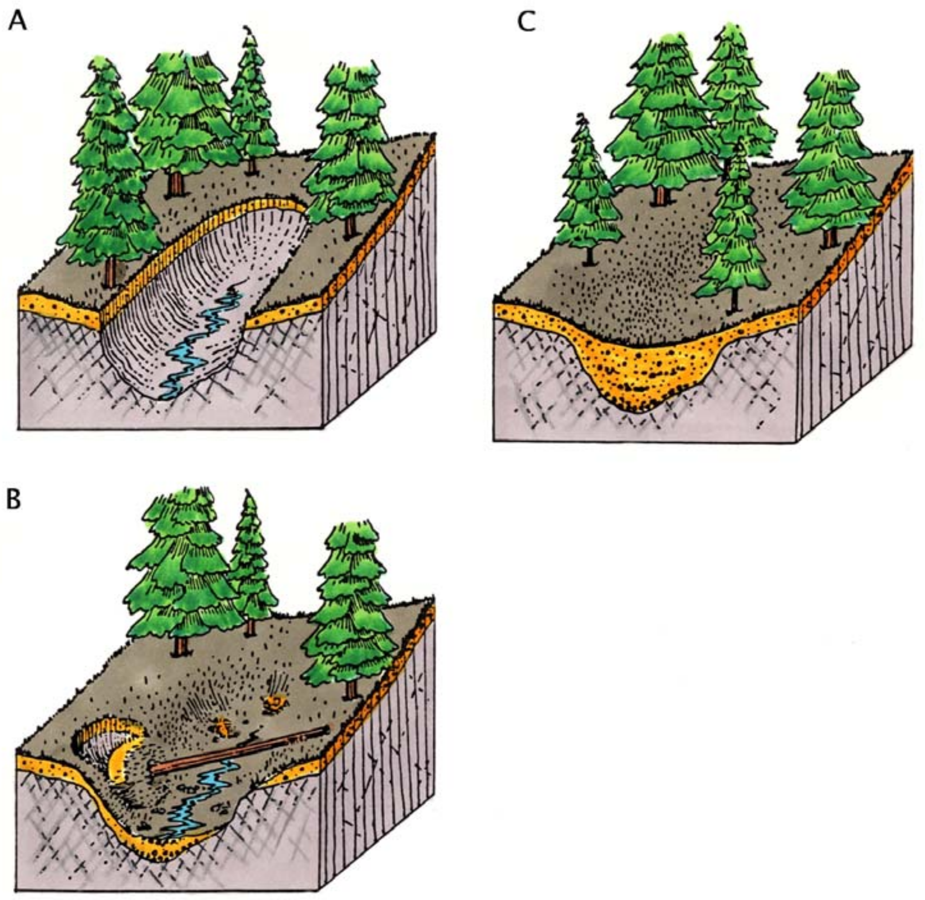


Geologists only recognize those features with which they have accumulated substantive experience

Mis-characterization most often occurs when people making the examinations have little previous experience in the area


Geologists use different technical terms, based on their experience, e.g. listric faults versus landslide slip surfaces, or colluvium vs slide debris

# THE COLLUVIUM CATCH ALL




- Colluvium is loose, heterogeneous, and incoherent mass of soil material and/or rock fragments deposited by rainwash, sheet wash, or downslope creep

- Block diagrams showing cycle of colluviual deposition and erosion

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# Technical terms connote genesis

- Slide debris is often mistaken for colluvium because the geologist doesn't see a slip surface

- Loose soil debris on a grassy slope will be deposited without a shear surface

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- The Dec 31, 1933-Jan 1, 1934 Montrose-LaCresenta debris flows damaged or destroyed 600 homes and killed 44. 600,000 cubic yards of material was deposited on the fan in one evening.

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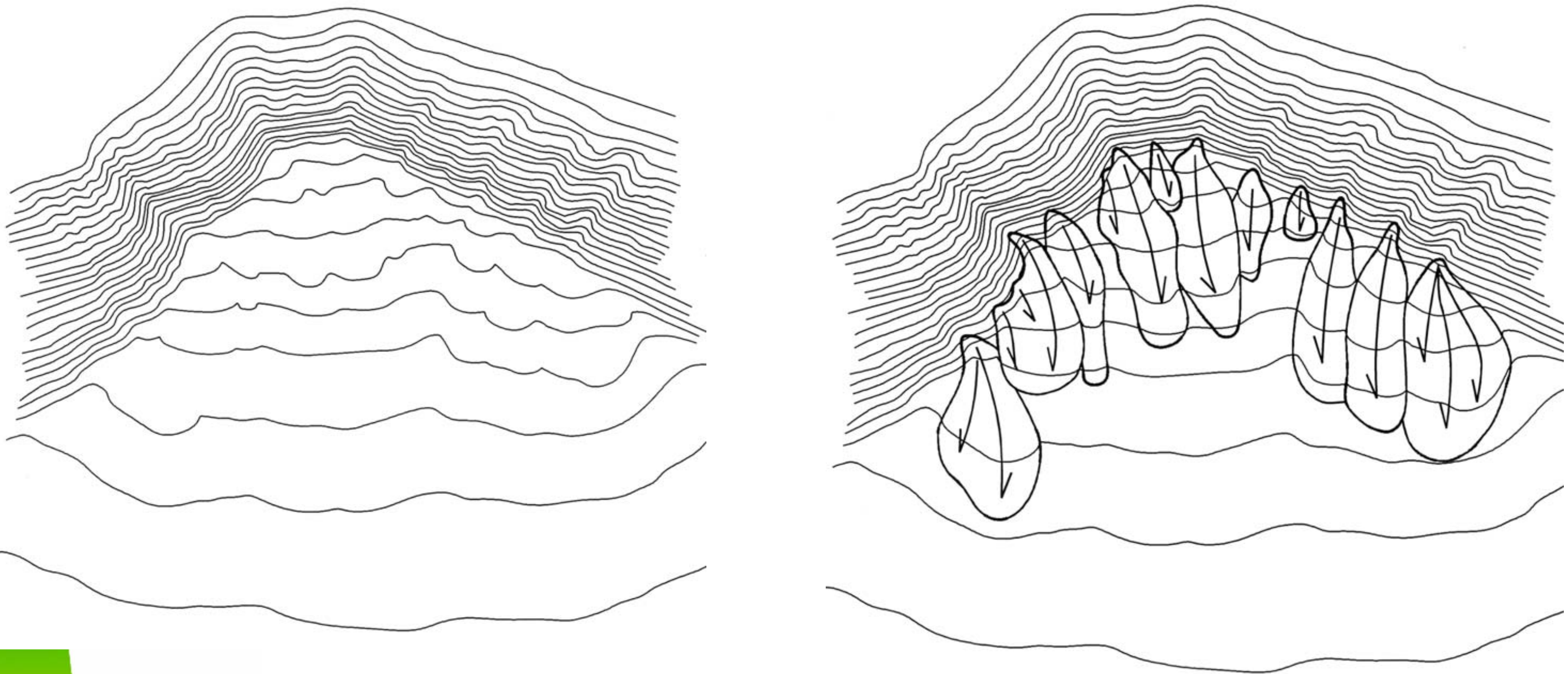
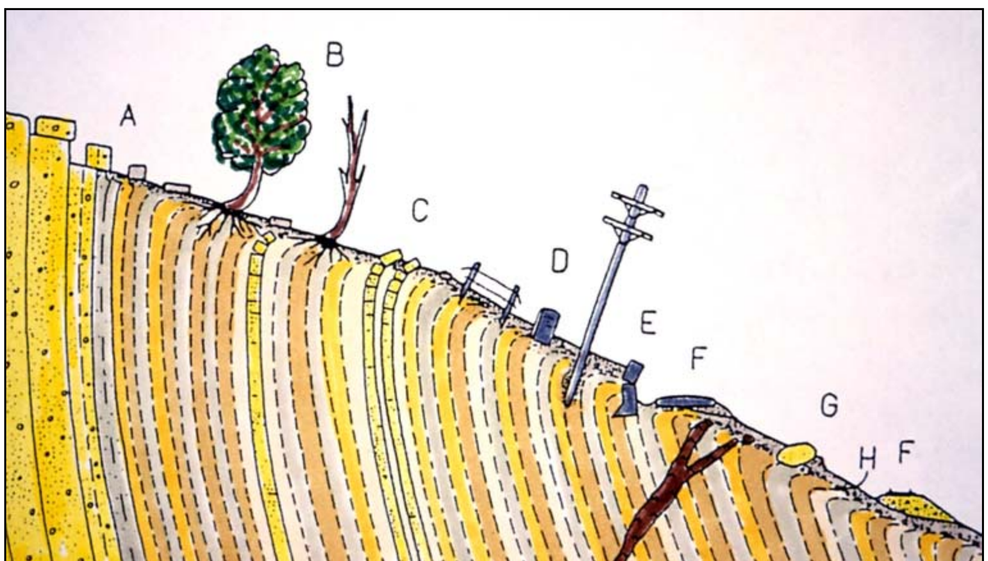


- **Many mapped alluvial fans (Qal) are actually debris fans, constructed by countless series of coalescing debris flows. One trench can expose the character and genesis of underlying material. If it is matrix-supported, it was likely deposited in a debris flow.**

# MATRIX SUPORTED MATERIALS

- **Debris flow deposits are typically deposited on channel slopes around 10%**
- **They are characterized by fine grained matrix between clasts, large variation in clast and particle sizes, and often, by inverse sorting**




# SLOPE CREEP

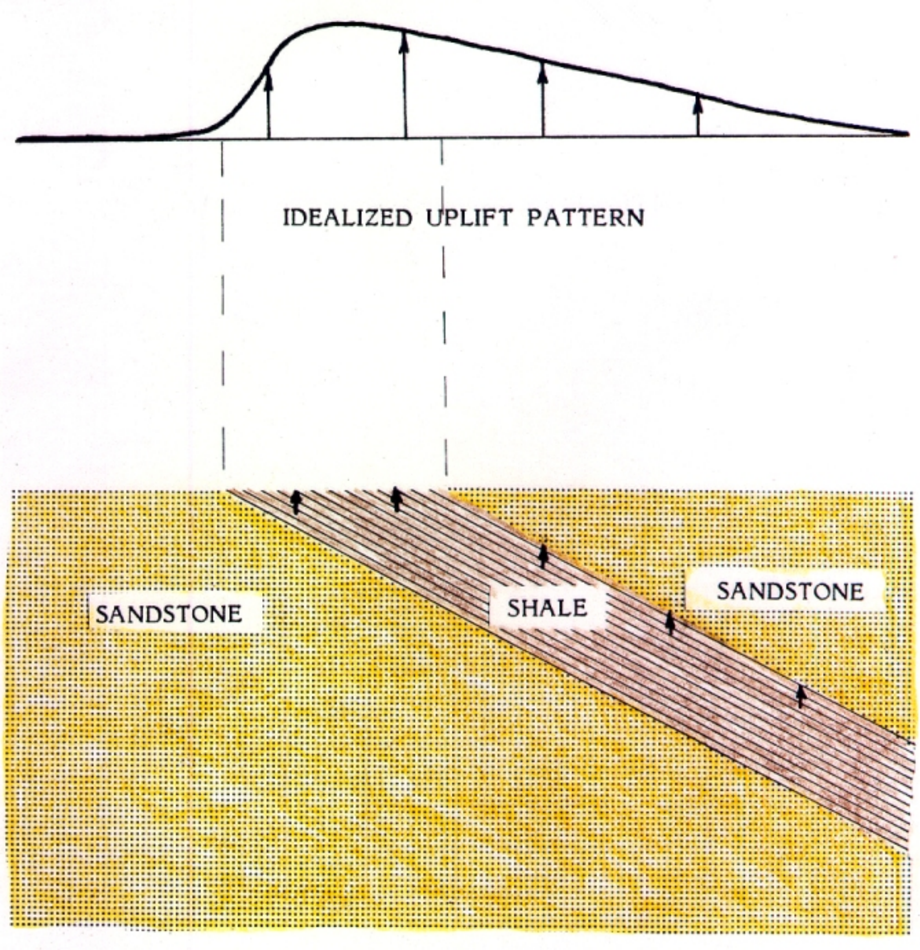
- Geologists are often asked to estimate depth and magnitude of slope creep
- Creep is a function of soil plasticity, slope inclination, seasonal moisture variation and height of slope

**Slope creep can exert passive soil pressures against embedded foundations**

# AGING FACTORS

- Clayey soils and argillaceous materials are susceptible to slope creep. Be careful to advise clients of likely movements and need for ongoing maintenance
- These comparative views of the same highway cut were taken in 1954 and 1986, 32 years apart. The benches were gone.

# DIFFERENTIAL HEAVE



IDEALIZED SUBSURFACE CROSS-SECTION

- **Differential heave is a recurring problem whenever expansive clay shales are sandwiched between non-expansive beds, as sketched at left**
- **Expansive soils are the #2 cause of property loss in the United States, second only to dry rot**

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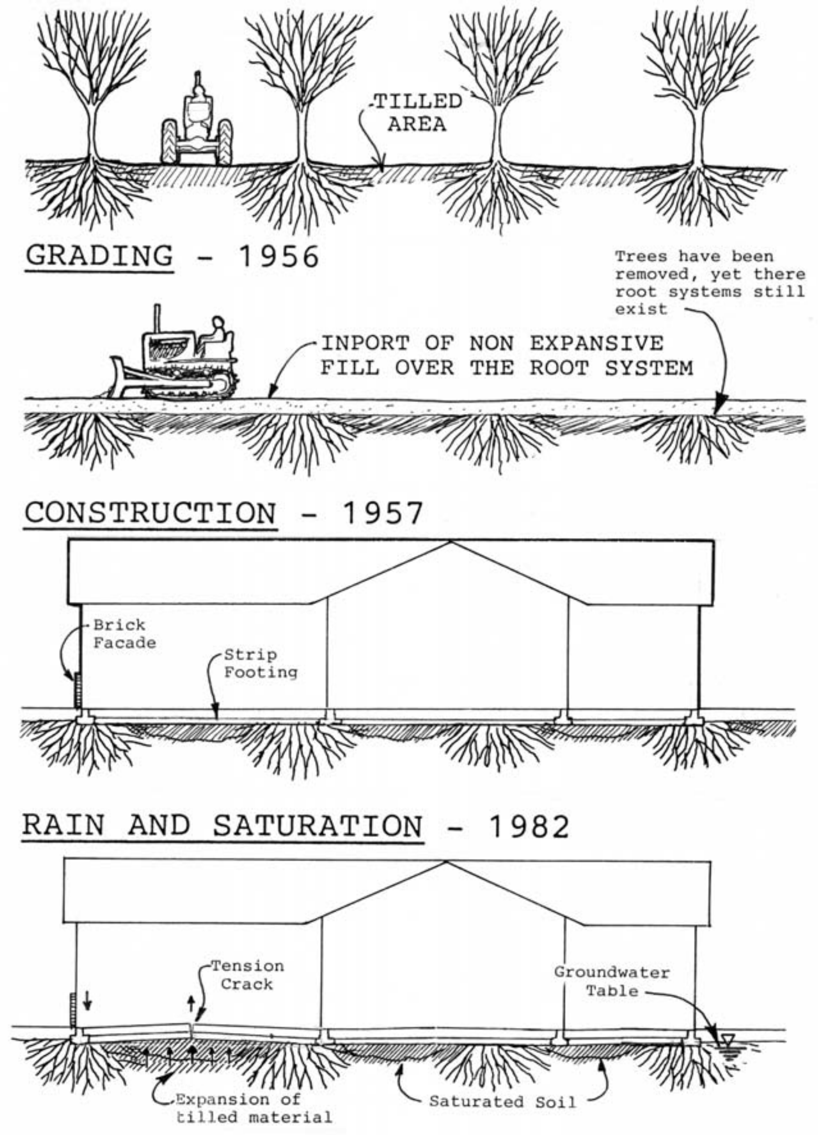
# PAST LAND USEAGE




- **A preliminary check of aerial photos is essential to understand what a site was used for prior to anticipated construction**
- **This shows the case of a subdivision in San Jose, CA which was built over an old orchard**

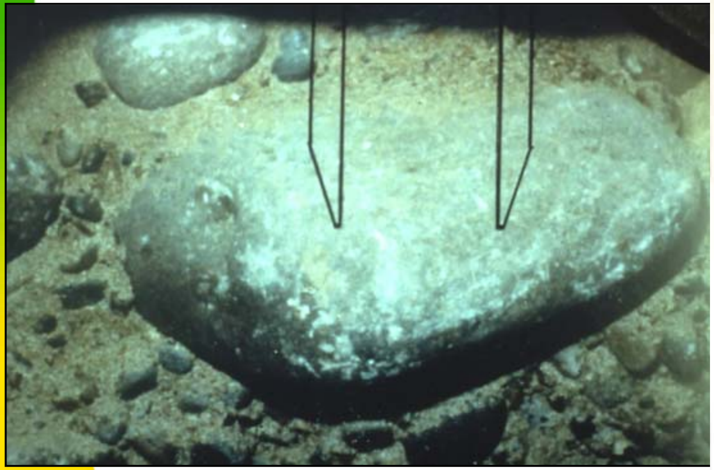
# FILLS AND OLD CHANNELS

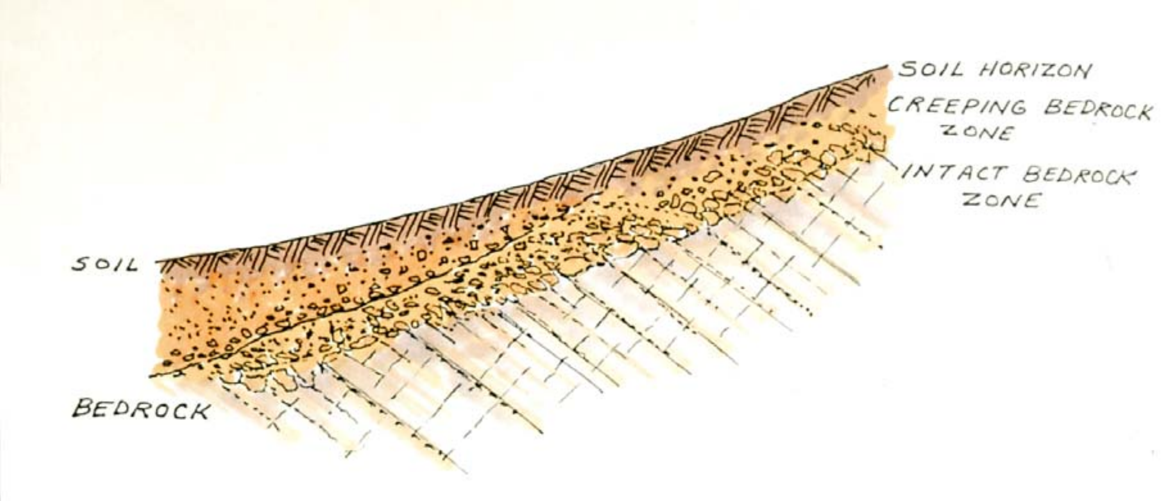
- **Check old maps and air photos to see where channels and sloughs were located prior to infilling, draining or re-direction.  This is a common problem in urban areas**

# INTERPRETING SUBSURFACE DATA

- Soils engineers tend to focus on providing foundation recommendations, not on detecting geologic contacts
- Proper interpretation of subsurface information requires experience on part of the drillers and the logging geologist
- Circulation problems can negate accurate assessments of cuttings depth and weak seams of horizons are easily missed

# CLASTS LARGER THAN SAMPLER SHOE






- Bedrock contacts are commonly misidentified when the sampler shoe encounters a floater of greater diameter, as sketched at lower left

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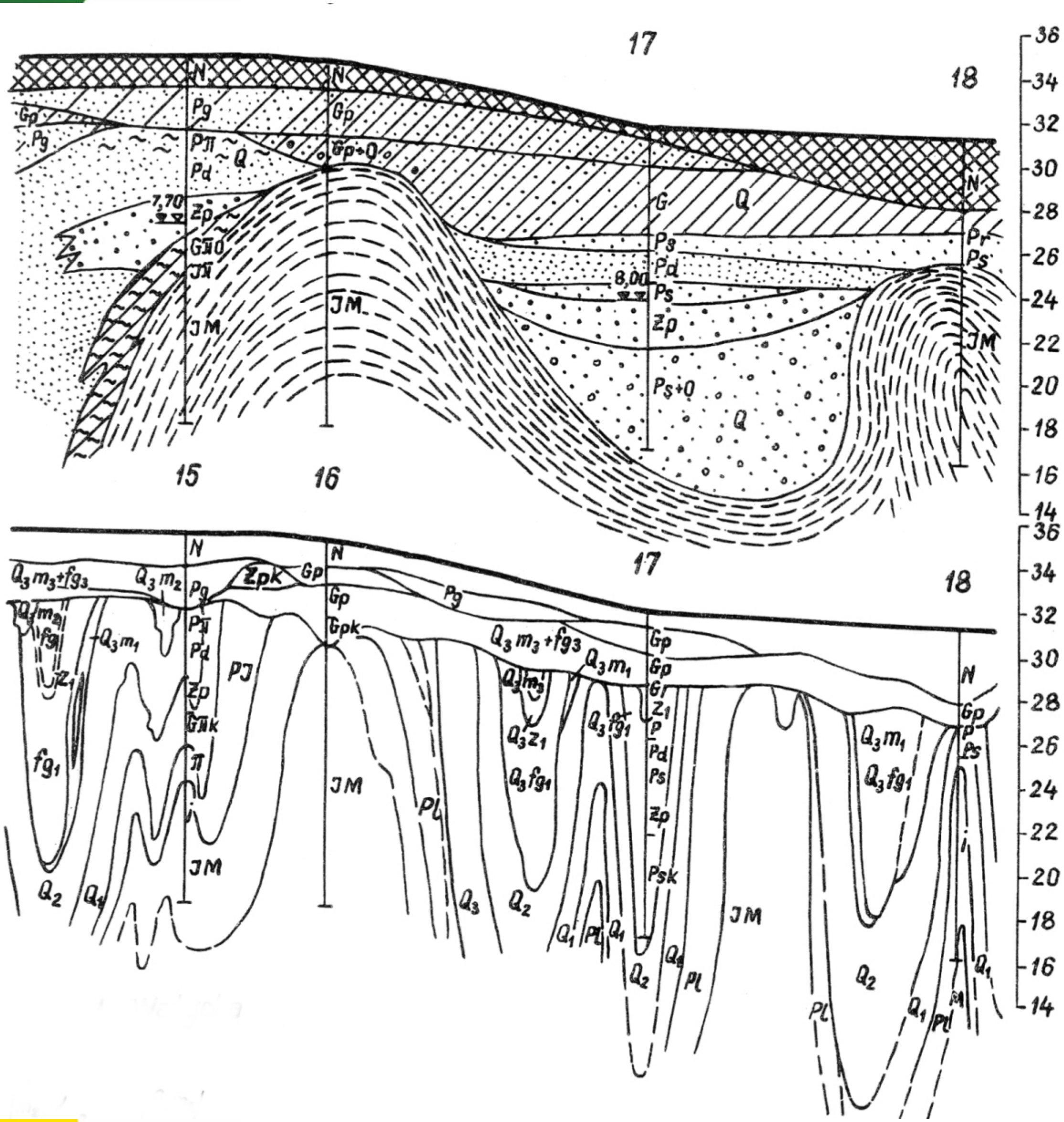
# MISINTERPRETATION OF DATA

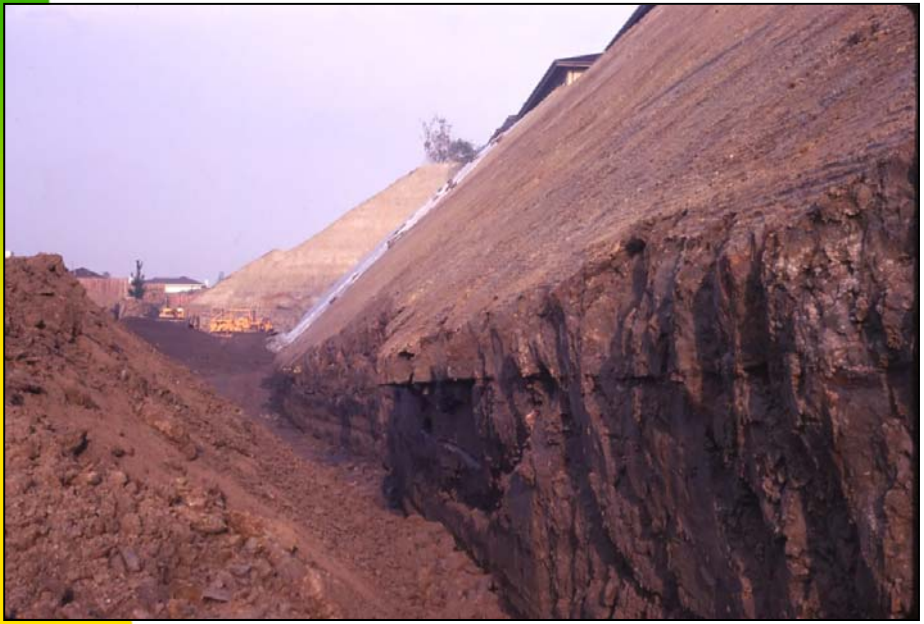



- **Subsurface data is easily misinterpreted when working in tectonically active terrain.**
- **This shows before construction (upper) and after excavation (lower) cross sections of the same site**




**Exploratory trenches can effectively expose geologic structures and the nature or genesis of key contacts**

# RECOGNIZING OLD LANDSLIDES

- Old landslide features can be difficult to discern, even for experienced engineering geologists
- One needs to be “looking” for such features in order to recognize them
- Case at lower left was old slide reactivated on slip plane inclined just 3 degrees, without any visible moisture

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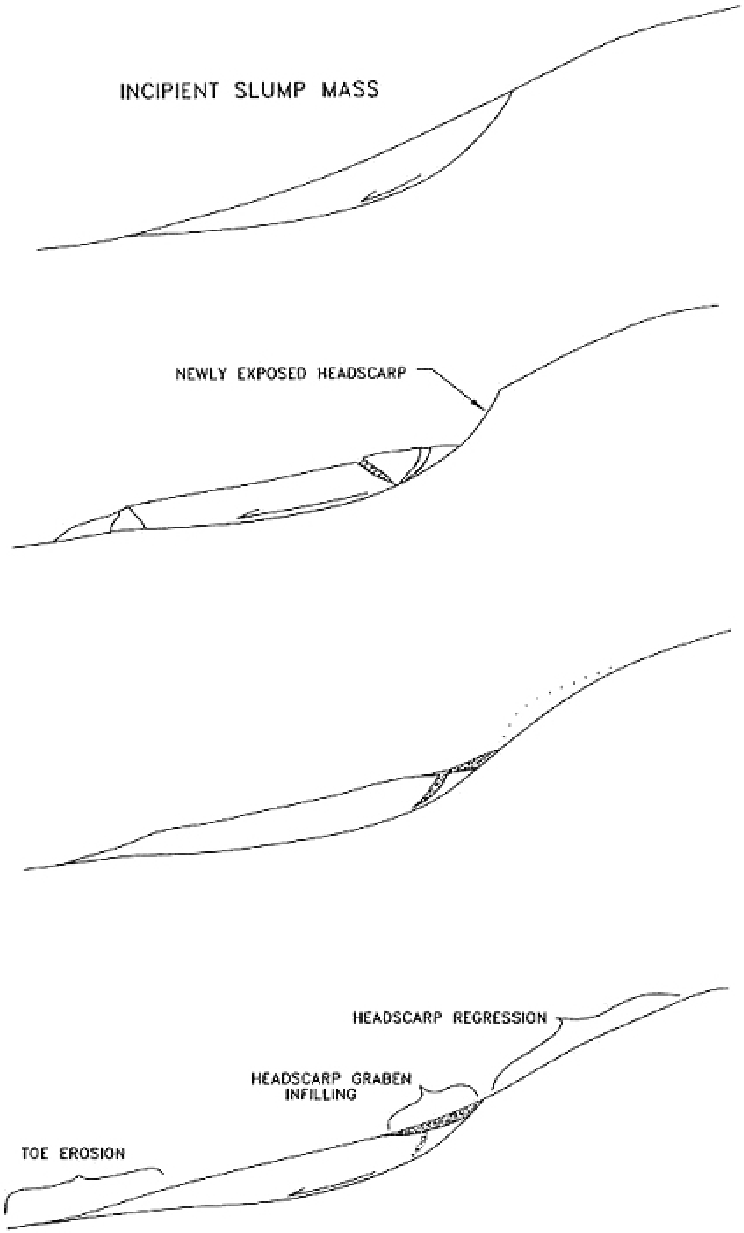
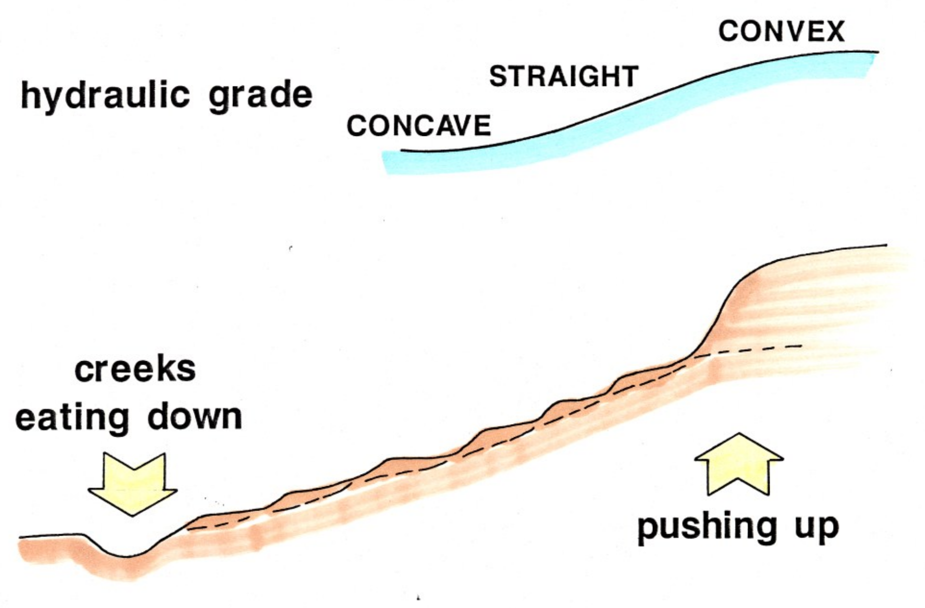
# TOPOGRAPHIC EXPRESSION




- **A key indicator of past landslippage is anomalous topographic expression, which becomes increasingly mollified with age, as shown in profiles at left**




# TOPOGRAPHIC EXPRESSION OF LANDSLIDES

- **Landslides tend to form coalescing complexes, with hummocky topography and deranged drainage patterns. Toe undercutting or tectonic uplift are common triggers**

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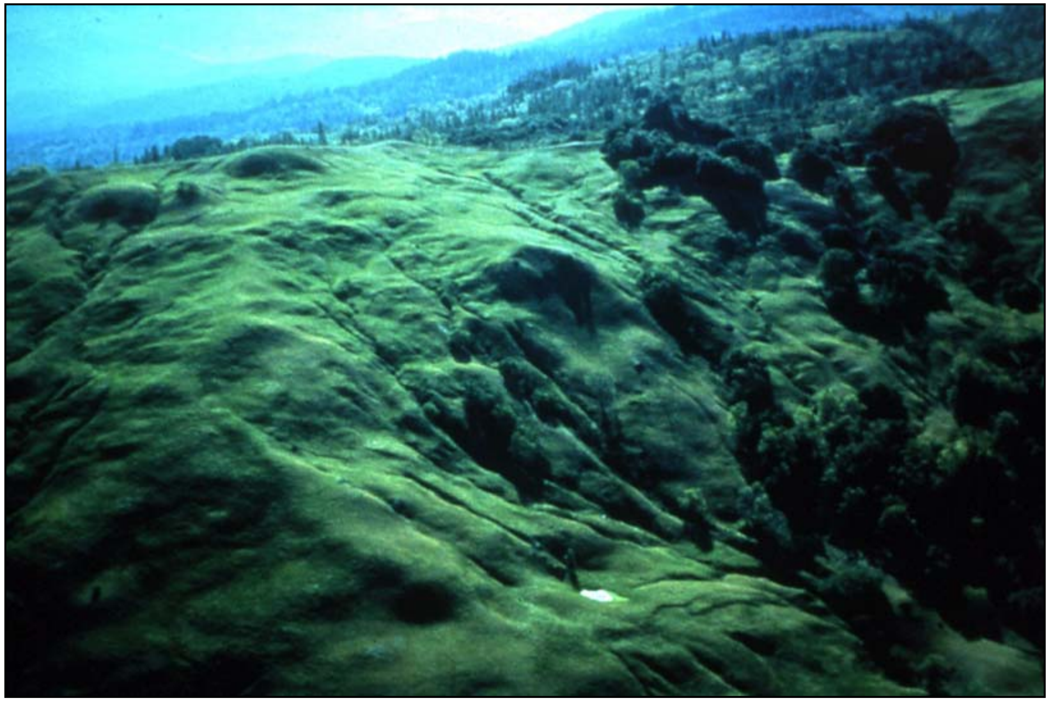
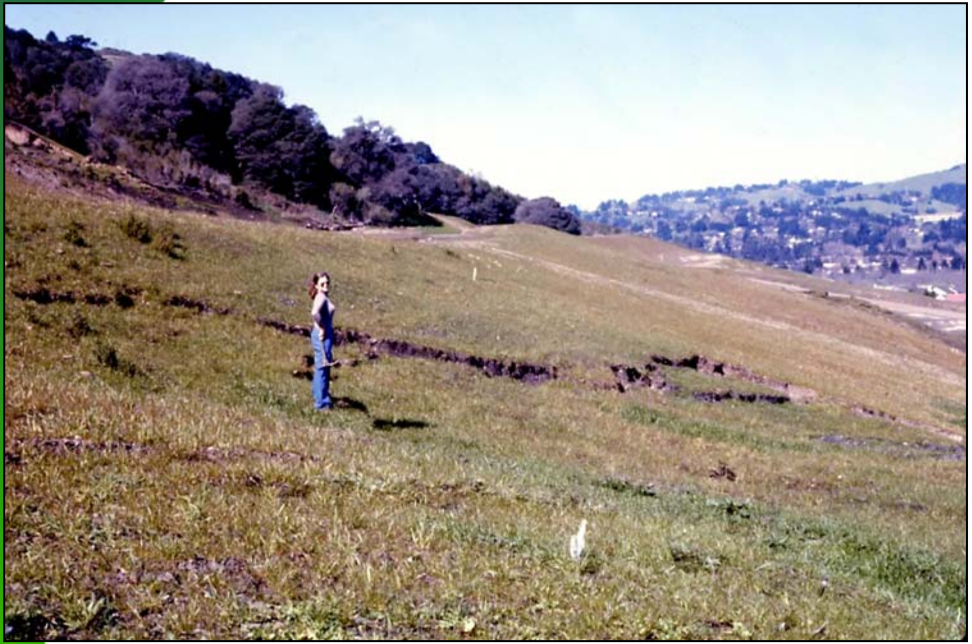
# RECOGNIZING OLD LANDSLIDES



Recent landslides like those at left are easily noticed, but older complexes can be difficult to discern, especially under thick tree cover.  The hummocky topography in the right image is typical of landslide-prone terrain.

# INCIPIENT LANDSLIPPAGE




- Incipient landslides are those that are beginning to fail, but have not fully ruptured
- They are easily identified by their arcuate tensile scarps crossing otherwise intact slopes

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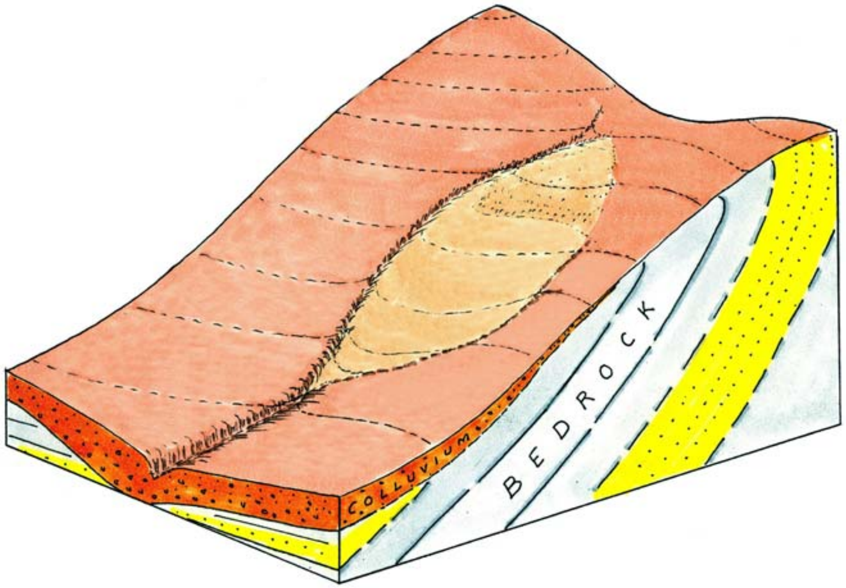
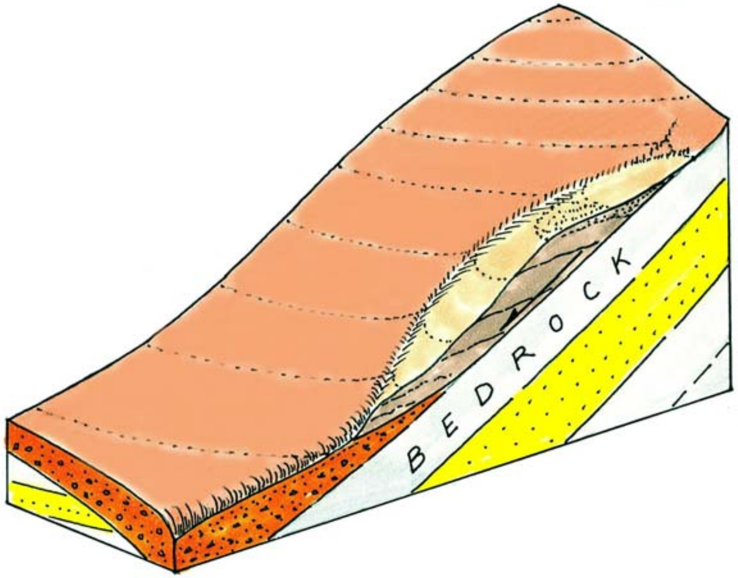
# OLD BEDROCK LANDSLIDES

DEEP-SEATED BEDROCK LANDSLIDE




CUT-AWAY VIEW OF BEDROCK LANDSLIDE




**Old bedrock landslides can be very difficult to identify. Key indicators are anomalous isolated benches and converging parallel drainages**

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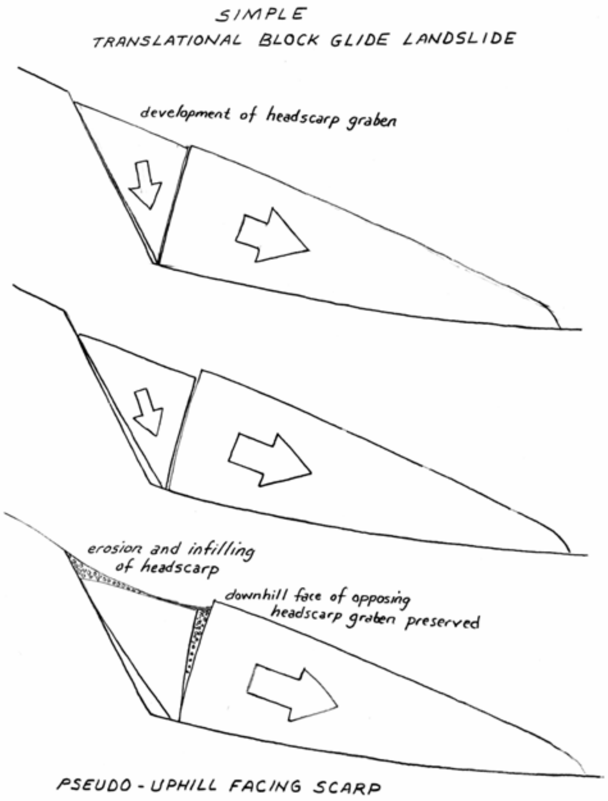
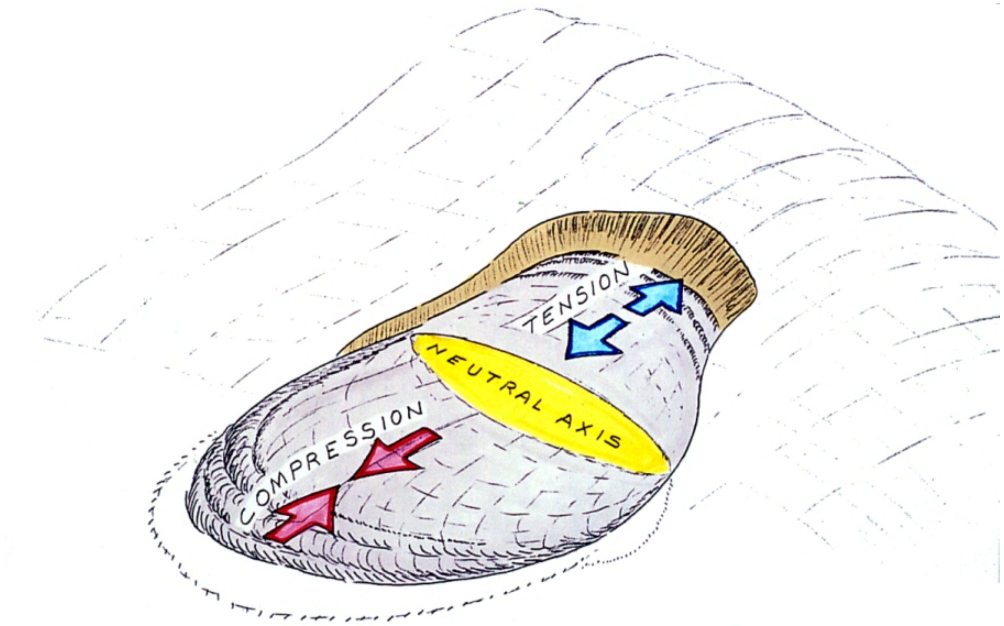
# HEADSCARPS

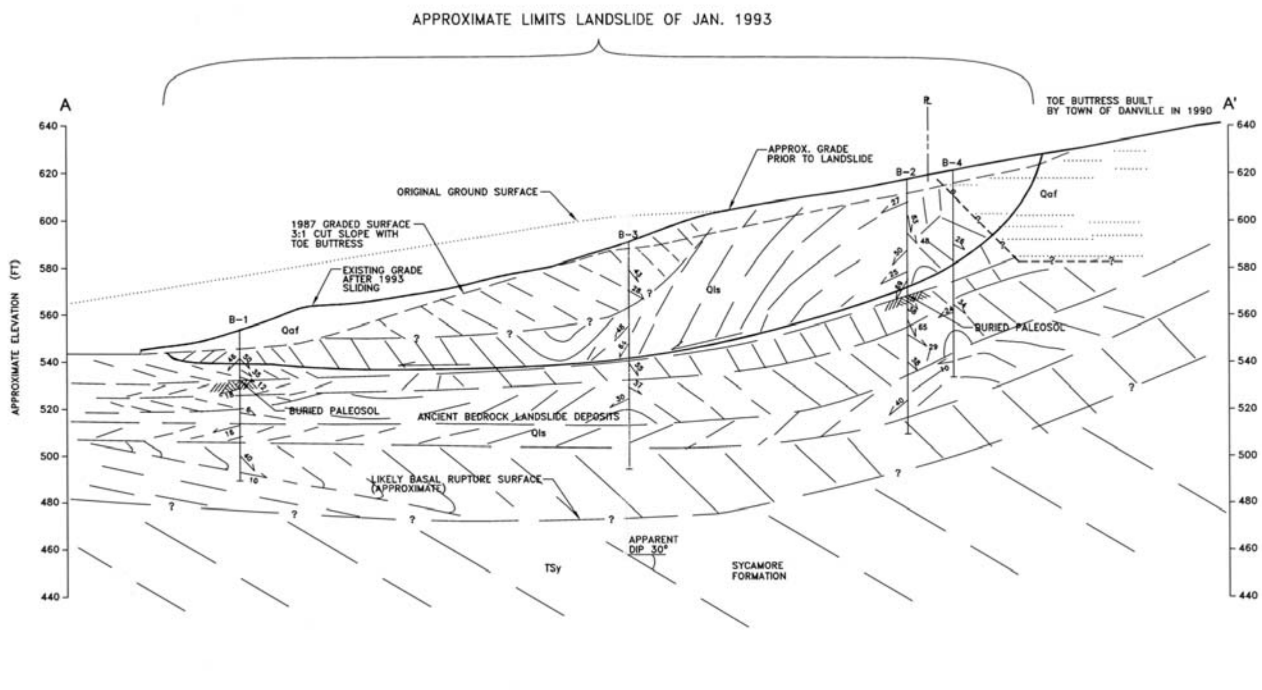



The arcuate nature of a landslide headscarp is due to tensile pull-apart as the slide mass translates downslope. It is easy to estimate the depth of sliding from the opposing scarps

# BUCKET AUGERS

**Bedrock landslides are best explored using large diameter bucket auger borings, which can be downhole logged**




GEOLOGIC CROSS-SECTION A-A' SHOWING APPROXIMATE STRUCTURE WITHIN LANDSLIDE MASS

- St. Francis Dam was unknowingly constructed against a paleolandslide developed in pre Cambrian age Pelona Schist in 1924-26.

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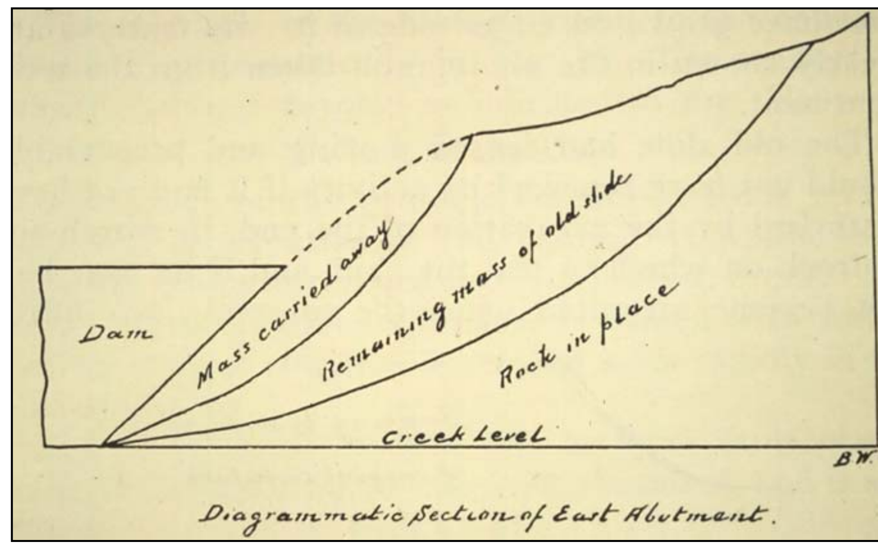


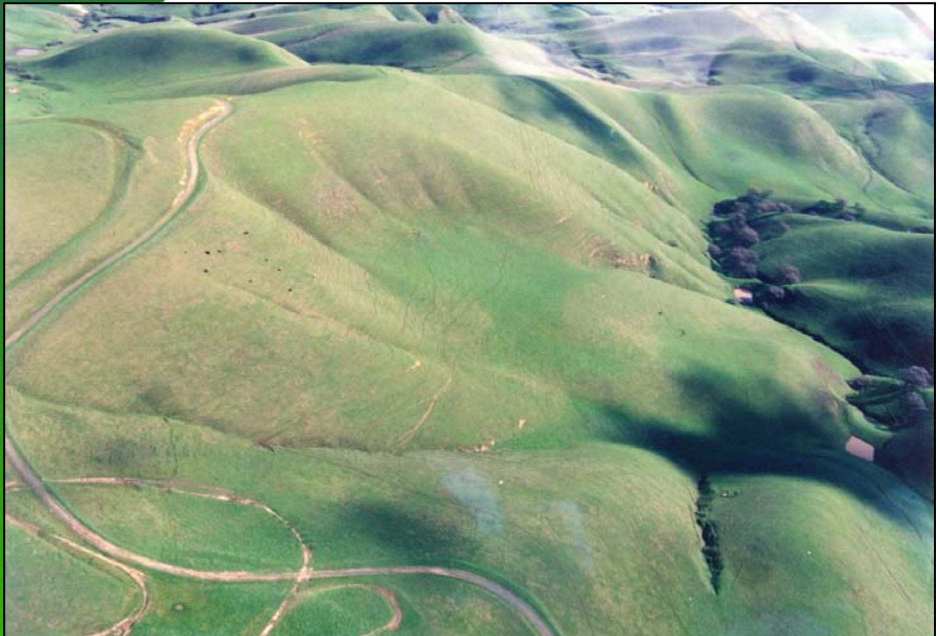

**535 million m$^3$ of schist in the dam's left abutment detached and slid downslope, destroying the dam.  Relaxation movements of up to 3 m were noted at elevations more than 60 m above the left abutment**

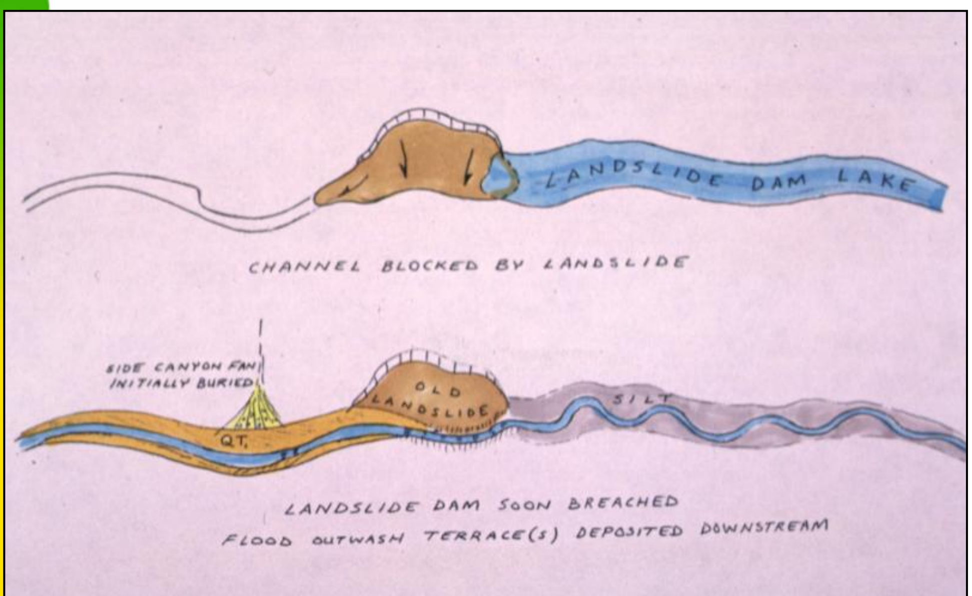
# SAN GABRIEL DAM

- **The San Gabriel Dam at the Forks Site would have been the largest dam in the world when construction began in September 1928**
- **These views show right abutment excavations at the Forks site in June 1929**
- **Plans called for 200,000 $yds^3$ excavation on each abutment**

**Three views showing before (left) and during (middle) and after (right) the massive detonation of the dam’s right abutment. The contractor detonated 87,430 kg of dynamite. On September 16, 1929 a massive slide of the right abutment occurred, bringing down 153,000 m of additional rock. This led to an investigation and eventual cancellation of the project by the State of California.**

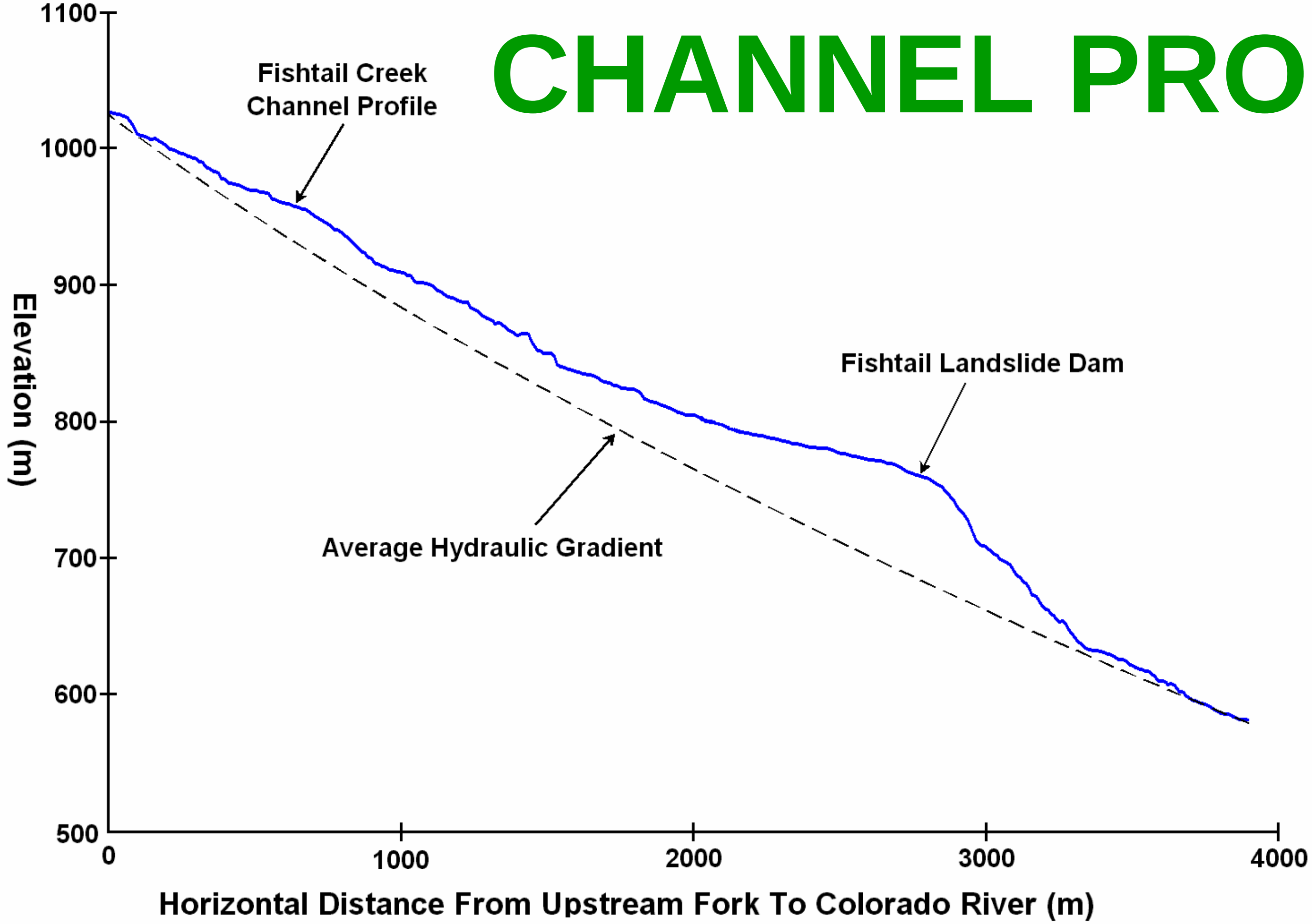
# LANDSLIDE DAMS






**Landslide dams perturb channel profiles. Lessened gradient upstream of blockage and increased gradients through the obstruction, as shown above. Channels often swing around the obstructions in a convex outward pattern.**

# CHANNEL PROFILE




- **Example of a channel profile perturbed by landslide damming in Fishtail Creek, Grand Canyon. Note lower gradient upstream of obstruction and increased gradient on downstream side.**

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# CHANNEL SCOUR

- Engineering geologists are often asked to estimate depth of channel scour, especially for bridges
- These are during and after views of a desert flash flood in June 1969 which developed 8 feet high standing waves. Note children for scale in lower image, taken a few weeks later.

# Arroyo Pasajero Wash Out

- A flash flood on March 10, 1995 brought a peak flow of 33,000 cfs through a constricted overcrossing for Interstate 5 near Coalinga, CA.  The channel was downcut by almost 30 feet, undermining the bridge caissons and dropping the twin spans.  7 people were killed.

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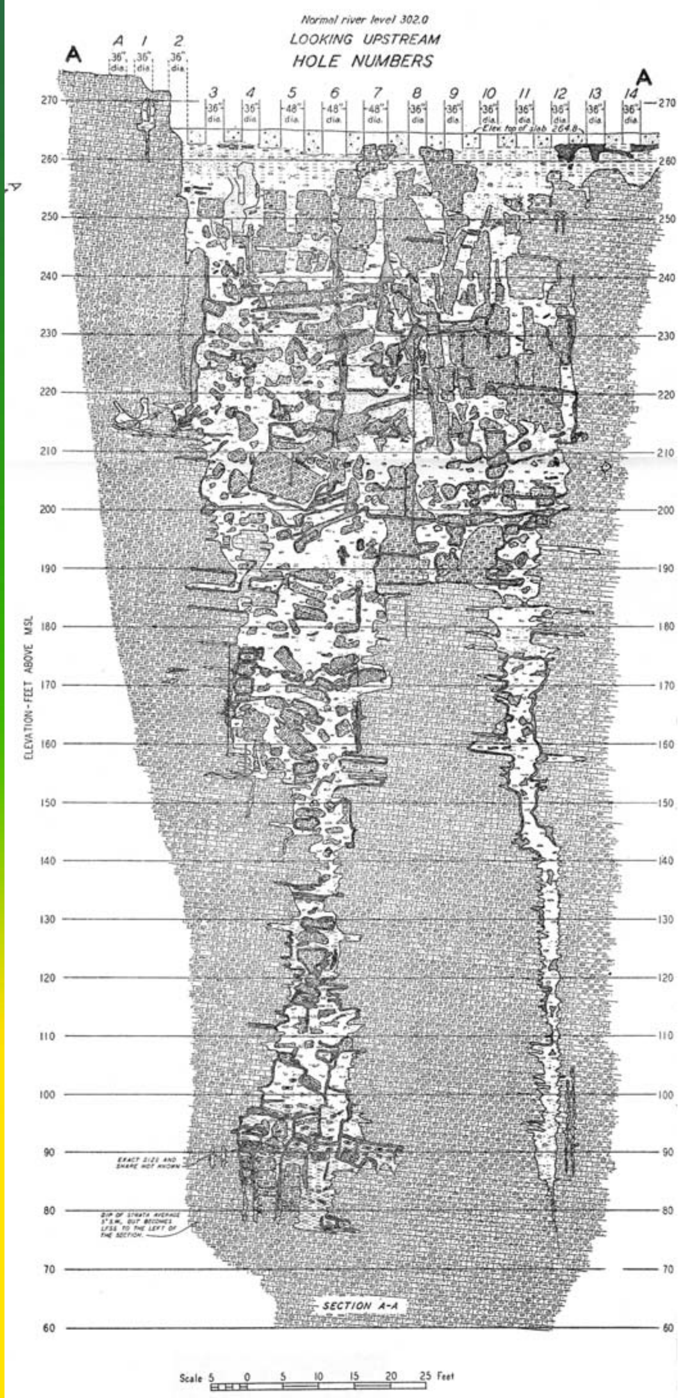
# DAMS THAT WOULD NOT HOLD WATER

Escondido (upper) and Morena (lower) Dams were both constructed around 1900 in southern California. They lost large volumes of water through alluvial gravels beneath the embankments.

Escondido Dam never filled beyond 2/3 capacity, losing 100,000 gpd.  Morena lost between 33,500 to 58,000 gpd, depending on head.

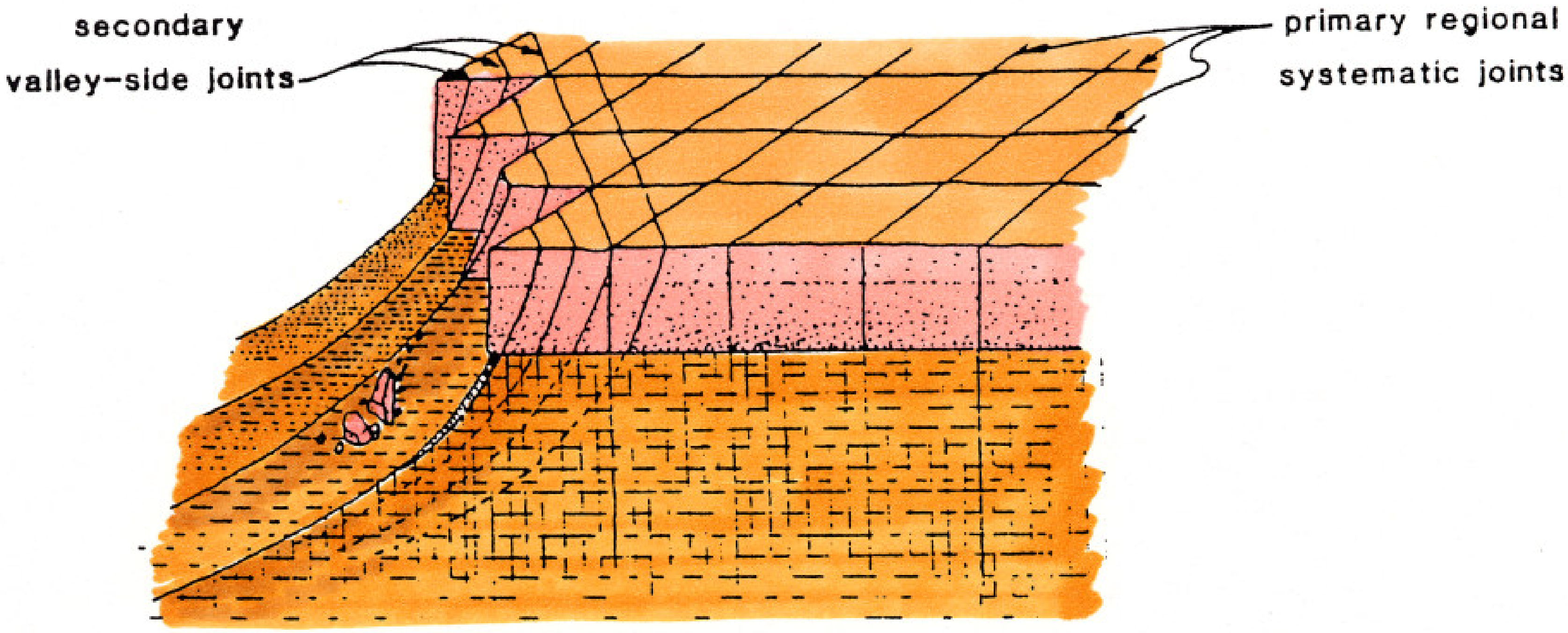



# KARST FOUNDATIONS

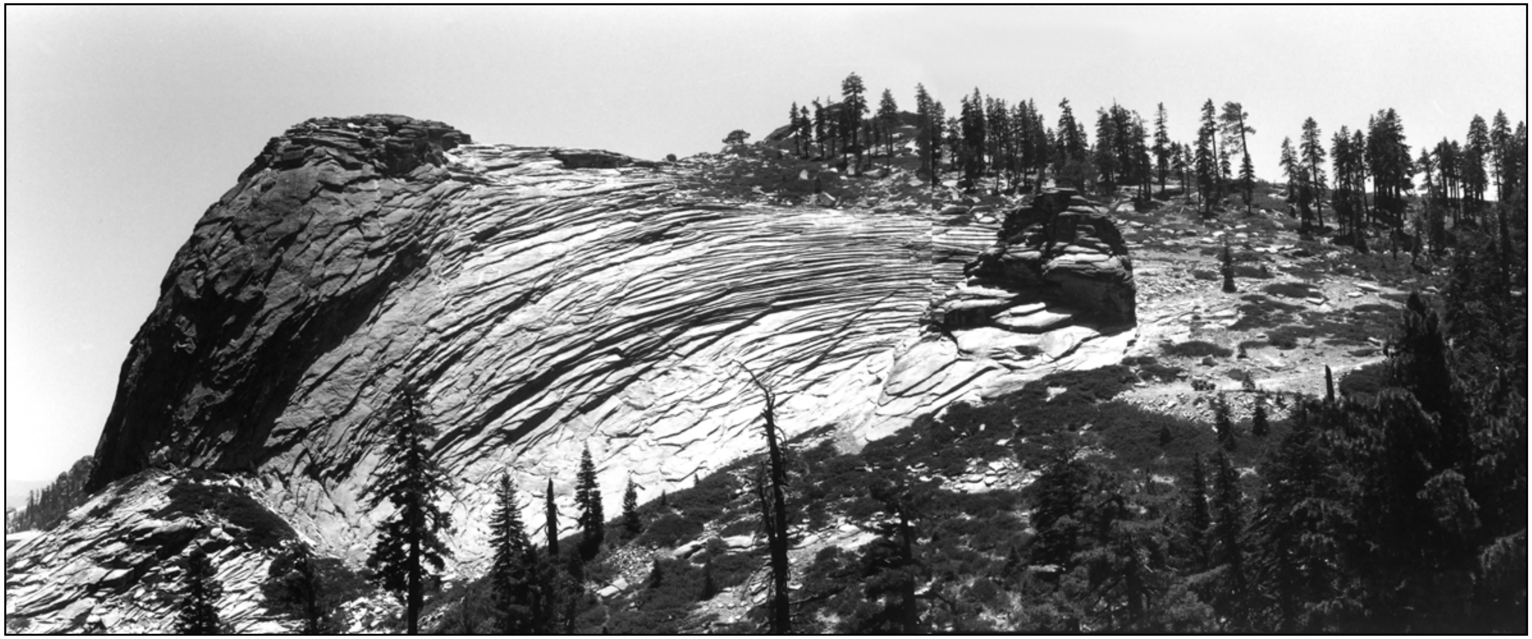
- Cross section through the foundation for Kentucky Dam on the Tennessee River (TVA, 1949).
- The Pleistocene Valley floor was about 70 feet lower than at present, with deep solution cavities extending 200 feet beneath the channel
- 734,000 sacks of cement were pumped into the foundation during construction (20,000 $m^3$)

- **Anchor Dam was built by the U.S. Bureau of Reclamation 56 km west of Thermopolis, WY in 1957-60. Reservoir water seeps downward into karstified redbeds of the Permian age Goose Egg and Triassic age Chugwater formations. The dam has never retained any significant volume of water.**

# OUT-OF-PLANE DISCONTINUITIES




- Valley-side stress relief joints tend to form parallel to free cliff faces, in response to stress changes engendered by excavation of the valleys, slope creep and thermally-induced stresses.  They are dangerous because they cannot be seen in casual mapping.



- **Exfoliation joints exposed in glacial cirque of Little Shuteye Pass, in California's Sierra Nevada Mountains, in the Mt. Givens granodiorite**

# SHEET JOINTS

- Sheet joints, valley side joints or exfoliation joints all describe the same features
- When the valley side is excavated new joints form beneath the unloading
- This caused problems at Mammoth Pool dam site in California, shown here
- Terzaghi recommended placing fill for dam and grouting the joints as construction progressed

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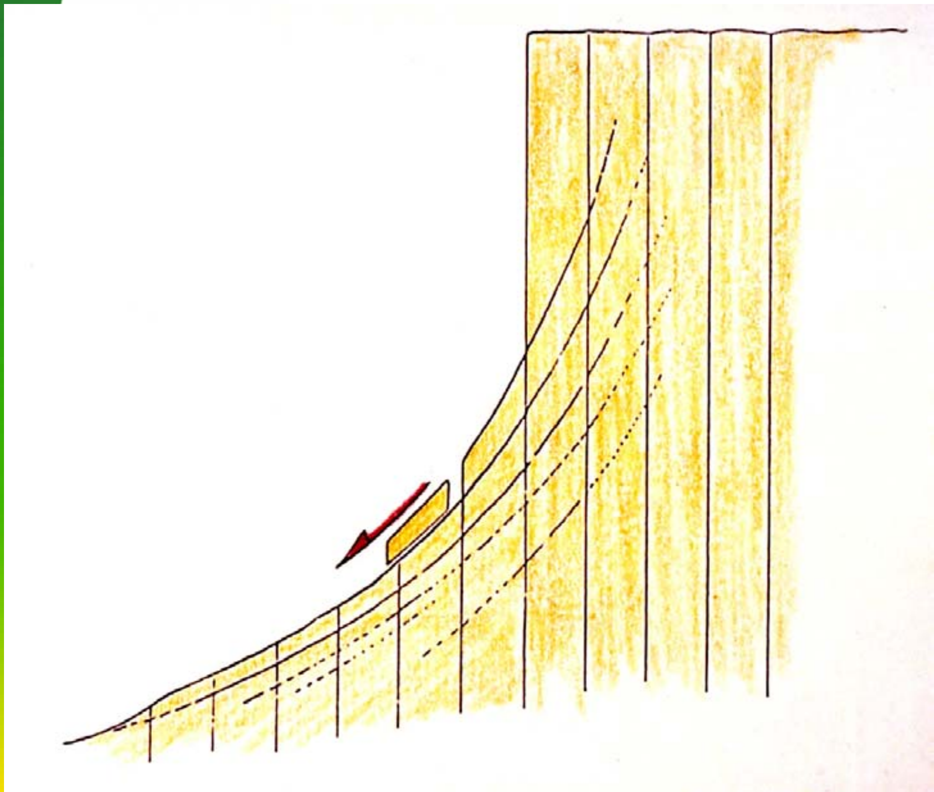
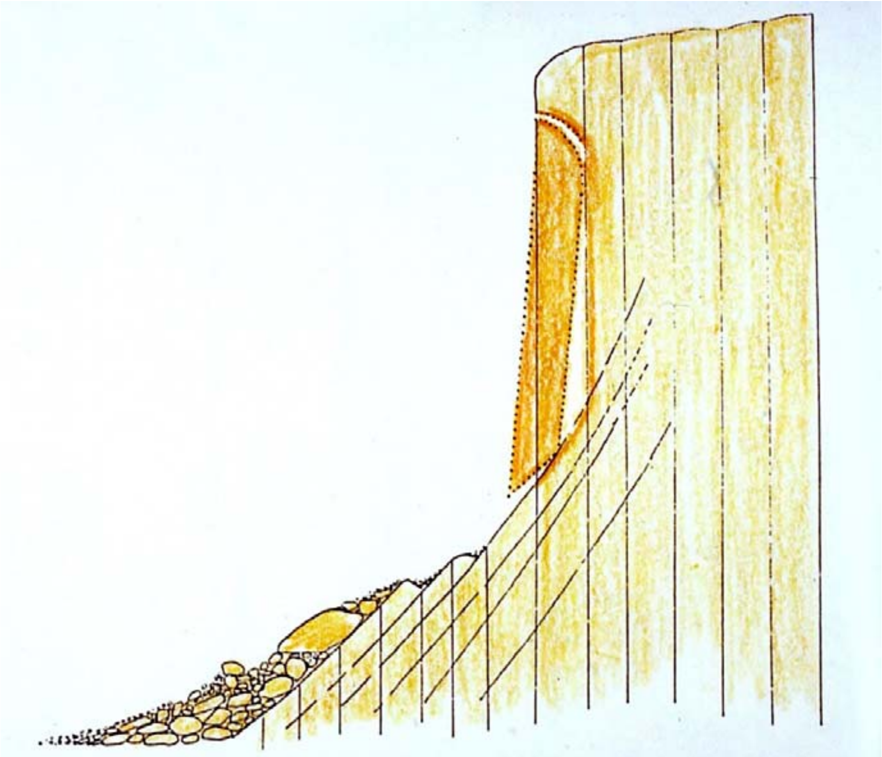
# VALLEY-SIDE JOINT FAILURE MODES





Block glide failure on inclined valley-side joints

- **Valley-side joints are particularly treacherous because they are usually inclined at close to 45-Ø/2 degrees from vertical (around 60 degrees), which offers the least shear resistance to slippage.**

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- **Catastrophic rockfall typical of steeply inclined bluffs with out-of-plane discontinuities.  This example is from 6 Mile Wash in Marble Canyon, Arizona**

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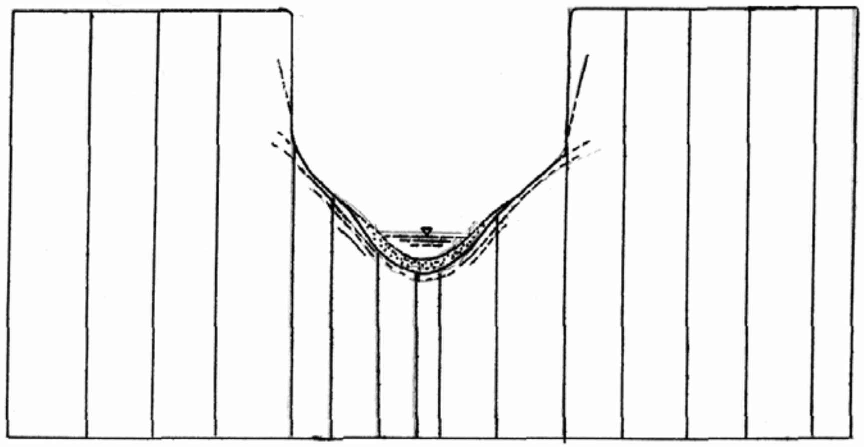
# HAUNCHES OF GLEN CANYON DAM



- **Glen Canyon damsite has prominent haunches formed by curvalinear valley side joints.  The upper vertical walls are controlled by regional systematic joints.**

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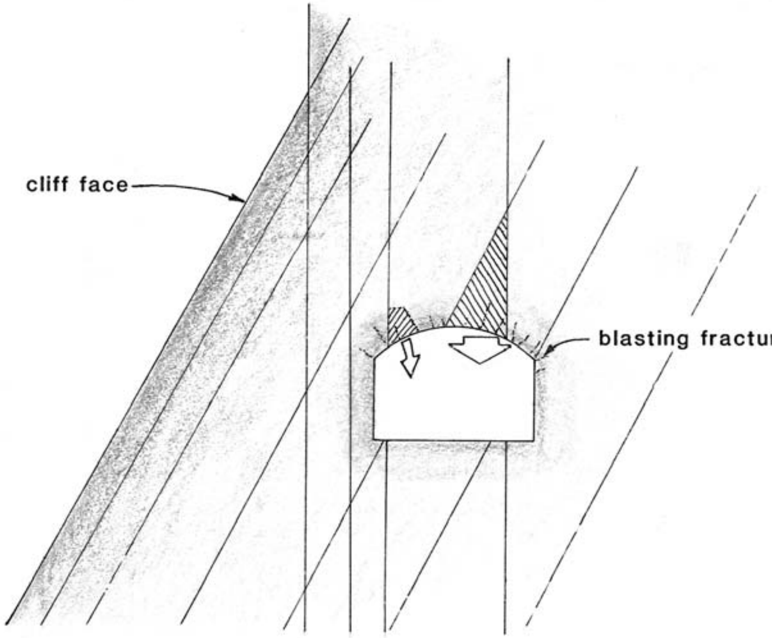
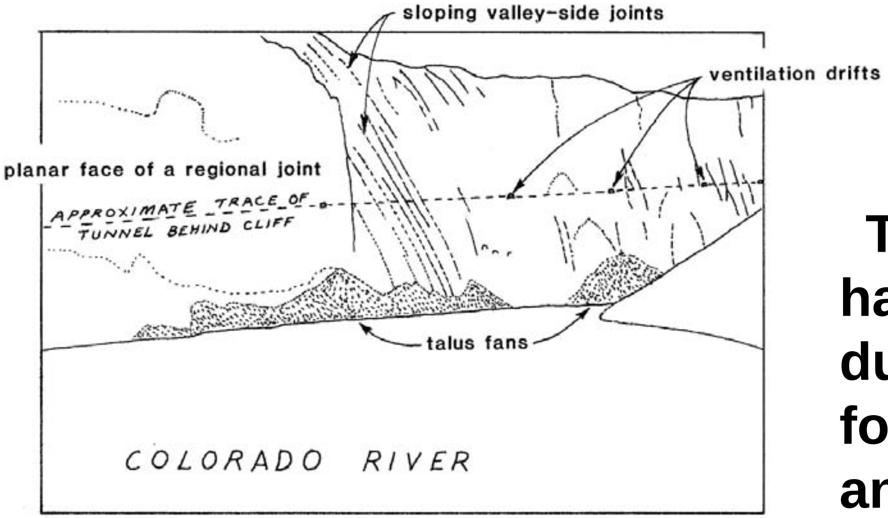
# GLEN CANYON TUNNEL FAILURE

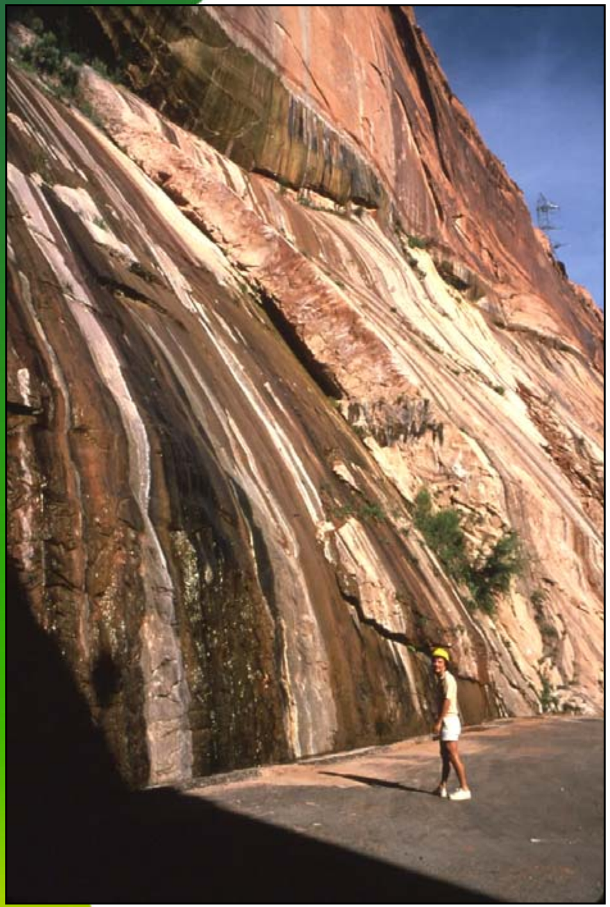


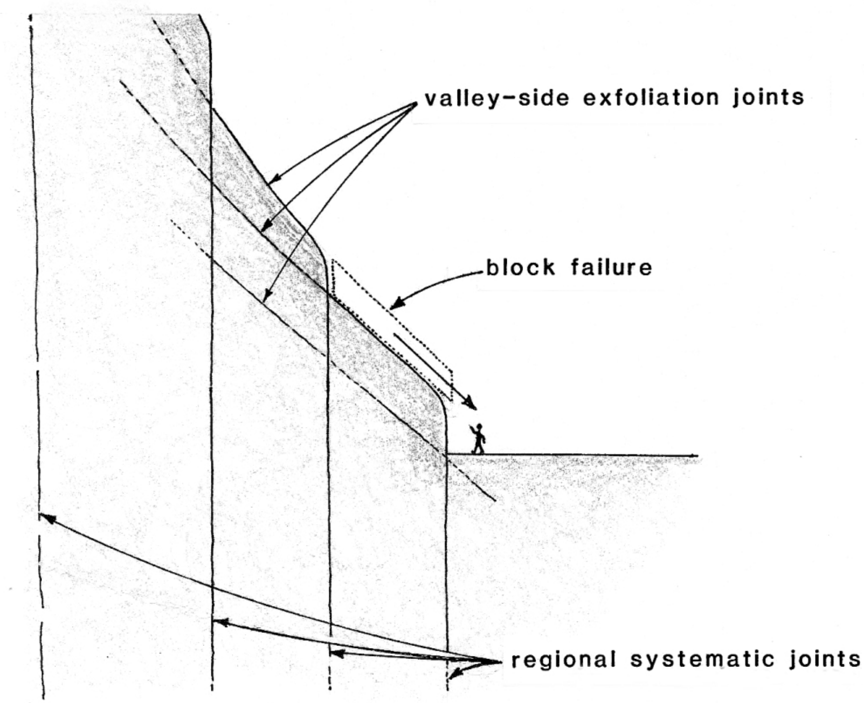

Roof cave-ins in the Glen Canyon Powerplant Service Tunnel during construction in 1958.




**The Glen Canyon Powerplant Tunnel had a series of deadly block failures during excavation because of wedges formed between inclined valley side and systematic joints, sketched above**

# BLOCK FAILURES

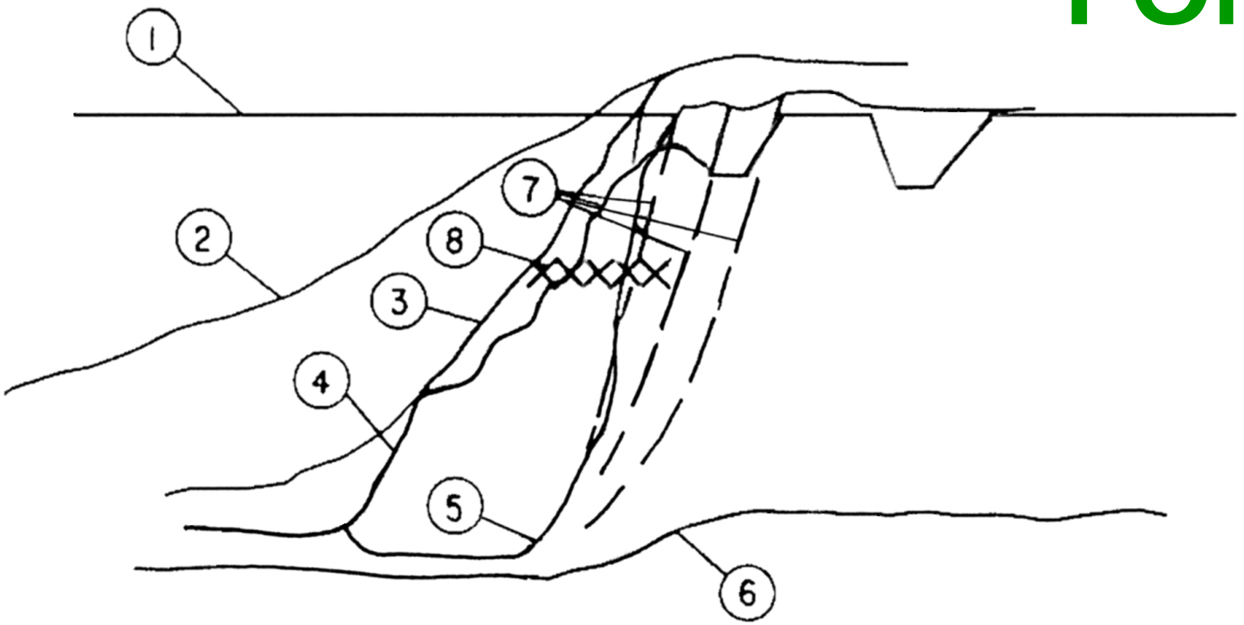





**Valley side joints are inclined. Where these intercept near vertical systematic joints, massive blocks are formed on steep inclines. When these are undercut the blocks slide off. A little bit of water hastens the process by decreasing the friction markedly.**

- Fontenelle Dam came perilously close to failing catastrophically in Sept 1965 during its initial filling. Seepage emanated from the right abutment. The same failure mode befell Teton Dam 11 years later.

# FONTENELLE DAM

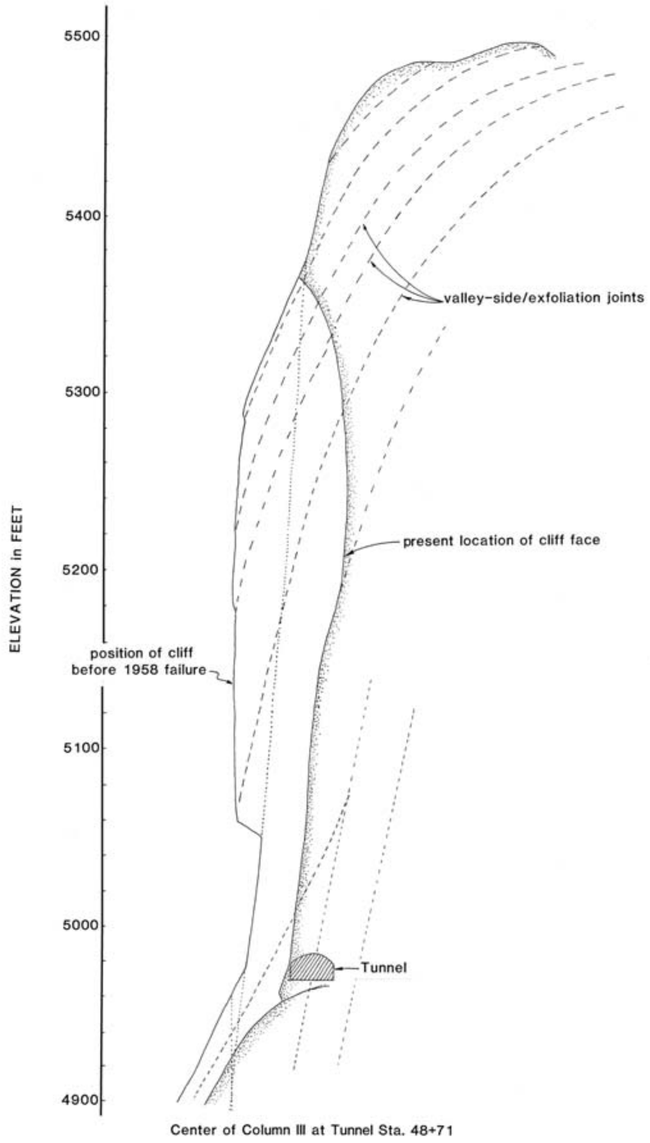


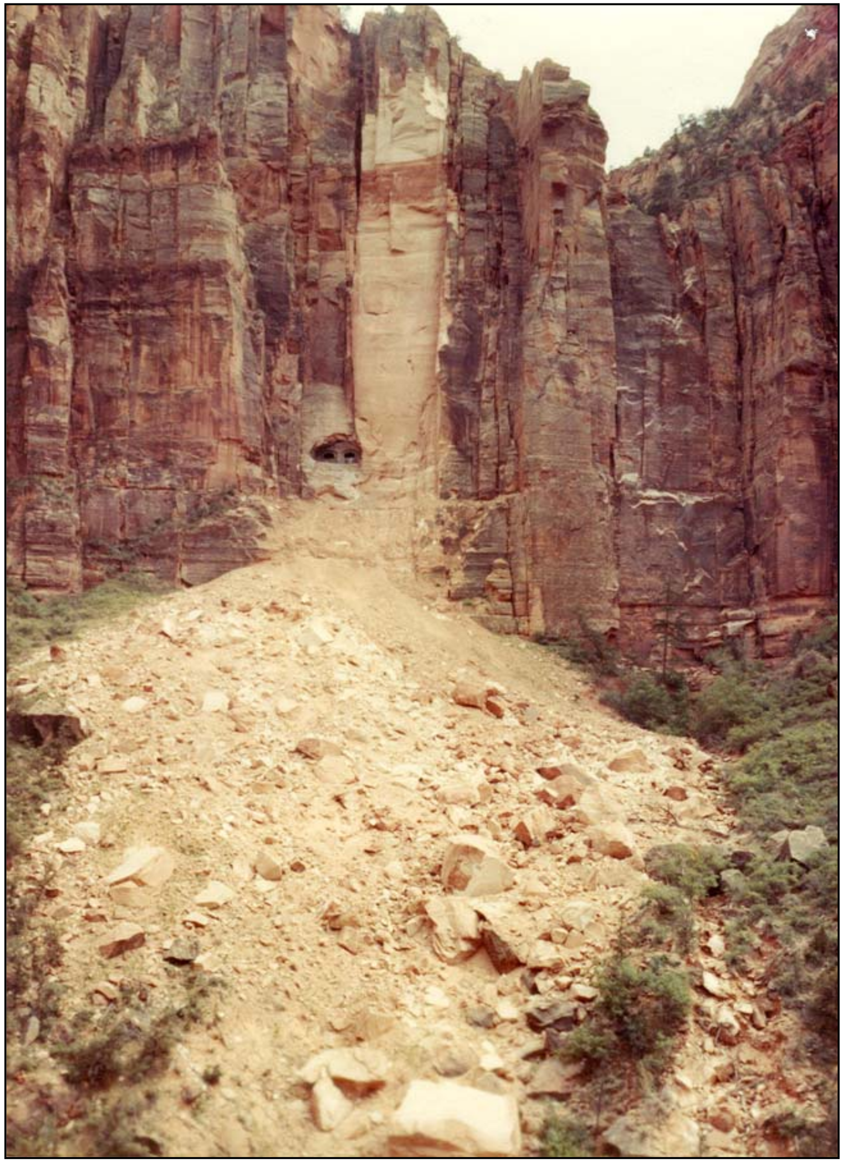

Right Abutment Detail.

Plan :
(A) Embankment.
(B) Spillway.
(C) Canal outlet.
(D) Road.
(E) September 3, 1965, leakage and slough.
(F) Open cracks.

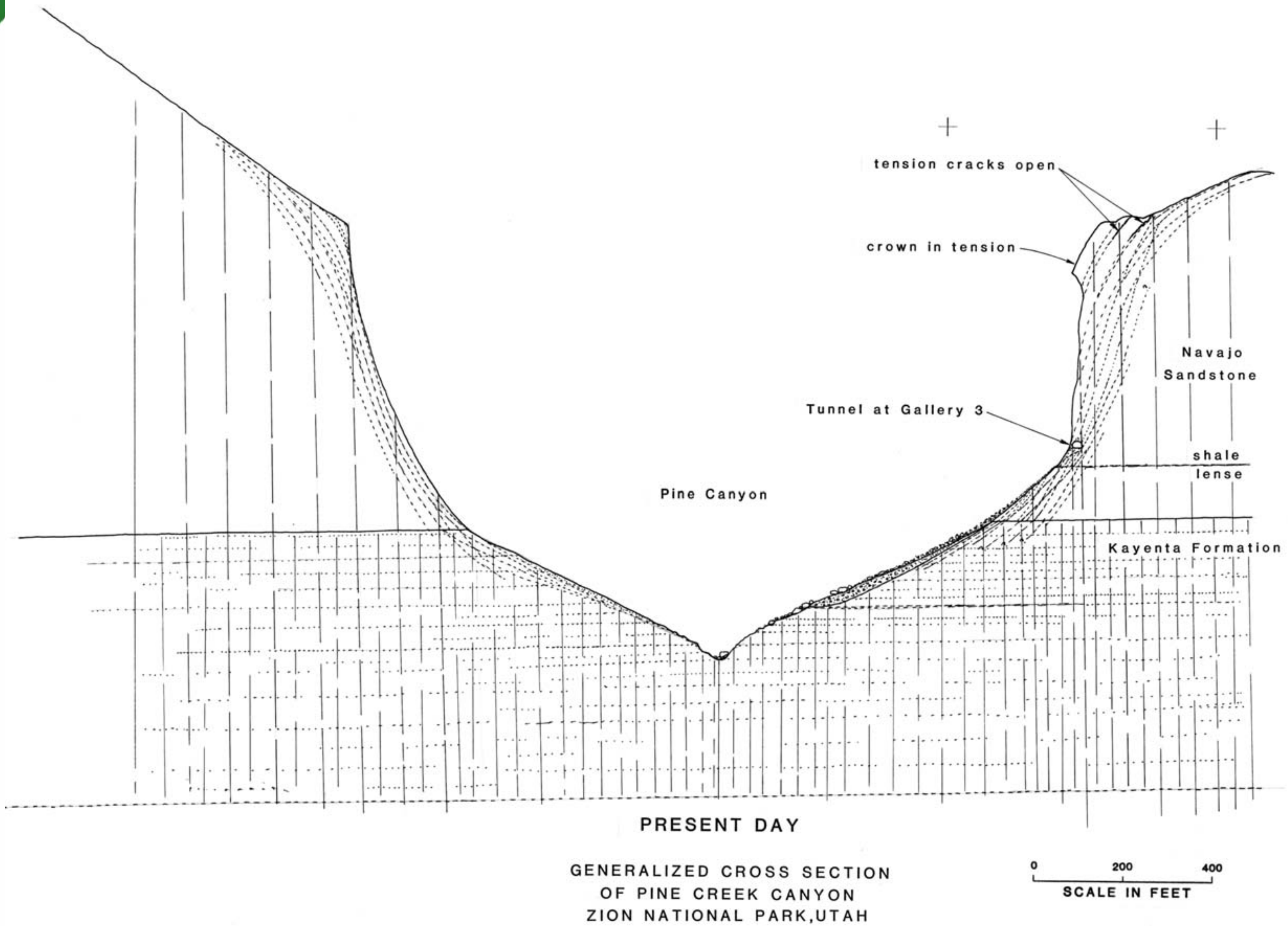
Section :
(1) Dam crest.
(2) Downstream abutment slope.
(3) Abutment slope at dam centerline.
(4) Bedrock surface at dam centerline.
(5) Upstream abutment slope.
(6) Lower limit of grout acceptance.
(7) Open cracks.
(8) Approximate location of leak.

- **Seepage percolated along undiscovered valley-side joints (#7) in bedded sedimentary rocks at position #8**
- **8 lines of grout holes were then drilled and filled with 203,500 sacks of cement**



- **The Zion-Mt Carmel Tunnel Gallery 3 failure occurred in April 18, 1958, spilling 84,000 tons of Navajo Sandstone onto the slope below and damaging the tunnel**




- **Cross section of Pine Canyon at location of the Gallery 3 rockfall. Note valley-side joints**

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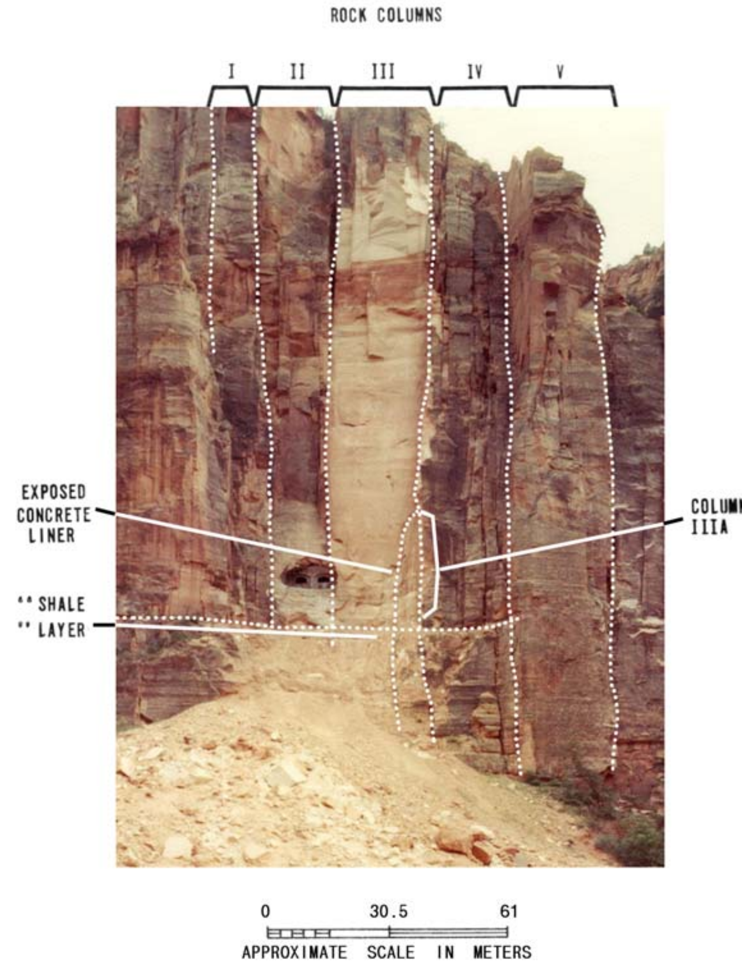


- **Unravel geomorphic progression** – **Cliffs tend to retreat in episodic steps. All of these steps are usually discernable at any given site.**

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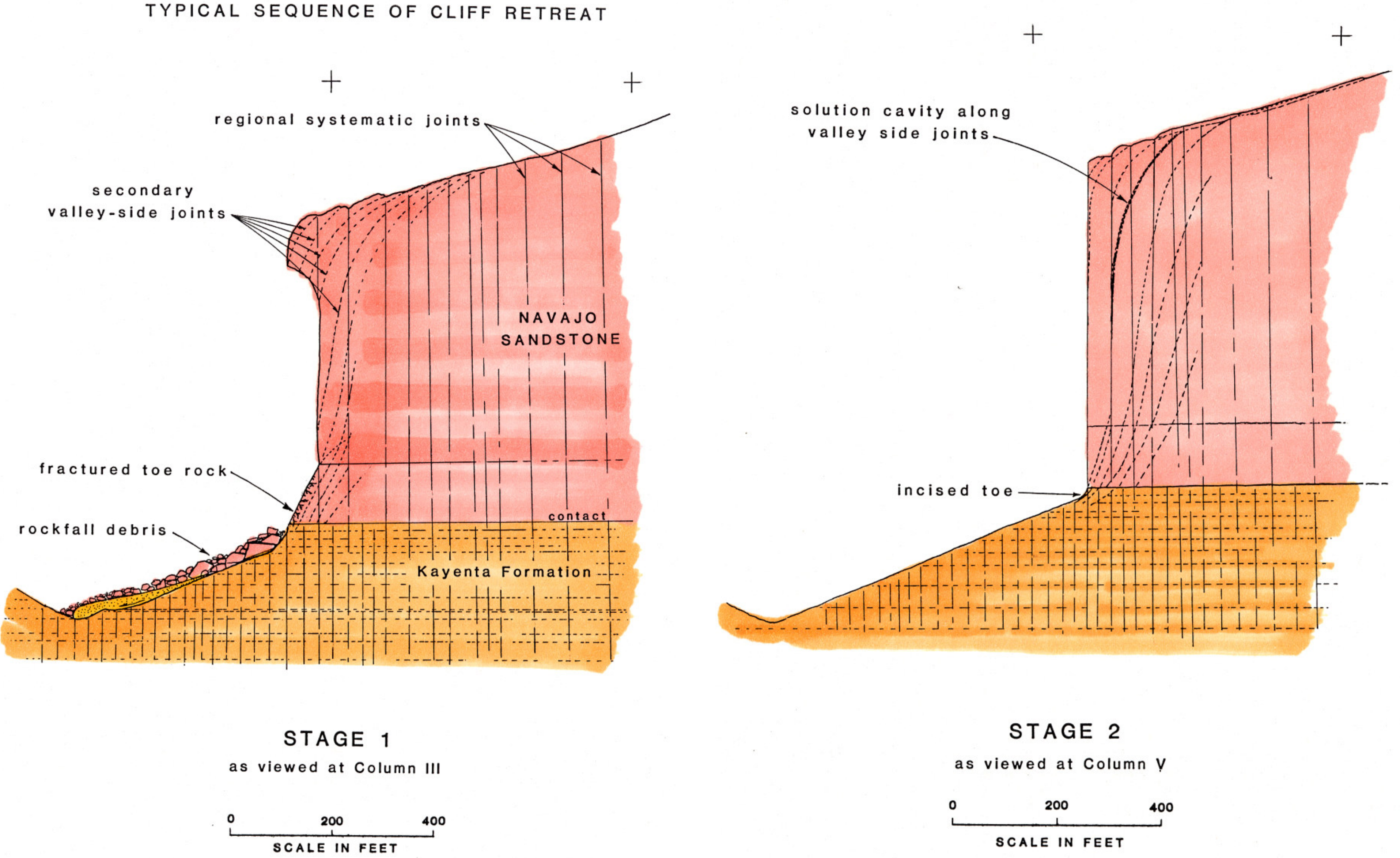


- **Stage 1 is gross cliff retreat immediately following a major detachment. After the remaining overhang drops, a completely smooth face forms, arbitrarily designated here as Stage 2.**

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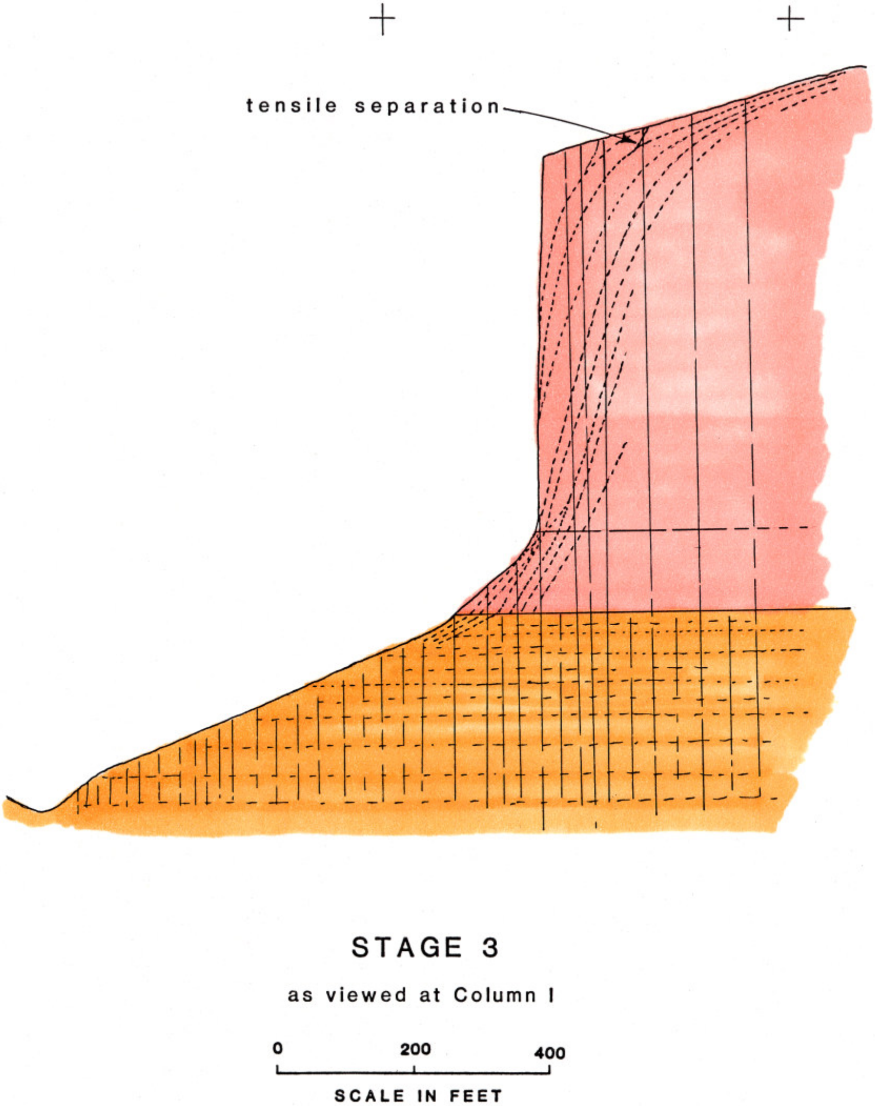
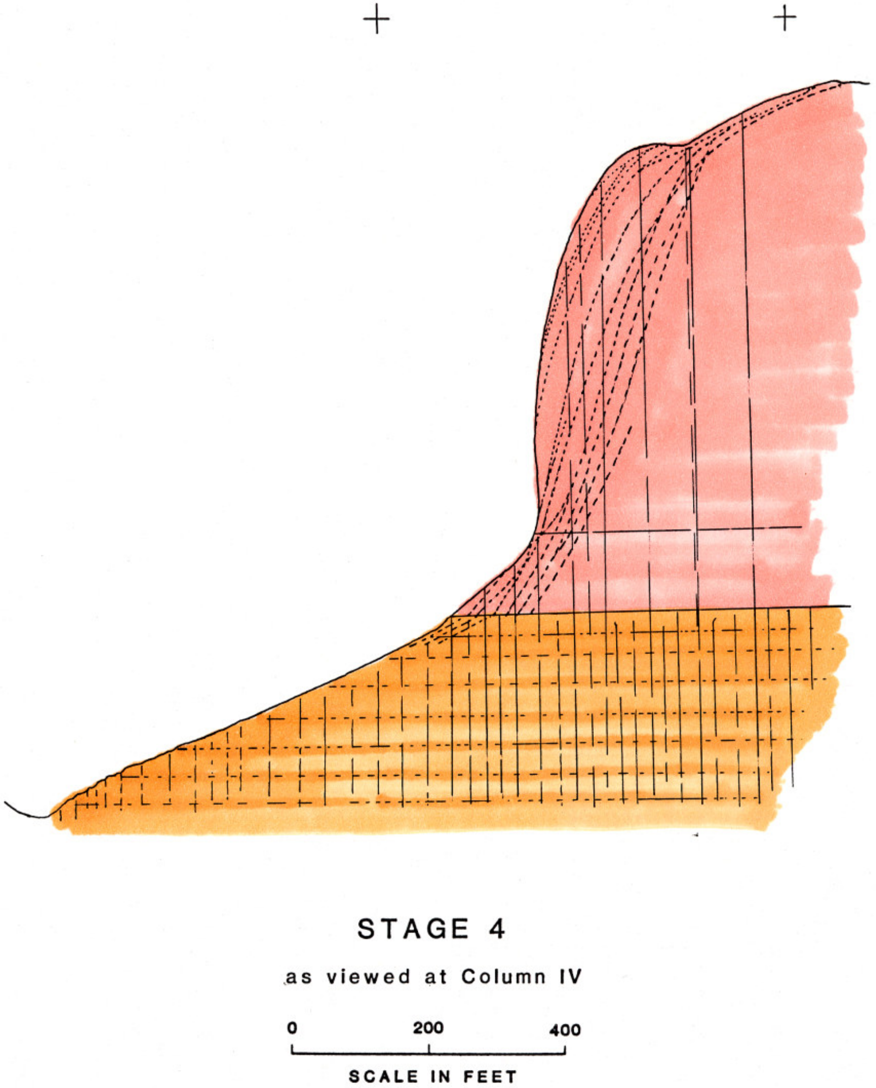
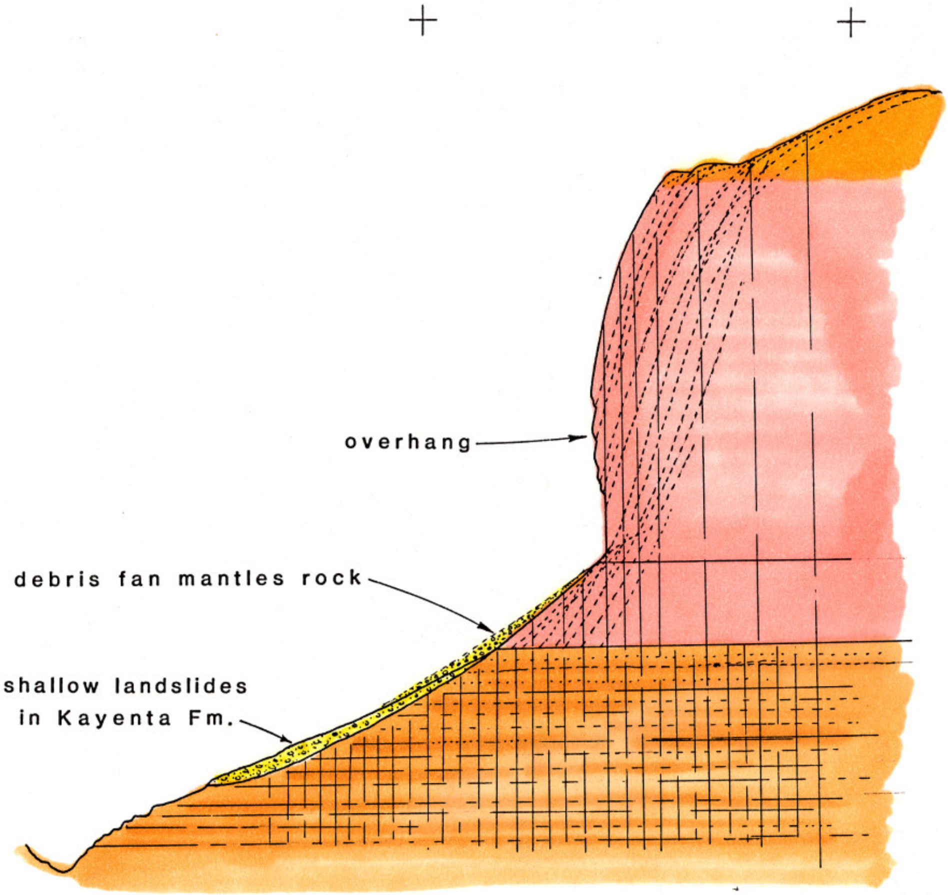



- **Stage 3 a sloping cliff toe forms, controlled by valley-side joints. In Stage 4 crown blocks have detached along inclined valley-side joints**




STAGE 5

as viewed at Column III before failure

0 200 400
SCALE IN FEET

- **Stage 5 is overhanging situation preceding massive detachment of block(s) along inclined valley-side joints**

# CONCLUSIONS

- Engineering geologists need to unravel the physical agents responsible for shaping the landscape around us
- This requires through background research, patient site mapping, a focused program of subsurface exploration, and a critical analysis of landforms
- We will not identify those geologic features we are not specifically looking for, or with which we have little previous exposure or experience

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