PRELIMINARY EVALUATION OF COMPOSITE LANDSLIDE MECHANISMS

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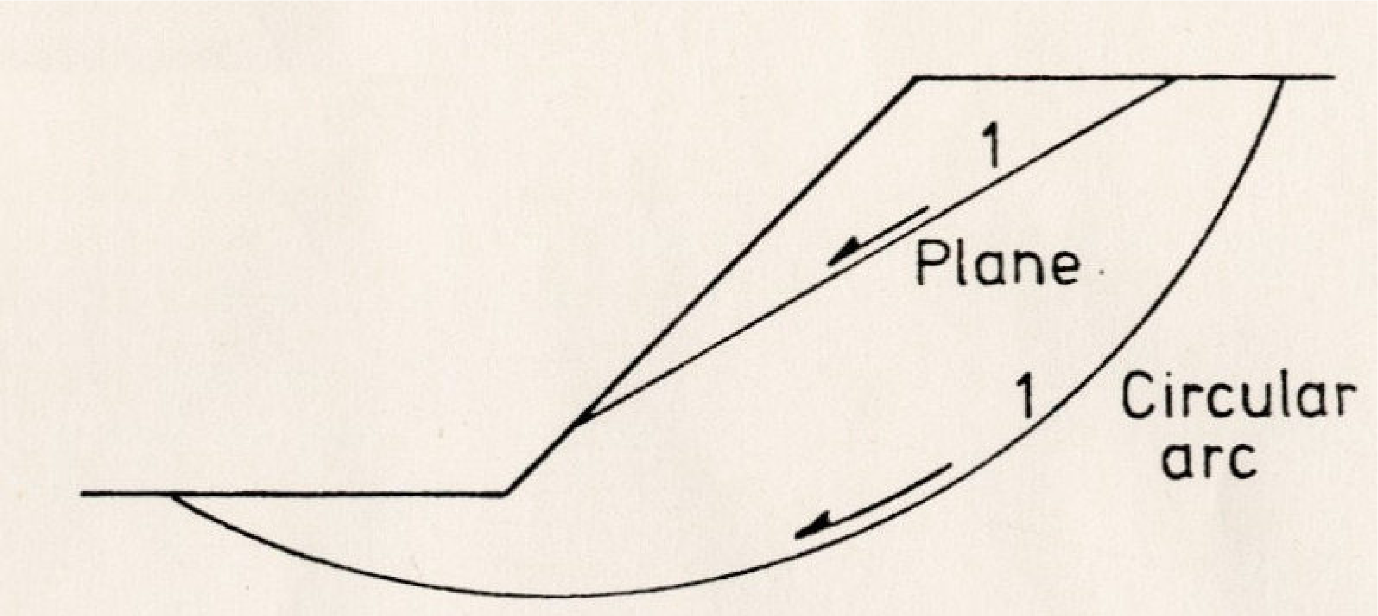
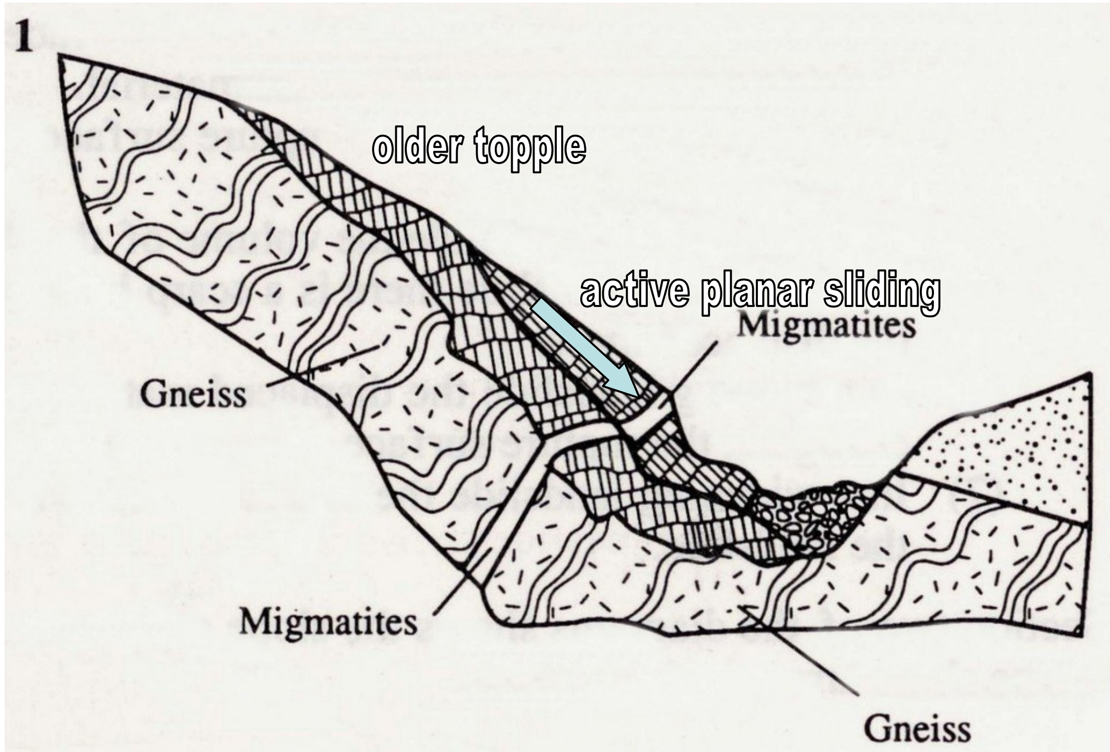
SINGLE LANDSLIDES



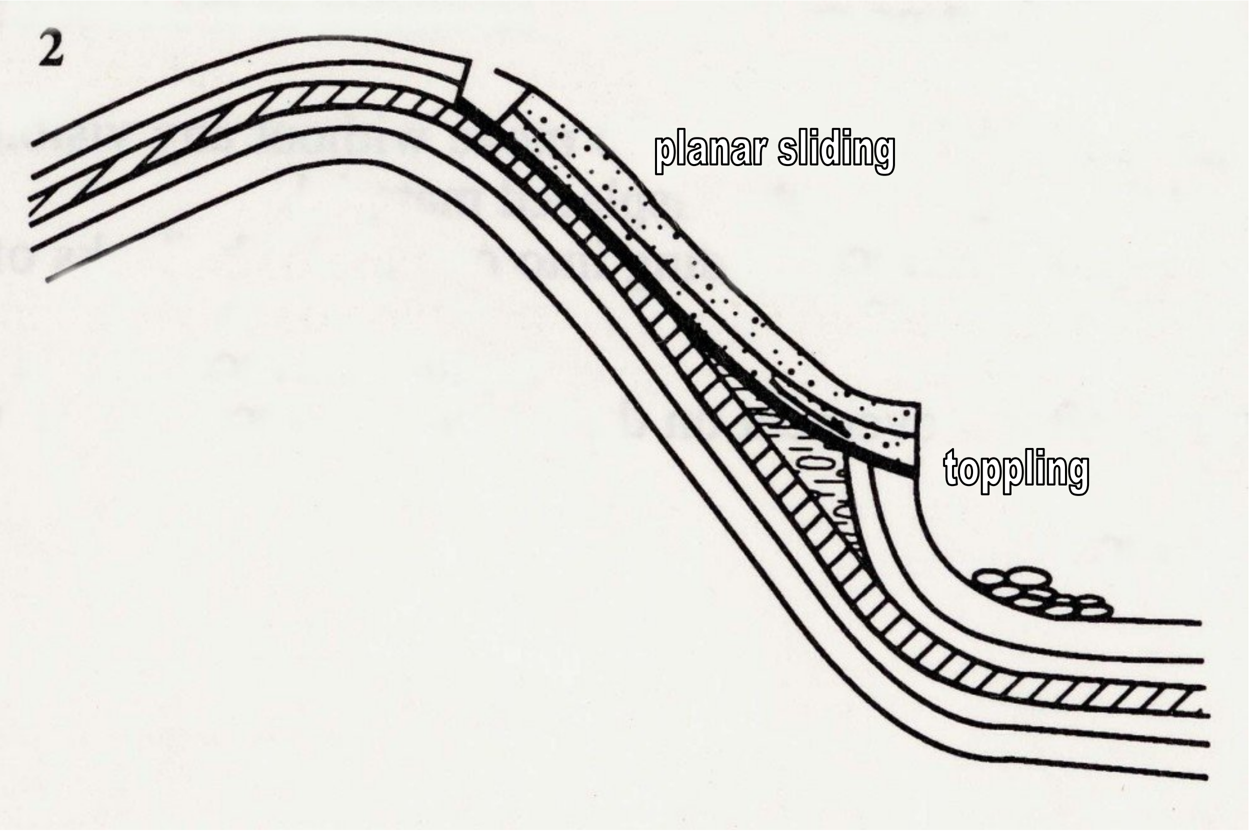
- Single landslides translate along a single rupture surface, which can be curved or planar
- These kinds of movements can be analyzed with limit equilibrium analyses

COMPLEX LANDSLIDES



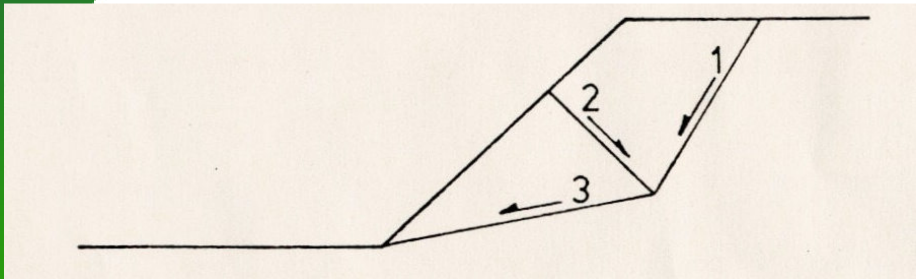
- **Complex landslides** exhibit at least two types of movement, such as falling, toppling, sliding, spreading or flowing. A portion of this topple has detached itself and is undergoing planar sliding

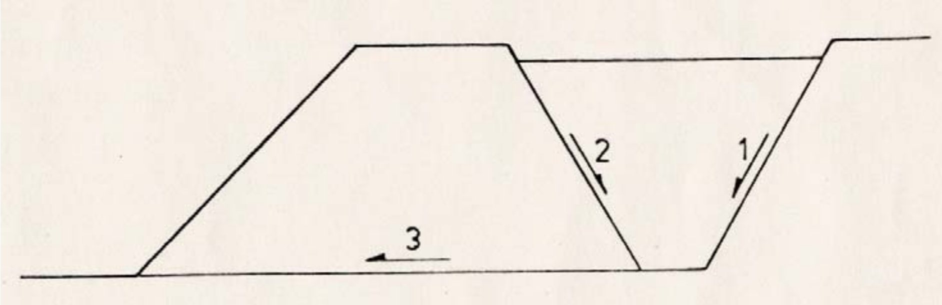
COMPOSITE LANDSLIDES

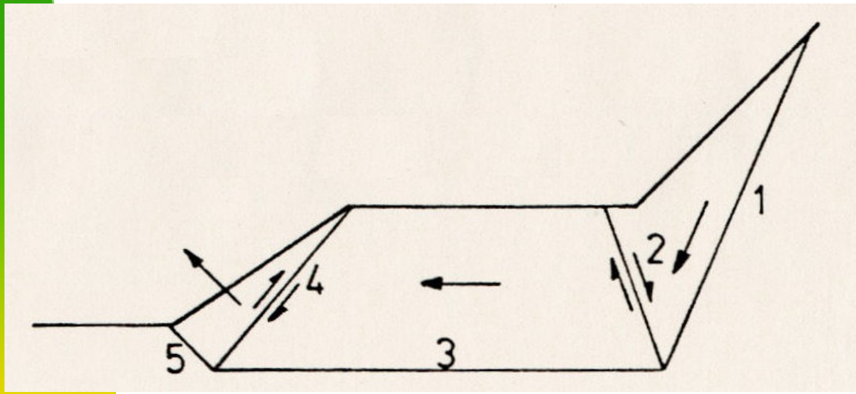


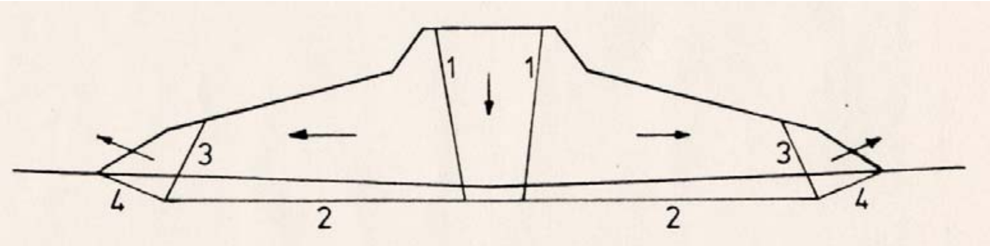
- **Composite landslides** exhibit at least two types of movements **simultaneously**, in different portions of the failing mass. Many large bedrock movements tend to be of this style

EXAMPLES of COMPOSITE LANDSLIDE MECHANISMS



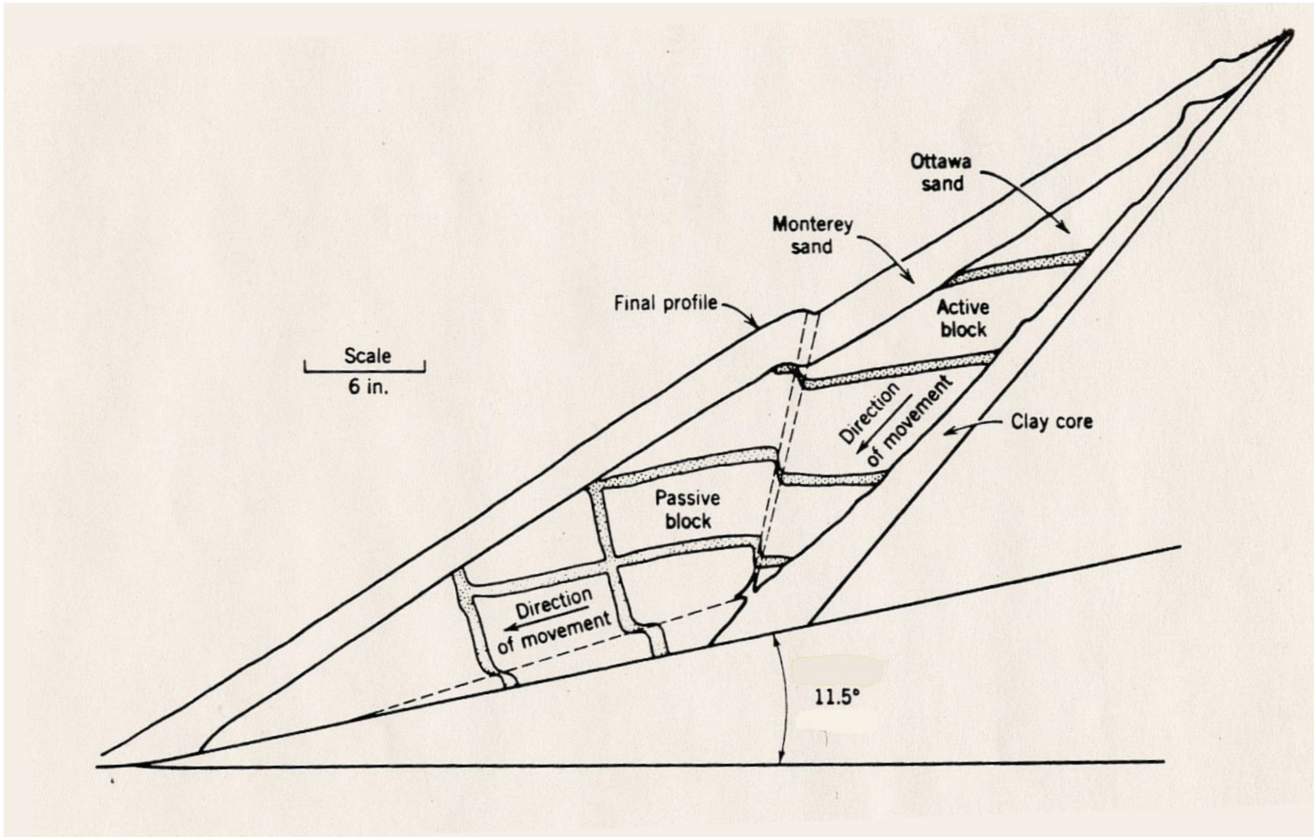






These kinds of movements defy analysis using conventional limit equilibrium methods

COMPOSITE WEDGE FAILURE



- Kinematic model of a **composite wedge failure** developed in stratified mine tailings piles. Note the **passive** and **active** blocks

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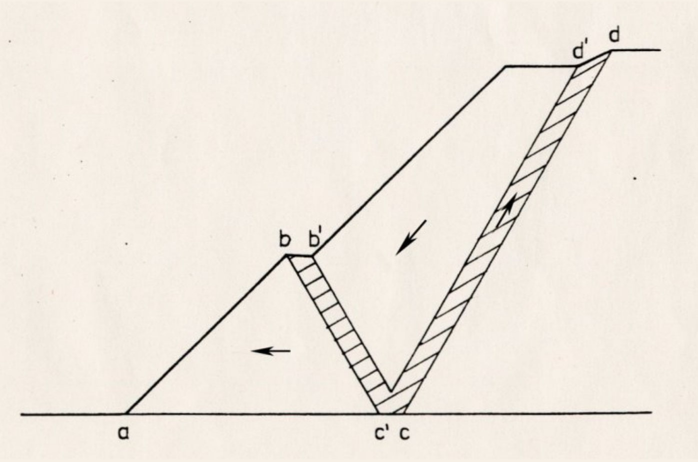
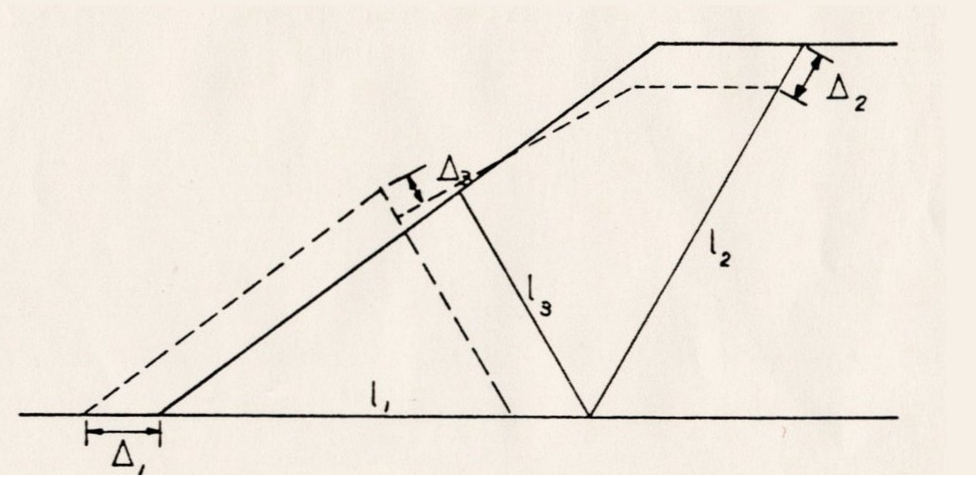
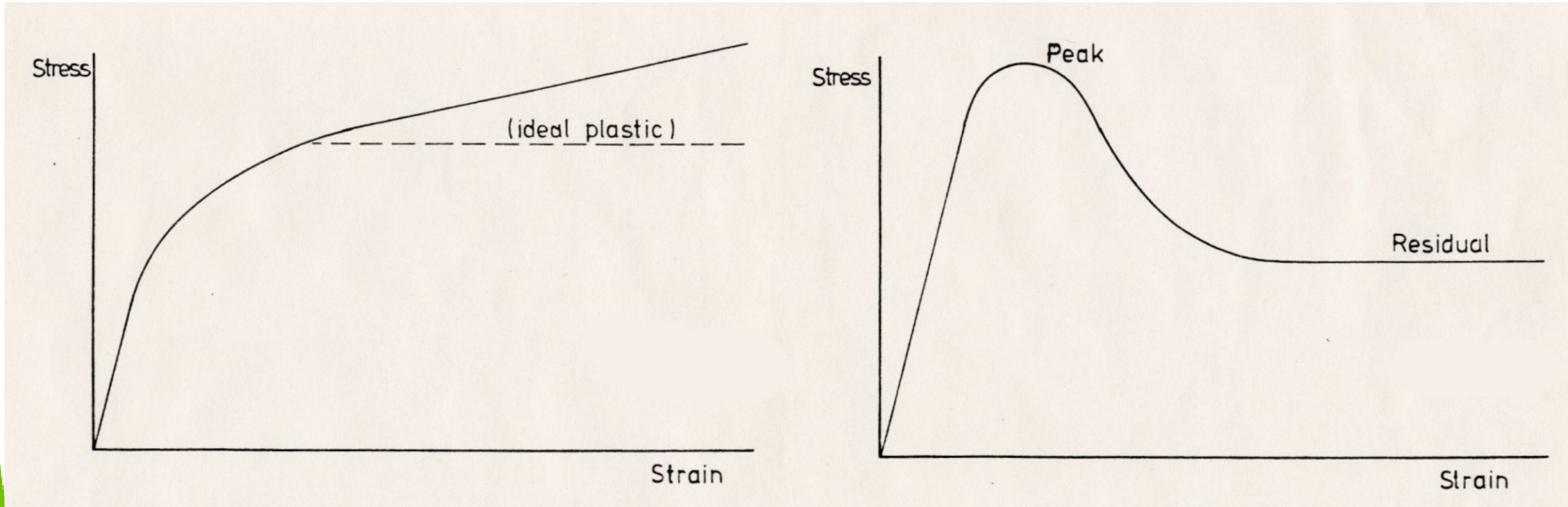
DEVELOPMENT OF QUASI-PLASTIC ZONES





- Planar blocks appear to form when quasi-plastic zones of **preferential shearing** develop between the active and passive blocks and the base of rupture. The failure is triggered by lateral translation of the toe wedge sliding on a newly developed shear zone where none had existed previously

STRAIN-HARDENING VERSES STRAIN-SOFTENING



- Normally consolidated clay is a quasi-plastic, or **strain-hardening** material, as shown at left
- Overconsolidated clay and most sedimentary rock tend to exhibit **strain-softening**, as shown at right

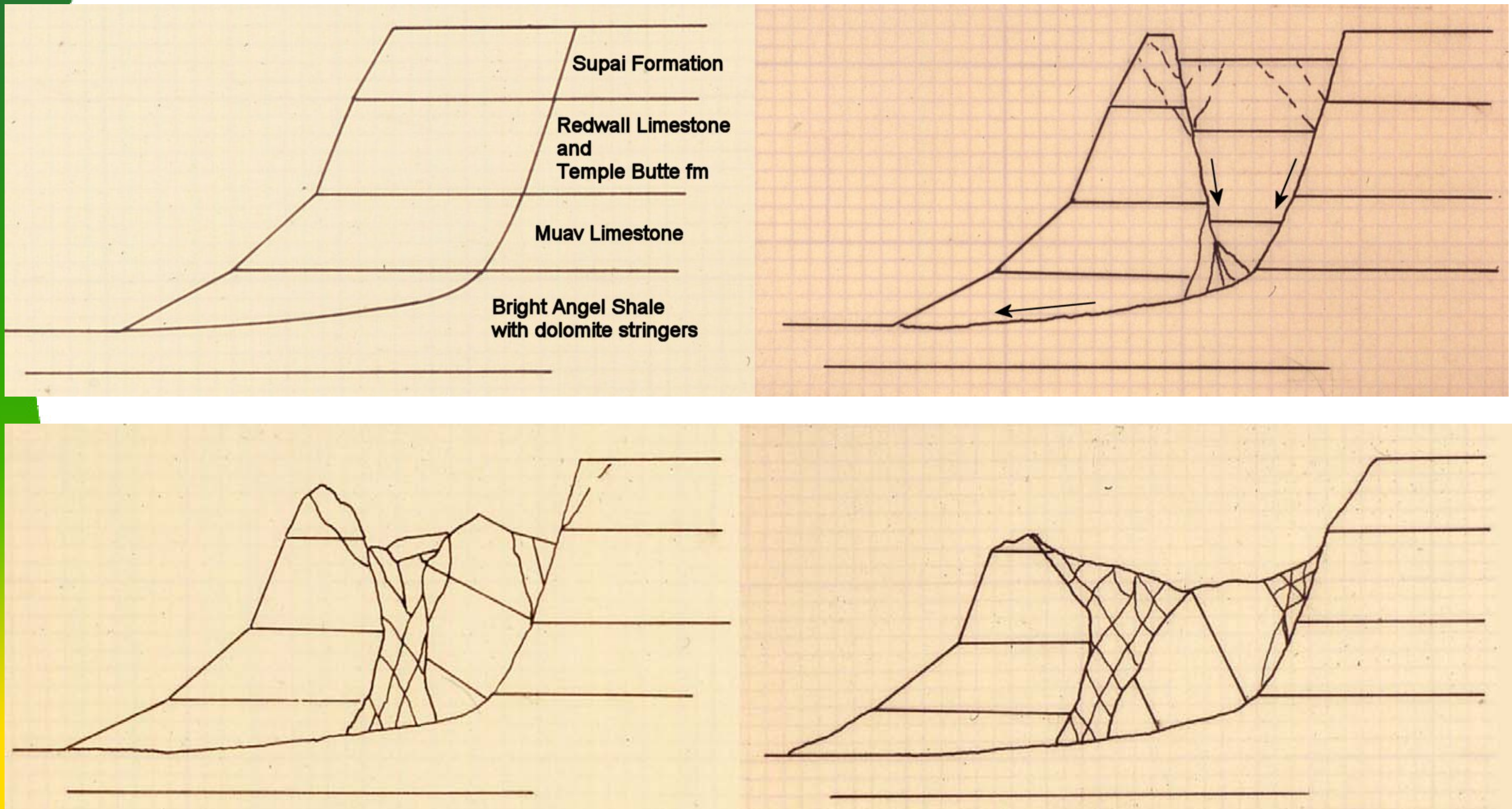
SO, WHAT'S THE DIFFERENCE?

- Quasi-plastic or strain-hardening materials **absorb energy** so that they more or less deform at constant volume near the maximum stress level. These are ideally plastic materials
- Strain-softening or quasi-brittle materials, **release stored elastic strain energy** in the post-peak range, until a residual condition of deformation at constant volume is attained
- Most lithified rock exhibits quasi-brittle behavior when initially sheared

THUNDER RIVER LANDSLIDE

- The Thunder River slide dropped about 600 m and translated horizontally about 800 m

BLOCK GLIDE WITH ROTATED GRABEN



A passive wedge of bedrock translated outward about 800 m

BASAL SLIP SURFACE

- The basal rupture surface of the Thunder River Slide is well preserved and accessible. It is curvalinear at the transition (above right) and follows a bedding plane in the shale for several hundred meters (shown at left)

FIRST DIRECT SHEAR TESTS WITH PORE PRESSURE MEASUREMENTS ON INTACT ROCK

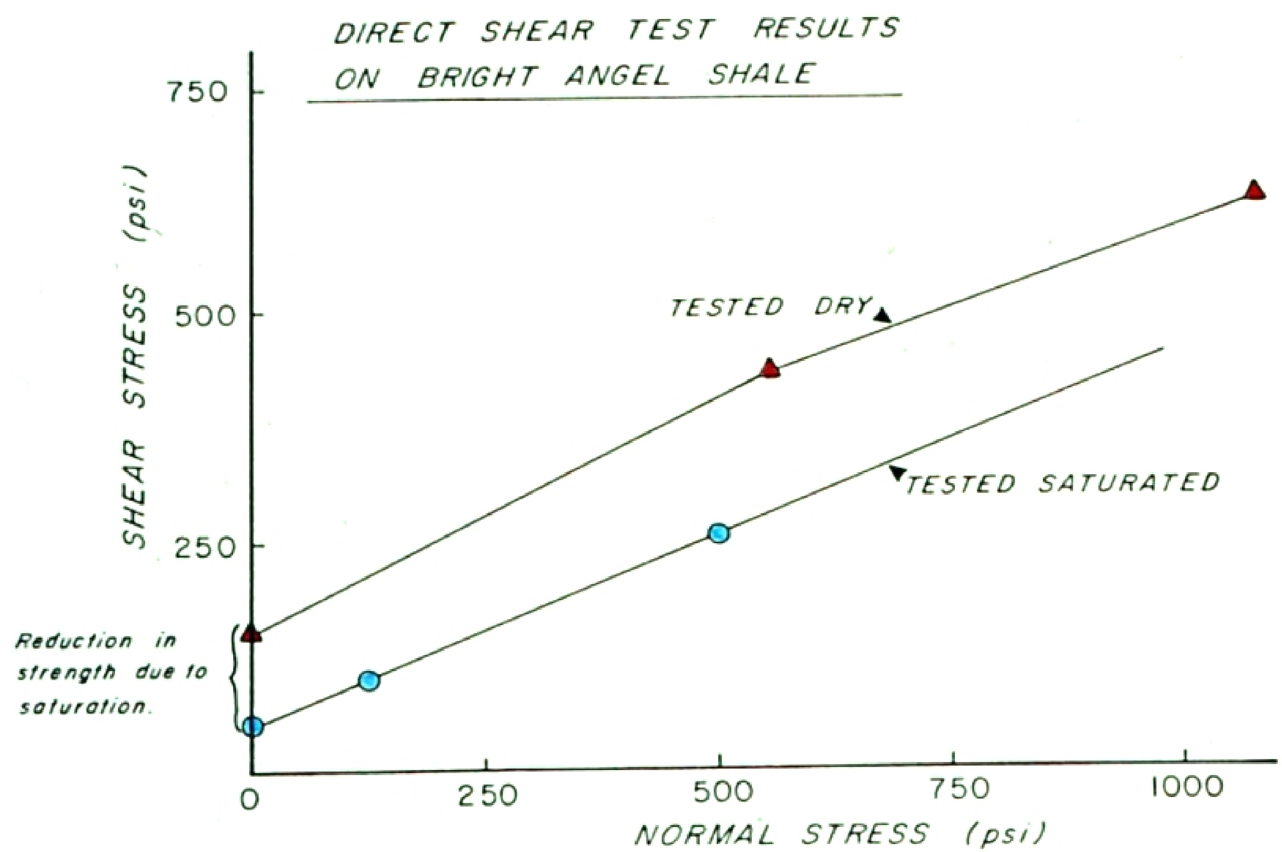
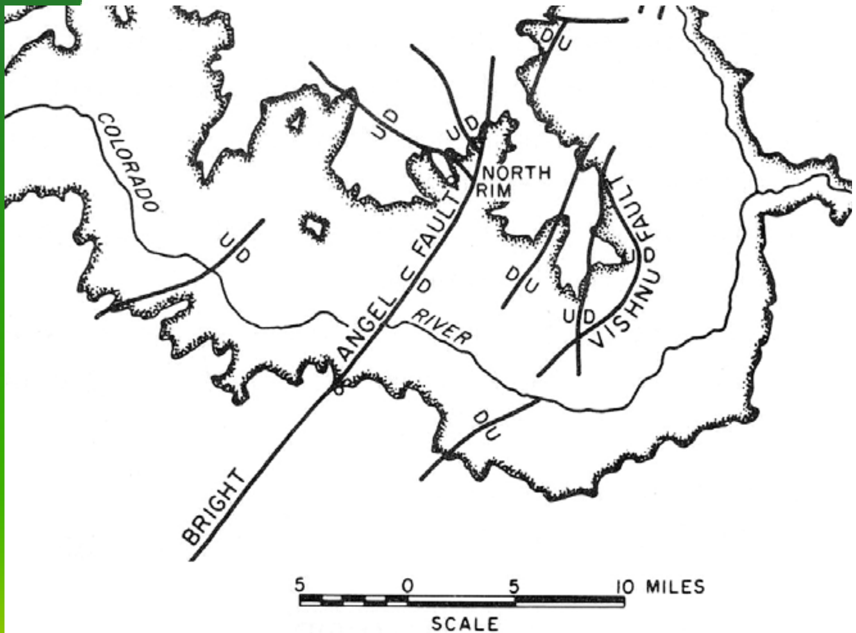


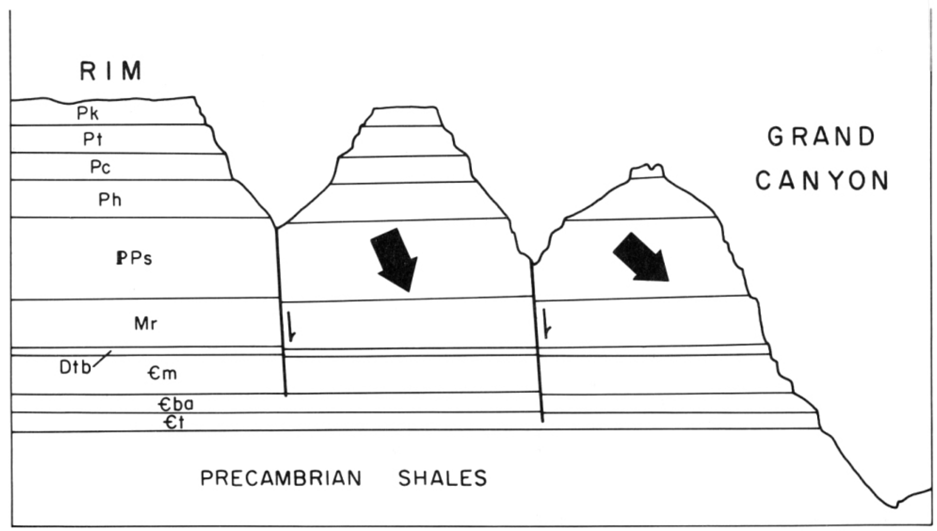
Figure 13 -

STRENGTH PARAMETER TESTING MICACEOUS BRIGHT ANGEL SHALE

- The Cambrian age Bright Angel Shale is very dense and micaceous
- It took more than 6 months to saturate the specimens under significant back pressure. The tests showed a **two-thirds reduction in cohesion** and a slight loss of friction with complete saturation
- The shale exhibited classic quasi-brittle behavior, as would be expected from a heavily overconsolidated material

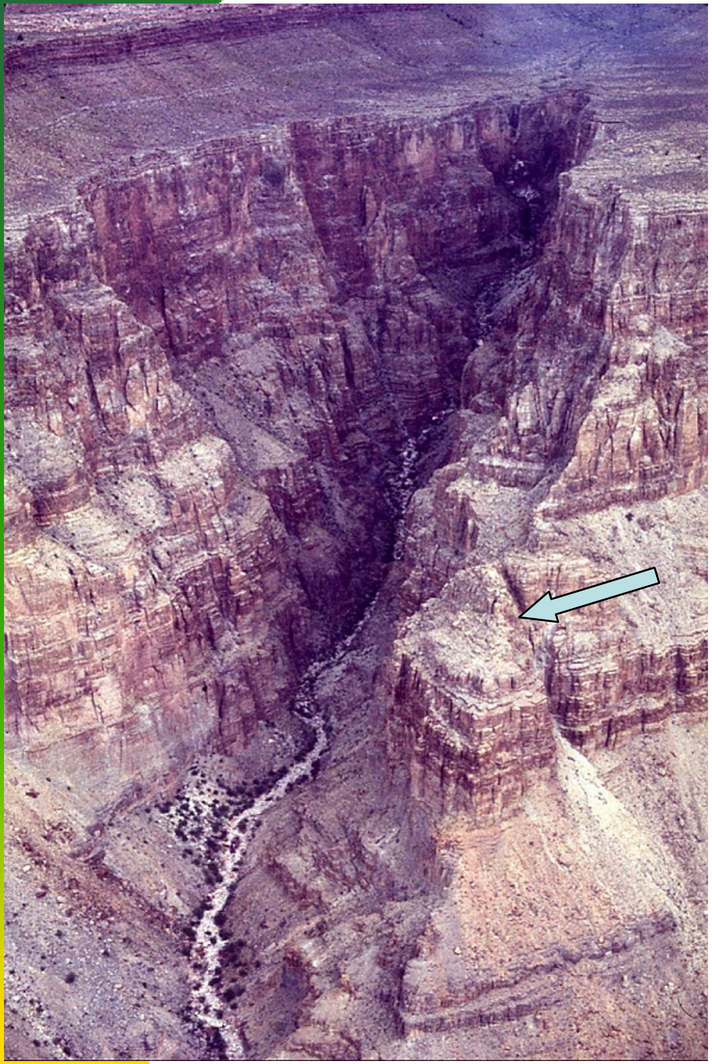
GRAVITY FAULTS

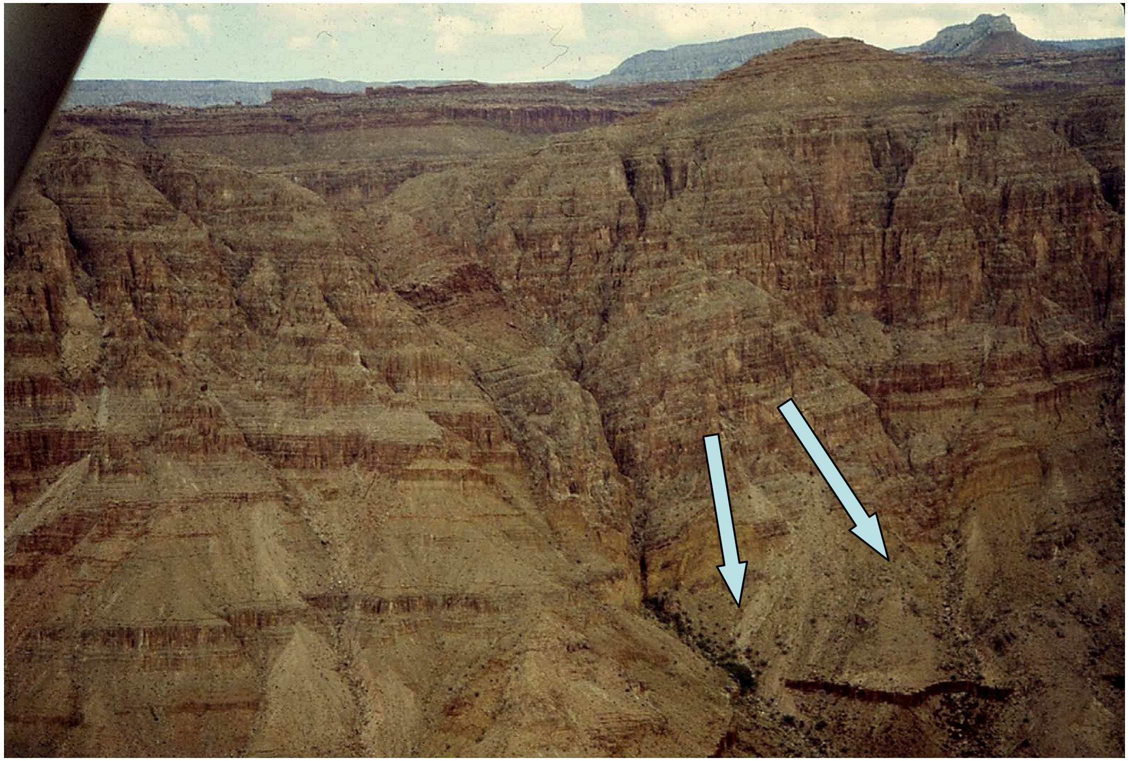




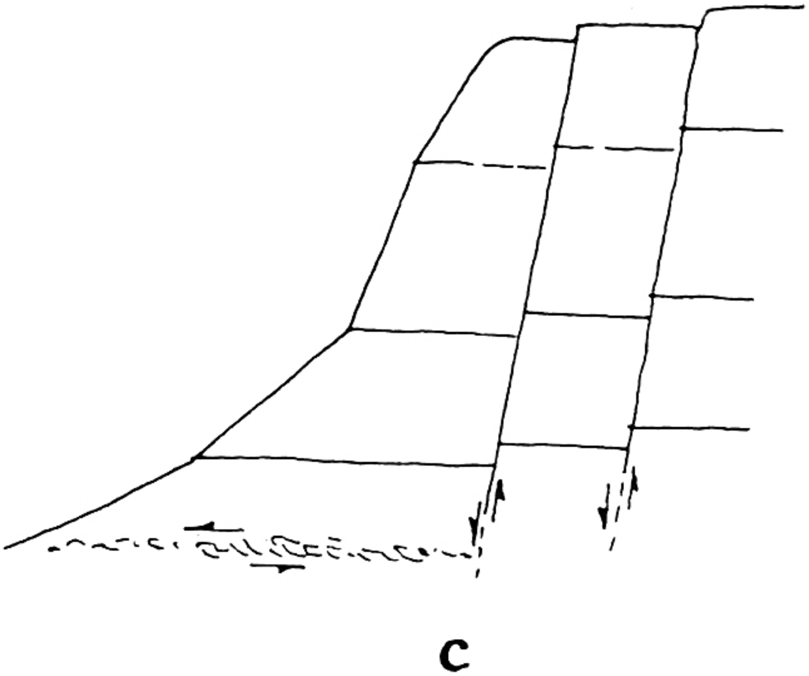
Heavy arrow shows relative movement of the butte

- About 30 years ago, Peter Huntoon described gravity fault structures in the eastern Grand Canyon





Gravity fault features range from very slight displacement (see arrow at left) to gross displacements promoting large scale landslippage (shown at right)



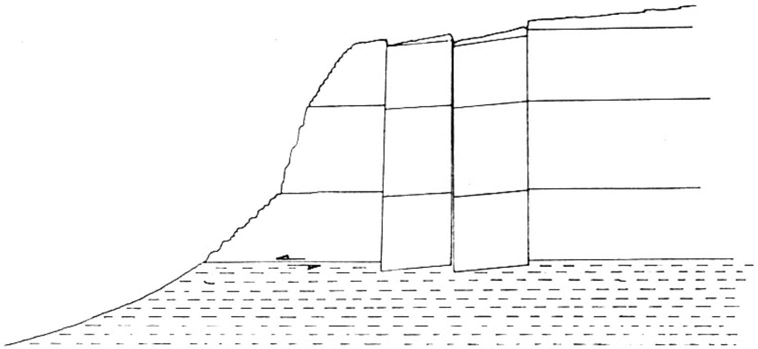
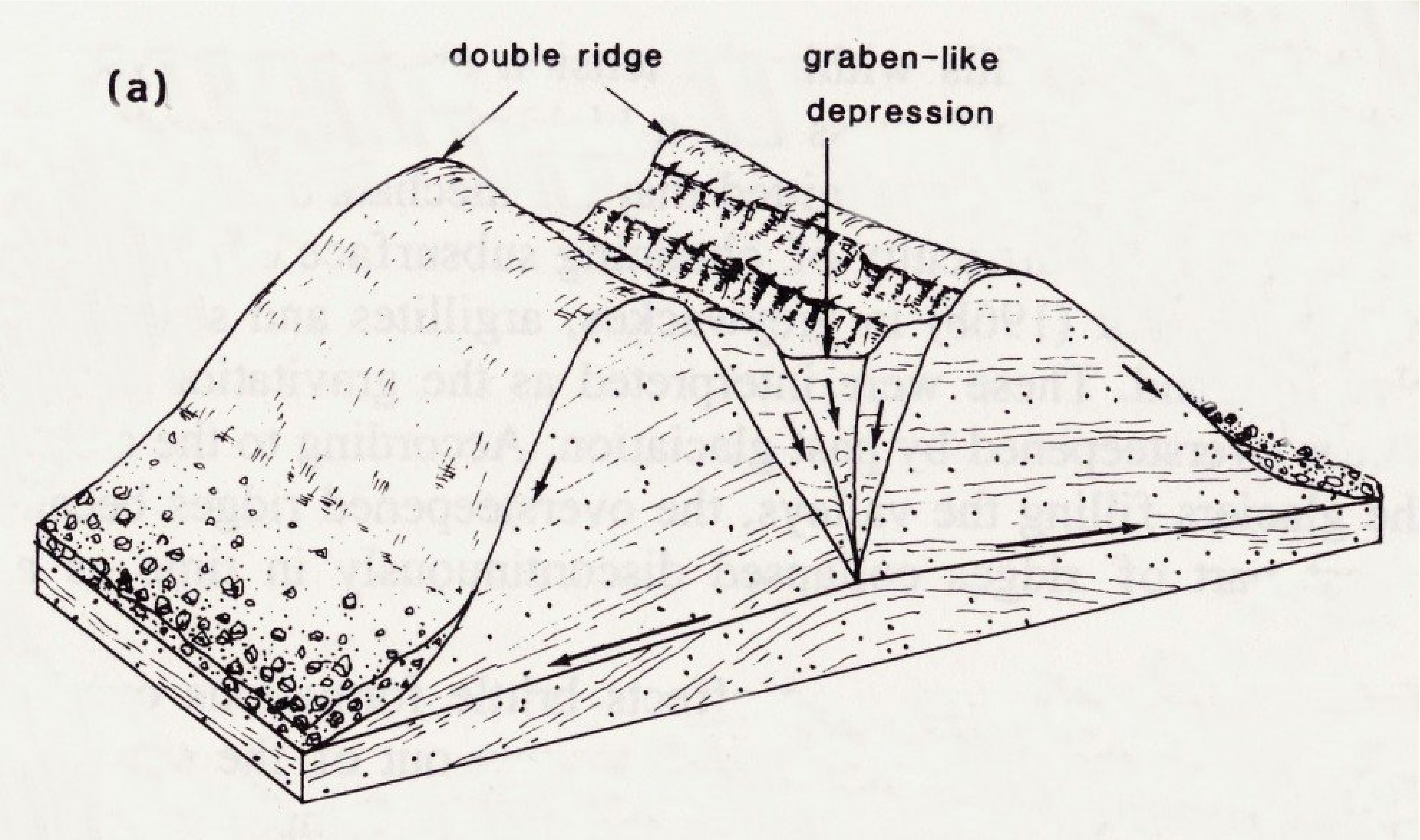


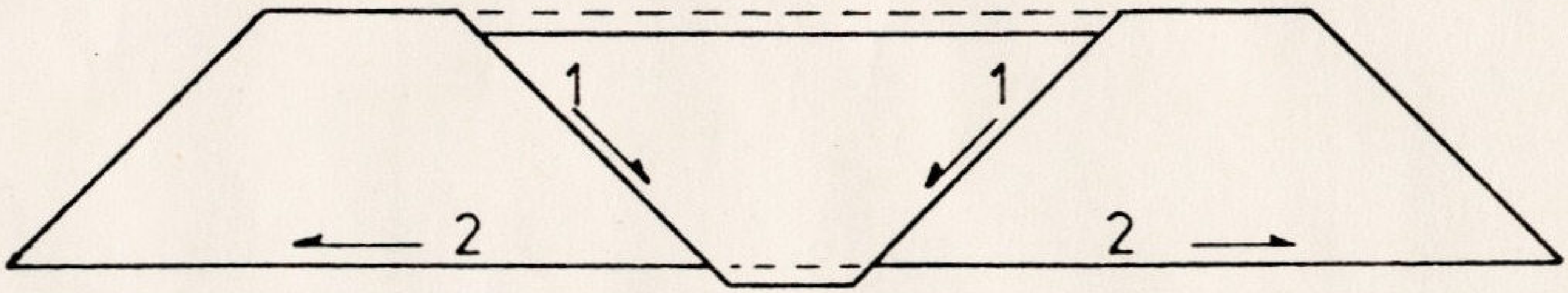
Figure 85 - Schematic section view of Gravity Faults (Huntoon, 1973) or "Sackung" (Radbruch et al, 1977). This massive form of slope displacements commonly occurs where stiffer rock assemblages overlie more plastic types (like shale). The straining process is very slow. Field cases are numerous in the Western Grand Canyon Region (Rogers and Pyles, 1979).

Various mechanisms have been proposed over the years to explain gravity fault-bounded blocks in the Grand Canyon. All of these assume the formation of a dispersed zone of plastic deformation within the Bright Angel Shale

SACKUNGEN FEATURES

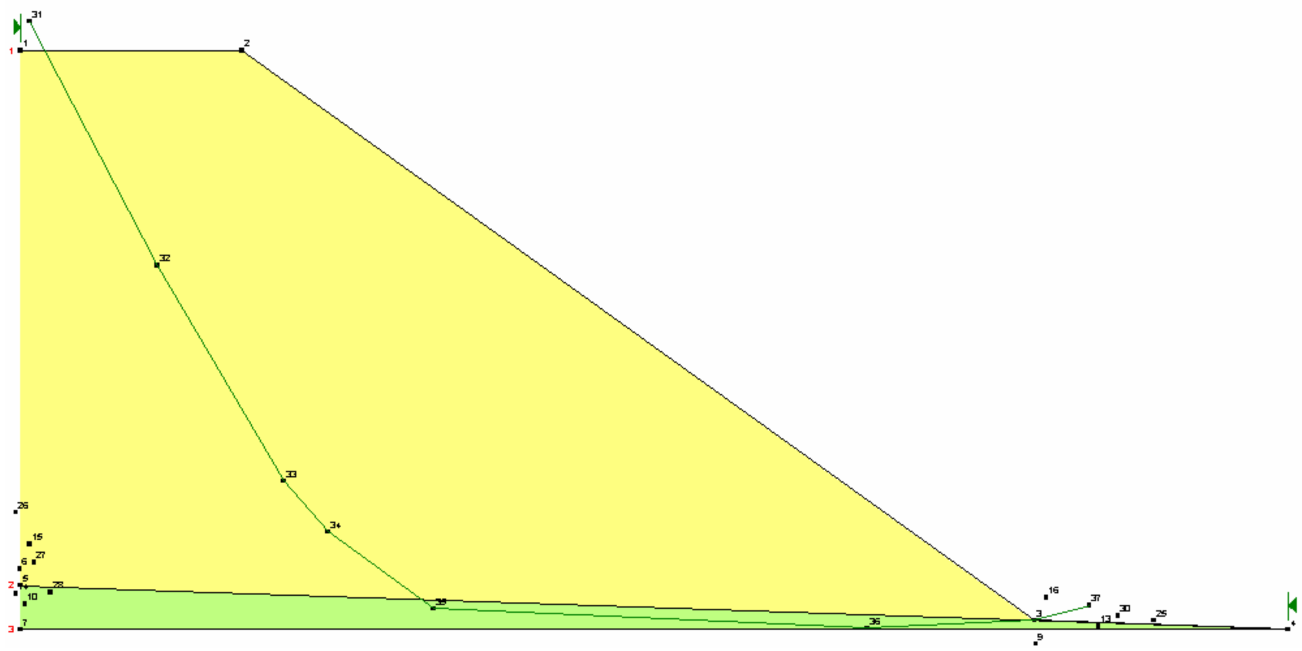


- Sackungen, or ridge spreading, features have defied explanation using limit equilibrium methods since their recognition 25+ years ago



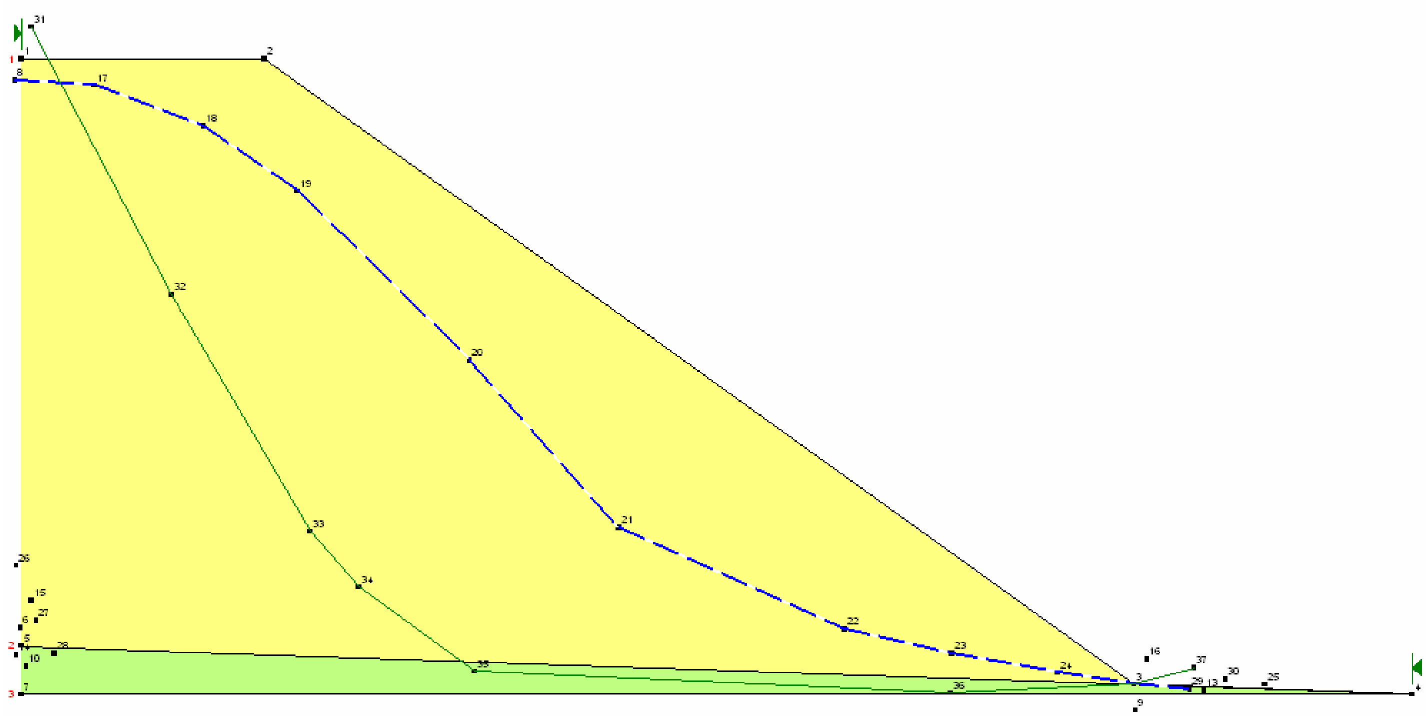
- Sackungen features are akin to two-sided composite wedge failures
- They tend to be bounded laterally by enormous passive wedges, with a central graben
- The graben is within a tensile environment, dropping downward; while the passive wedges are sliding laterally, usually on very low gradients

DRY LOADING CONDITION



- Conventional slope stability analysis of a “half sackungen feature”, assuming completely dry conditions and using strength parameters taken from units in the Grand Canyon
- The Morganstern-Price method gave a Factor of Safety of 2.3

STEADY STATE SEEPAGE CONDITION



- With an assumed water table shown above, the Factor of Safety with respect to conventional slope stability dropped to 1.7

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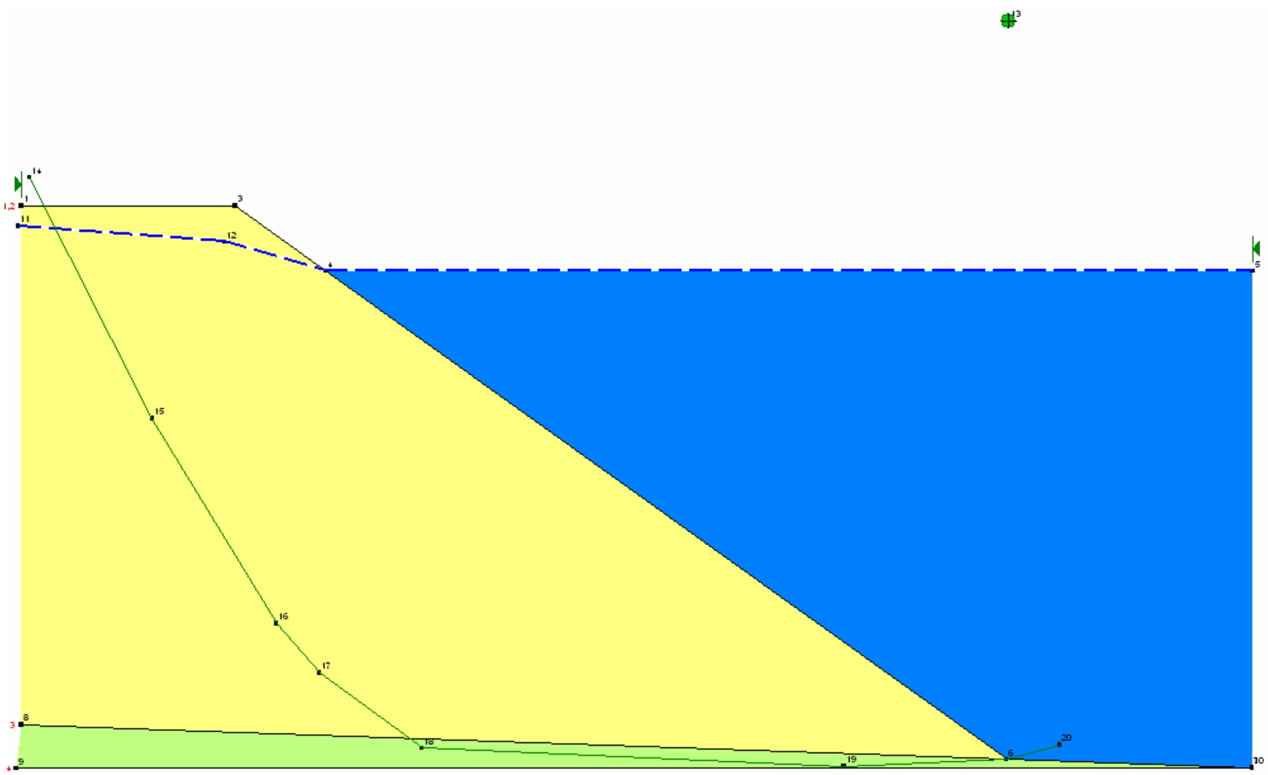
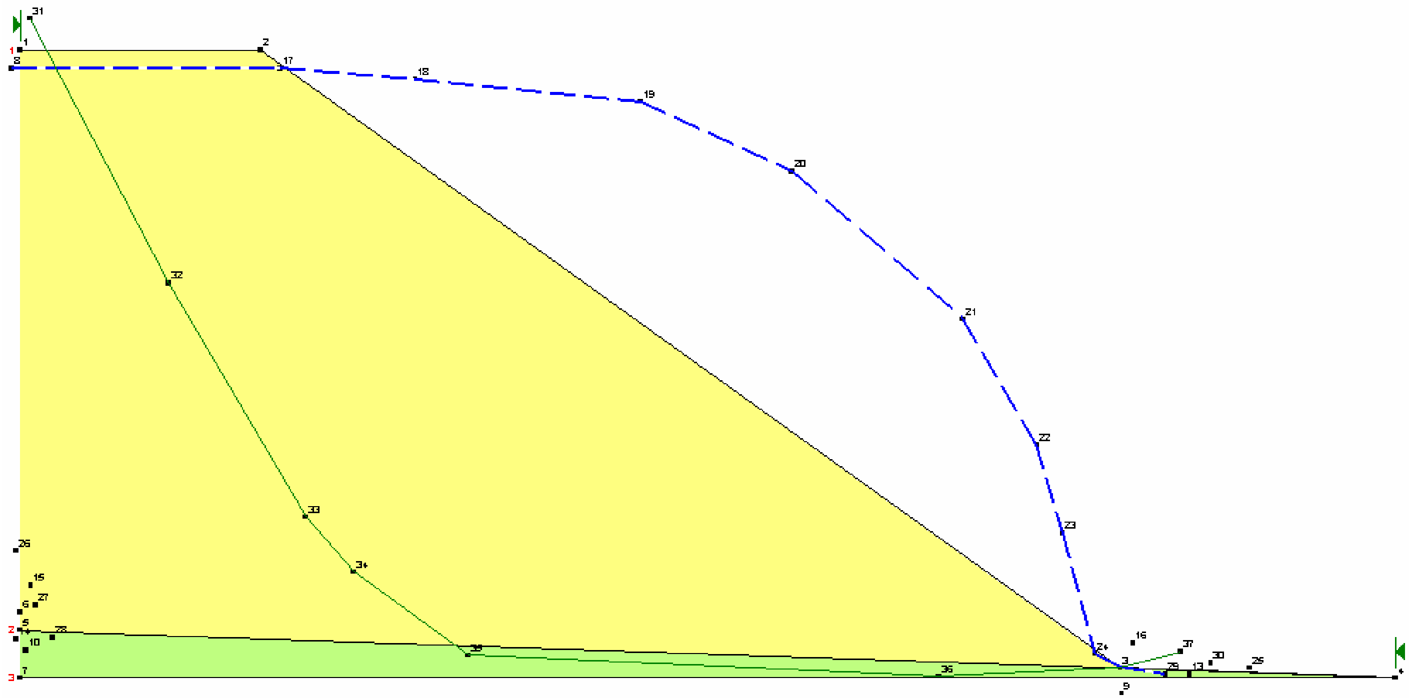
FULL RESERVOIR CONDITION



- With a reservoir developed against the slope, the factor of safety increases to 2.4

RAPID DRAWDOWN CONDITION



- In a rapid drawdown of the reservoir pool the computed factor of safety approaches unity, and failure along a slightly inclined plane in the Bright Angel Shale is predicted

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PRELIMINARY CONCLUSIONS

- The last series of analyses assumed significant strength loss of the Bright Angel Shale under conditions of complete saturation; as we would expect in a quasi-brittle material
- The development of **significant** pore pressure appears necessary to trigger the style of shear failure observed in gravity faults or sackungen features

IS PORE PRESSURE ENTRAPMENT RESPONSIBLE FOR THESE FEATURES ?

- Finite element analyses of direct shear tests of relatively impermeable substances such as clay suggest that significant pore pressures develop during shearing due to fluid entrapment.
- The pressure that develops appears related to the ratio of strain rate to drainage
- This mechanism may explain sackungen features, gravity faulting and large composite bedrock landslides which presently defy explanation using conventional slope stability methods