Erth 16 Lecture 2: Grand Canyon - interpreting the sedimentary record

Questions from last time?

Quick review

- geologic time scale - Phanerozoic part constructed from fossil record. We'll return later to how absolute ages are assigned to this time scale.
- two types of sediments
- superposition and original horizontality as principles for interpreting the sedimentary rock record

Inferring the depositional environment of sediments

- Today we're going to illustrate that we can get considerably more information about the history of the Grand Canyon by examining the sediments more carefully.
- Let's begin at the top of the Canyon and work our way down.
- Kaibab formation (Permian)
    - forms the cliff at the top of the canyon
    - *composition*:
        - by this we mean, what minerals (remember minerals are the building blocks of rocks; *mineral* = naturally occurring compound, with a fixed chemical composition, and atomic order) are present.
        - Kaibab is almost entirely calcite ($CaCO_3$)
            - sigificance: calcite typically forms by precipitation from seawater (either direct precipitation or through biological mediation)
    - *texture*:
        - texture = relationship between grains of minerals forming a rock
        - includes shape, size, contact relationship (discrete grains or interlocking grains)
        - Kaibab has interlocking grains (in common with igneous rocks, this texture indicates that the grains precipitated from solution - water in the case of calcite and a silicate melt in the case of igneous rocks)
    - *fossils*:
        - corals indicative of marine environment
        - crinoids - sea lillies (particularly abundant in Paleozoic)
        - indicate Permian age
    - *depositional environment*
        - shallow marine and far from land
            - why shallow?
            - why far from land? few other minerals (such as quartz) that might be derived from land
        - modern equivalent - Bahama bank which has a relatively small areal extent. In the Paleozoic and at other times in earth history, shallow seas (called epeiric seas) were much more widespread.

- Toroweap (similar to Kaibab, also Permian)
- Coconino
    - composition
        - almost exclusively quartz grains
        - significance: Q is resistant to weathering (which can occur by both chemical and physical means)
    - texture
        - clastic rock
        - all grains are relatively well rounded, small (< 1mm)
        - significance: significant or very intense transport, which results in reduction of grain size and rounding of particles.
    - fossils
        - no marine fossils
        - vertebrate tracks
    - sedimentary structures
        - a fourth type of observation
        - presence of angular layers within the overall sedimentary layers
        - does this mean that the sediments have been tilted? no, since we know of a plausible mechanism to generate such features: dunes
        - migration of dunes or ripples >> cross bedding
    - depositional environment
        - terrestrial environment
        - preservation of large scale cross beds suggests aeolian (dune) environment
    - cliff former
        - as with Kaibab, cliffs indicate that the rock is resistant to erosion in the present environment.
        - transition from sediments to sedimentary rock
            - cement grain together
            - compaction
            - recrystallization
        - calcite mud >> limestone; sand >> sandstone
    - *uniformitarianism*
        - physical processes have been constant through time, so that we can examine the kinds of rocks forming today (and their environment) and infer similar environments for ancient rocks with similar features
        - present is key to past
- Hermit (Permian) and Supai group (Pennsylvanian)
    - slope former
        - why? softer and more susceptible to erosion
    - *formation* = mappable unit (distinctive lithology - rock type - that can be recognized over a large area and thus could be drawn on a map)
    - composition
        - some quartz, finer particles (clay minerals)
        - reddish stain - hematite (Fe_2O_3)

        - significance: hematite is common alteration mineral in terrestrial environments (plentiful oxygen); other components not particularly distinctive
    - texture
        - mixture of fine grained layers (clay size particles) and sand size particles in other layers
        - energy of environment: high energy needed to move larger particles, low energy OK for very fine particles
        - significance: environment where we could have alternations of high and low energy
    - fossils
        - plant remains
    - sedimentary structures
        - fine laminations
        - ripples (and cross bedding) on scale of 10s cm
    - depositional environment
        - broad coastal plain
        - river systems and possibly near shore dunes
        - illustrate how meandering streams might produce changes in fine and coarse sediment over very short spatial distances (or equivalently short times)
- Redwall limestone (Mississippian) - similar to Kaibab
- Temple Butte (Devonian) - shallow water carbonate
    - In contrast to the formations we've discussed to this point, the Temple Butte limestone does not form a continuous layer throughout the canyon.
    - Why might this be?
        - *principle of lateral continuity* = sedimentary layers extend laterally until the sedimentary supply is exhausted or the depositional space is interrupted
        - another clue is the formation underlying the Temple Butte, and that is the Cambrian Muav limestone
        - ~100 m.y. of time (part of Devonian, Silurian, Ordovician) missing
    - such missing time in the rock record is called an *unconformity*
        - how can we recognize that time is missing? fossils
        - *disconformity* = gap in the rock record between two flat-lying sedimentary units
        - inference: either we have nondeposition or erosion
- Muav Limestone (Cambrian)
- Bright Angel Shale (Cambrian)
- Tapeats Sandstone (Cambrian)
- We'll return to these three units in a moment, but for now let's look at the very bottom of the canyon (below the lowermost horizontal sedimentary unit)
    - in some places we more sedimentary units, but they are no longer horizontal.
        - Grand Canyon series: sediments and some lavas

        - 1.1 to 1.4 Ga so a big gap from 540 Ma to 1.1-1.4 Ga, also an unconformity
        - what does the tilting tell us? original horizontality says that the sedimentary beds (as well as lava flows that erupt and flow over the surface) started out horizontal so something must have happened.
        - *angular unconformity* = gap in the rock record in which tilted sedimentary rocks are overlain by flat lying sediments (or lavas)
        - inference: deformation, then erosion (to truncate the rocks), then deposition of flat laying sediments.
    - in other places below the Tapeats sandstone we don't find sediments at all, but rather igneous and metamorphic rocks.
        - *igneous* rock = rock form by cooling and solidification of silicate melts (700-1200°C), resulting in texture of interlocking crystals
            - extrusive - formed by eruption of lava at surface of earth and consequent rapid cooling (fine grained)
            - intrusive - formed by slow cooling of magma below the surface of the earth (coarse grained)
        - *metamorphic* rock = rock formed by solid state changes in mineralogy and texture resulting from exposure to temperature and pressure conditions different than those in which the parent rock (protolith) originally formed.
            - contact metamorphism - primarily elevated temperature due to proximity to igneous body
            - regional metamorphism - elevated temperature and pressure (typically higher in one direction due to mountain building); result is texture with preferred orientation of grains
        - *nonconformity* = gap in the rock record in which igneous or metamorphic rocks are overlain by sedimentary rocks
        - inference: substantial amount of time of missing since both igneous and metamorphic rocks form at high temperatures (not at surface) and time is needed to erode the overlying material and expose these rocks at the surface (where sediments will be deposited)