Erth 16 Lecture 3: Grand Canyon - geologic history and canyon formation

Questions from last time?

Quick review

- inferring sedimentary environment (composition, texture, fossil content, sedimentary structures - e.g. mudcracks, crossbedding)
- uniformitarianism
- unconformities (disconformity, angular unconformity,[nonconformity])

Igneous and metamorphic rocks

- Angular unconformity: Tapeats sandstone overlying tilted sediments (and lavas) of the Grand Canyon Series (1.2 to 0.8 Ga so a big gap from 540 Ma)
- Elsewhere beneath the Tapeats sandstone we find very different kinds of 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)

Mountain building and deformation

- Logical question is how did these igneous and metamorphic rocks form?
    - at the time of the Vishnu schist and Zoroaster granite, the Grand Canyon area was located at a boundary where two plates were colliding
        - deformation
            - *fault* = break in rock layers
                - when rocks are deformed at low T (shallow) or at high strain rates
            - *fold*
                - rocks can bend without breaking if conditions are right (higher P, T and if deformation occurs slowly)

        - elevated temperatures and pressures
            - thickening crust and geothermal gradient are sufficient to produce high temperatures deep in mountain belt

Establishing relative time

- With sediments, we have used two basic methods to establish the relative age of units: *superposition* and *faunal succession*. In the more general case with igneous, metamorphic or sedimentary rocks we have some additional tools for establishing relative time.
- How do we tell whether the igneous or metamorphic rock is younger?
    - *crosscutting* relationships
        - A younger feature (generally, an igneous intrusion) cuts across older features or bodies of rock.
        - A related concept is that the age of deformation (faulting or folding) must be younger than any of the rock units that are affected by this deformation.
        - When hot magma intrudes into pre-existing rocks (called the *country rock*), the intrusion heats its immediate surroundings, producing a zone of contact metamorphic rock. This contact metamorphosed rock is called a contact metamorphic aureole or halo, which may also help delineate cross-cutting relationships.
    - *principle of inclusion*
        - Fragments of a rock unit (*xenoliths* meaning foreign rock) which are included in another (host) rock unit must be older than the host rock. This may occur in sedimentary environments, where pieces of pre-existing rock can be ripped up and included in younger sediments. Alternatively, when igneous rocks are intruded, fragments of the country rock may be incorporated into the intrusion.

Early history of Grand Canyon

- Let's apply these principles to interpret the history of the Grand Canyon, working our way forward in time.
- ~2 Ga: deposition of sediments that would later become the Vishnu schist
    - how do we know that the precursor was sediment? mica rich schist tells us that we have lots of Al in protolith, clay minerals are most likely source of this Al
    - how can we estimate the age? difficult to do, but possible if we find datable minerals that are not reset during metamorphism
- mountain building episode culminating around 1.7 Ga
    - deformation and metamorphism of sediments
    - intrusion of granite
- 1.7-1.2 Ga: erosion of Mazatzal mountains
- 1.2-0.8 Ga: deposition of Grand canyon series
    - sediments and some volcanic rocks
- ~800 Ma: uplift and faulting

    - movement along faults (tension)
    - little deformation or volcanism
- 800-540 Ma: erosion of this faulted landscape

Transgressing and regressing seas

- Remaining rocks are flat lying sediments, some of which are marine deposits, others were deposited in terrestrial environment. The relative position of sealevel can be reconstructed from the rock record. First three units (Tapeats sandstone, Bright Angel shale, Muav limestone) are classic record of a rise in relative sealevel.
- Formations of the Tonto group
    - Tapeats sandstone
        - quartz, feldspar
        - medium-coarse sandstone; conglomeratic at base
        - trilobites, brachiopods
        - cross bedding, bimodal directions
        - beach environment (to few 10's meters)
    - Bright Angel shale
        - clay, mud
        - fine grained - lower energy
        - trilobites and other marine fossils
        - laminations
        - middle shelf below wavebase (~ few 10's meters)
    - Muav limestone
        - calcite, some terrigenous material decreasing to W
        - laminated
        - outer shelf (> few 10's meters to ~100m, far from land)
- Walther's law
    - energy and sediment supply in depositional environment can change laterally. For example, on broad continental shelf we may have sands being deposited near shore, muds farther off shore and carbonate muds with little terrigenous material still farther off shore.
    - *Sedimentary facies* = different sediment types that are accumulating at the same time in adjacent areas
    - *Walther's law* = facies adjacent to one another in a continous vertical series also accumulated adjacent to one another laterally
- movie of marine transgression
    - note time lines (dashed lines) indicate different sediments being deposited in different parts of the continental shelf
    - *transgression* = relative sea level rise
    - *regression* = relative sea level fall
- http://strata.geol.sc.edu/movies/CLASTICSYSTEMTRACTS.MOV