Western North America Stratigraphy and Depositional Environments

Brief overview of sedimentology and stratigraphy and the influence of the western basins on current stratigraphic models

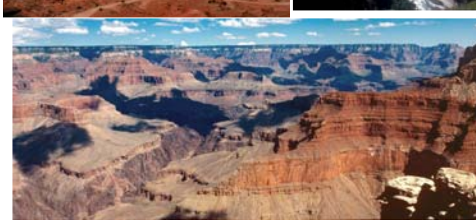
What's the plan?

- Brief review/introduction of controls behind deposition.
- Overview of the sedimentary patterns and depositional changes from pre-Cambrian to near present.
- Look at examples from around the Cordillera.

Why is he wasting our time?

- That's the way it is.
- Tectonics dominates the major trends in regional stratigraphy – the understanding of one ties into to understanding the other.
- Ability to mess with the minds of tour guides and park rangers.
- The perception of Western North America is to the images of sedimentary formations.

Which Picture is not from the Western Cordillera?



“Quick” review of stratigraphy-sedimentology

Controls

- What dictates whether a sandstone, limestone or pelagic mud deposit?
- How does this relate to the Western Cordillera?
- So what?

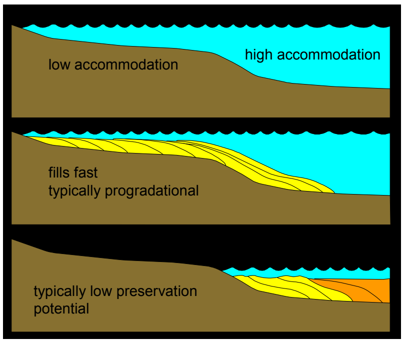
Main Controls

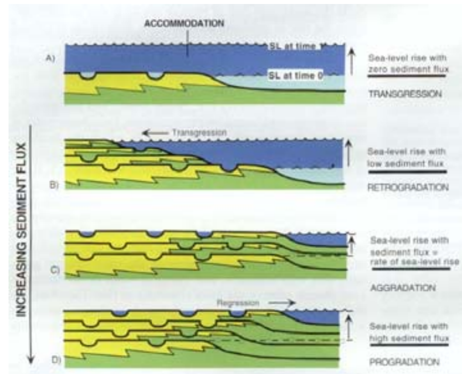
- Energy
  - too much leads to greater carrying capacity, and erosion
  - too little leads to no carrying capacity
- Space (accommodation)
  - low accommodation will typically result in very thin or no sedimentary deposits (low preservation potential).
  - high accommodation will have thicker sedimentary deposits (high preservation potential).

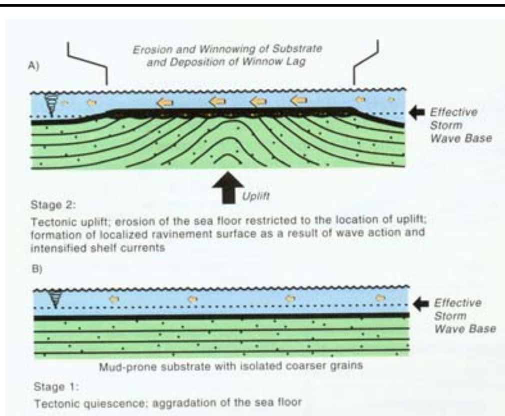
Energy

- Second Law of Thermodynamics – Entropy Law: Heat flow, directional flow of energy and more unrelated crap than you could imagine.
  - ExxonMobil’s stratigraphic research section is currently focusing on the Second Law to model sedimentation – sedimentation as a means to disperse energy.
    - major flaw – only applies to single vector clastic systems – no waves, storms, contour currents, longshore currents or heterogeneity allowed.

Accommodation

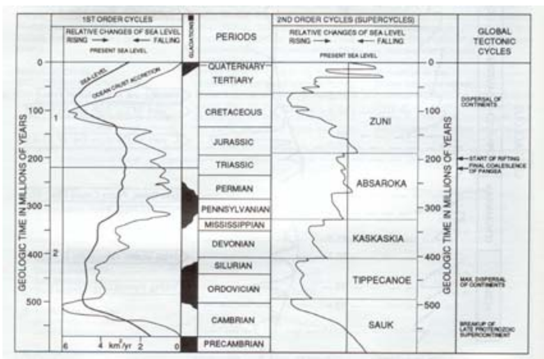






Other Controls: Cyclicity

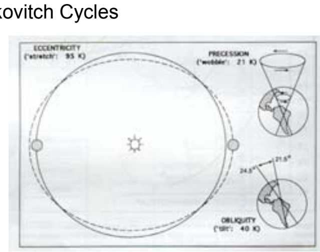
- Precursor of sequence stratigraphy lies in the 1950's and 1960's with the concept of continent-spanning sequences (Sloss) and global cycles (Vail – (Sloss' student)
- Rhythmic patterns and repetitions observed in nature at various time scales from hourly (tides) to yearly (summer-winter alternations) and larger
- Milankovitch cycles – orbital variances that have an observed periodicity of ~20,000, ~40,000 and ~100,000 years



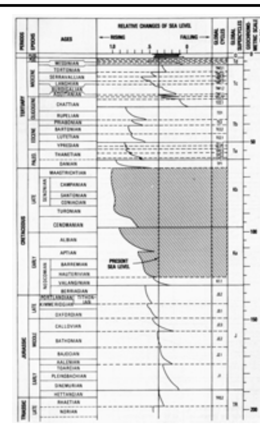
(Sloss Sequences)

Fig. 3.1. Recurrence time of periodic and episodic processes and events in geology. (Einsele et al. 1991b)

Milankovitch Cycles



The main effects of orbital irregularities are long-duration controls on global climate.

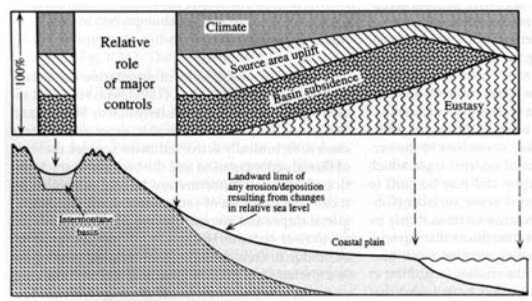


"Global" (eustatic) sealevel curve from Vail, 1977. Derived from ammonite and foram biostratigraphy primarily from the petroleum industry's work in the Cretaceous and younger basins in western NA.

Clastic Controls

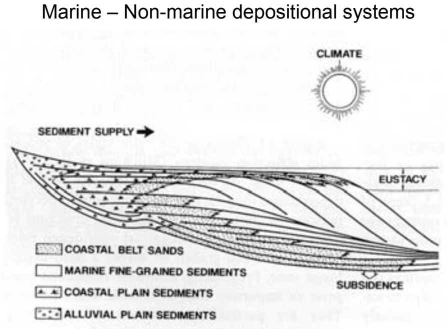
- Source needed – tectonic/volcanic highlands, uplifted older clastic deposits.
- Transport mechanism – wind, water, gravity – the more localized the mechanism the localized the deposit.
  - Bed Load/Carrying capacity – a transport mechanism that is capable of carrying more material will erode; one the is at maximum will deposit.
- Climate – wet climates breakdown minerals faster – more clays and smaller mineral grains.

Controls - location

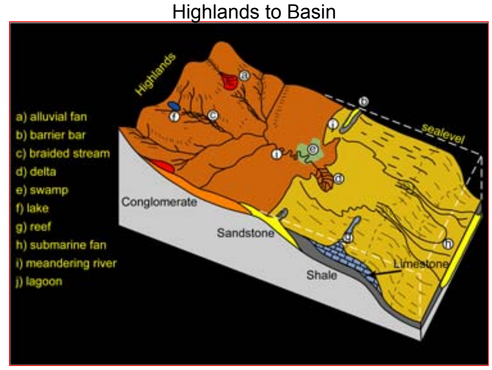


Completely Terrestrial | Varies over time | Completely Marine

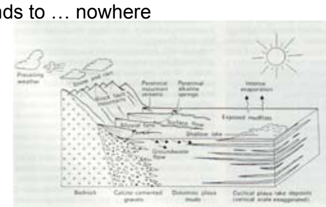
Marine – Non-marine depositional systems



Clastic depositional environment model from Highlands to Basin



Highlands to … nowhere

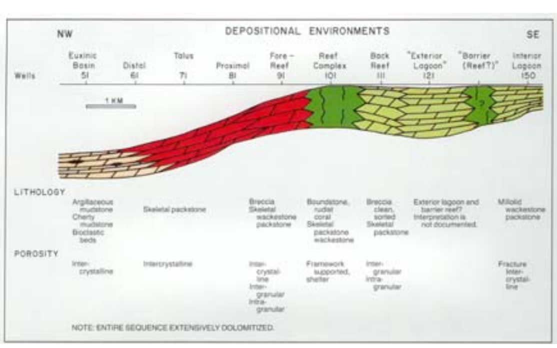


On the small scale (Rocky Mountains/Sierra Nevadas) – typical alluvial fans grade into an alluvial plain – an arid expanse with a few ephemeral streams that drain into playas
However, when considering huge events (Himalayas and similar continent-continent collisions) where the amount of sediments being shed is much greater – the alluvial fan and alluvial plain are not climate controlled (although the large mountain range will typically change the climate) and the entire system grades from fan – to plain – to marine basin – like the Catskill Delta.

Carbonate Depositional Controls

- No or low clastic input
- Temperate of water – corals like temperatures between 15-25^{o}C
- Salinity – not too fresh or too salty
- CO_2 balance – algae associated with the corals need CO_2 supply
- Water depth – ~pressure
- Local currents
- Light penetration and local turbidity
- Length of day – latitude (30^{o} N&S)

Parts of an idealized carbonate platform



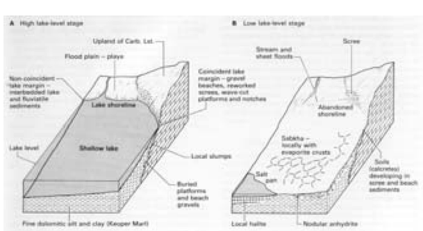
Non-carbonate non-clastics

- For the most part - evaporites or coals
  - evaporites have similarities to carbonates, but require higher temp, lower energy- generally a carbonate system where things go climatically wrong.
  - coals/peats local vegetation overwhelms any clastic or carbonate signal. Needs to have fast growth (source), high death rate, and low oxygen (preservation).

Evaporation – non clastics

- Generally closed off basins or any place where the rate of evaporation exceeds the rate of water replenishment
- Conditions are typically hot
- Can occur along coastlines, but in western NA, more likely ephemeral/perenial lacustrine deposits.
- Primary dolomites, some calcites, halites, gypsums and sylvite

- Lacustrine Facies are definitely climate controlled – in arid climates the lakes (playas) will (mostly) dry up forming evaporite deposits.
- In climates with consistent rain the lake is essentially a fresh water marine environment with similar deposit seen in oceans



Marine evaporite model

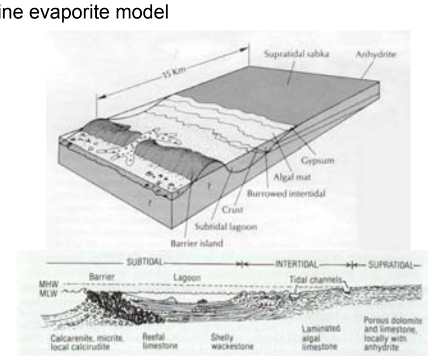
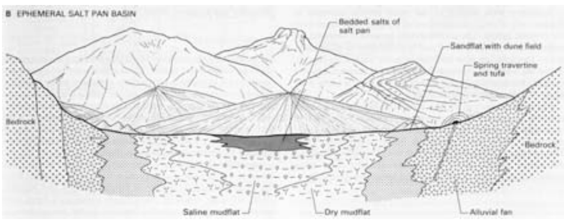
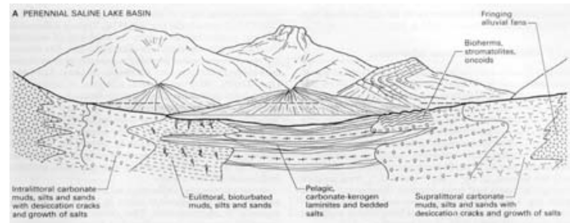


Fig. 9-21. Diagrammatic transverse section showing the principal subenvironments and deposits of a carbonate-producing reef and lagoon. MHW = mean high water, and MLW = mean low water.



Ephemeral Basins – not too much rain – reflux (periodic or continual addition of “fresh” water) is low, just enough to carry more brine to the playa

Deposits are mostly evaporites and mixed mud/salt at the center grading to the normal alluvial deposits towards the highlands.



Perennial Lakes – the rain is seasonal – such that the streams flow regularly during one period of the year then turn ephemeral flowing only if the rainfall is unusually high.

Deposits are alternating evaporite with mud and high organic influx (kerogen-rich shales) towards the center, and carbonate algal mats or clastic sands and muds form the shoreline (both will show signs of desiccation structures – finally grading to the alluvial fans.

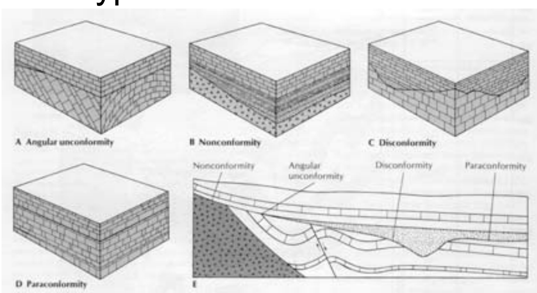
Pelagic Controls

- Deep water – little direct clastic input
- Low energy – see above
- Low rates of accumulation (1mm to 6cm per 1000 years.
- Hemipelagic- bastardized name for deep water sediments that are mostly pelagic but also contain distinct terrigenous sediment input
  - Turbidites
  - Volcanic ash layers
  - Pelagic-Shale boundary (extreme edge of the clastic sediment deposition)
  - Reef-carb talus edge

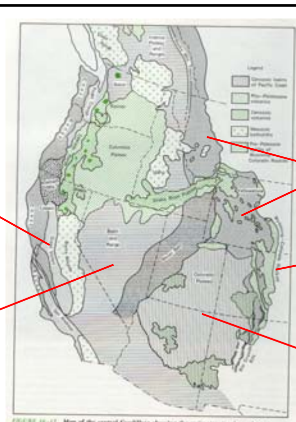
Hiatuses Erosion and Lacunas

- Deposition in never constant
- Hiatus in deposition or erosion will form gaps in the stratigraphy – unconformities.
- Chronostratigraphic term – lacuna; implies some basic ability to distinguish time in the rocks.

Types of Unconformities



Western North America Stratigraphy



Cenozoic sediments shed off the Sierras

Paleozoic sediments in thrusts

Cretaceous-Tertiary sediments of interest to petroleum exploration

Cenozoic sediments shed of the Rockies

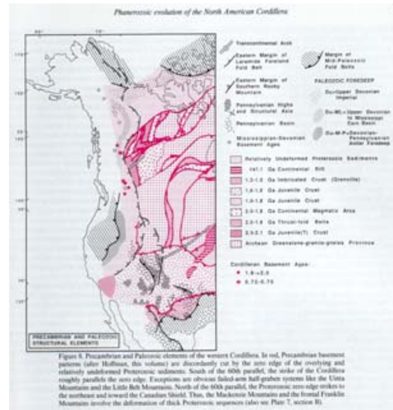
Permian-Cretaceous (+older) sediments most people know or think of from Western NA

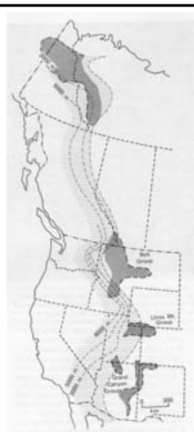
Paleozoic and older

- Not too many examples – particularly surface exposures
- preCambrian units are typically metasediments or approaching metaseds.
- distinctive units are generally coarse-grained clastic sediments adjacent to tectonic zones.

MID & UPPER PROTEROZOIC

- < 1.7 Ga Age
- Thick Section of Red Bed Clastics
- Marine to Non-marine Origin
- Belt and Purcell Supergroups
  - turbidite complexes
- Tectonic Environment Unclear





LATE PROTEROZOIC RIFTING

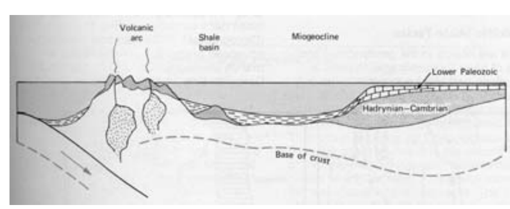
- Renewed Rifting 780-730 Ma
  - Along Whole Length of Canadian Cordillera
- Deposition of Windemere Supergroup
  - 780-570 Ma Rift Phase Clastics

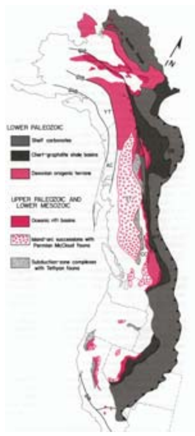
Cambrian to Devonian

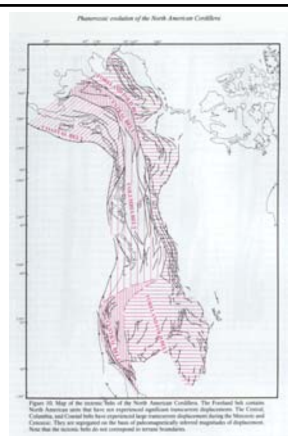
- The western continental margin ran approximately along New Mexico-Colorado-Nebraska-Dakotas trend.
- Mid Cambrian and Early-Mid Devonian are the only periods of major regressions
- All other periods are predominantly marine deposition.

Cambrian - Devonian

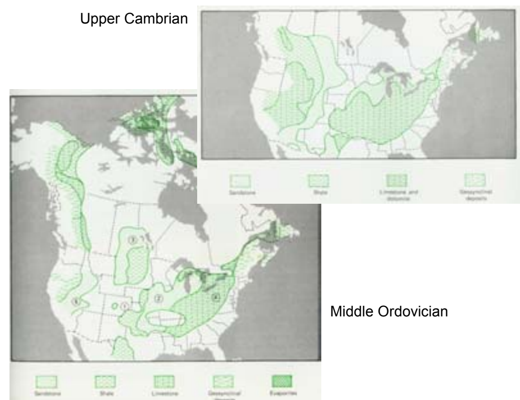
- Sediments are typically:
  - carbonates (on shelf and shallow environments)
  - or pelagics and black shales (basins and similar ocean floor environments)
  - Passive margin complex
- Why?
  - Little or no clastic input – no major highlands particularly to the east.





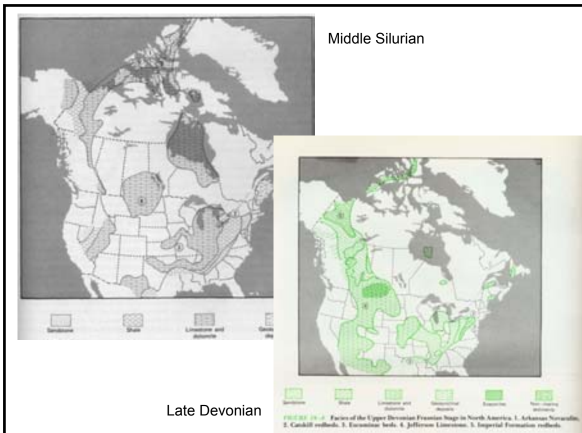


Upper Cambrian

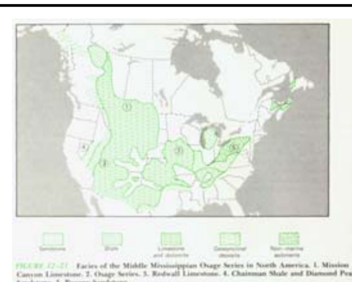


Middle Ordovician

Middle Silurian



Late Devonian



Middle Mississippian

From Cambrian to pre-Antler orogeny – the typical deposition reflected a passive margin complex of shoreface sand to shale to carbonate.
The western continental margin ran approximately along New Mexico-Colorado-Nebraska-Dakotas trend.
Mid Cambrian and Early-Mid Devonian are the only periods of major regressions

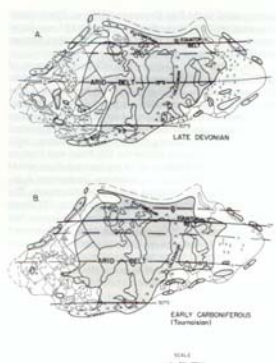
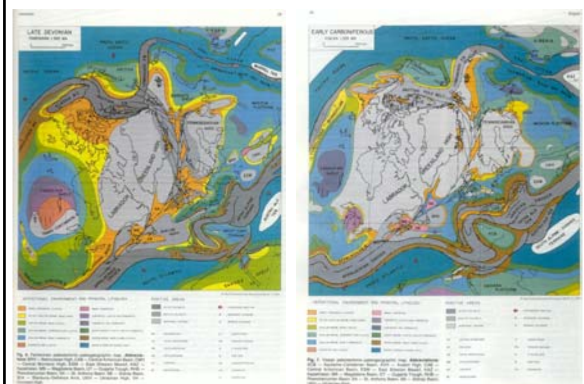


Fig. 2. Interpreted Late Devonian and Tournaisian paleogeography of Euramerica; sketch maps. Symbols as in Figure 1. Hachured line marks approximate edge of black shale facies.



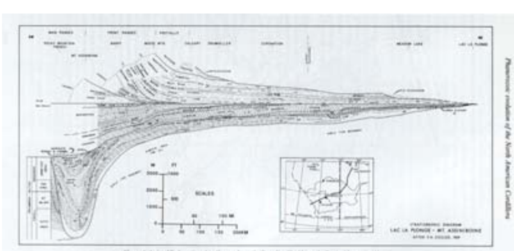
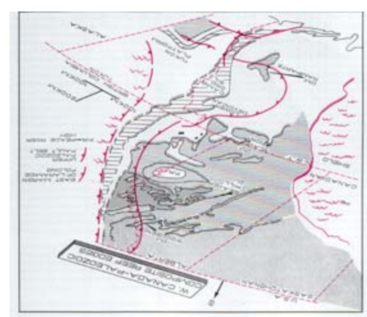
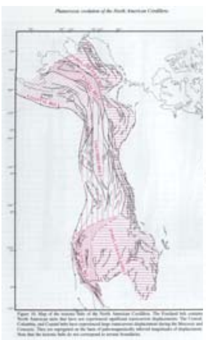
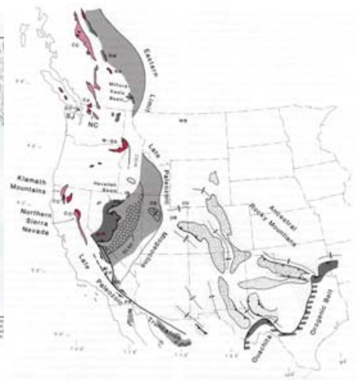


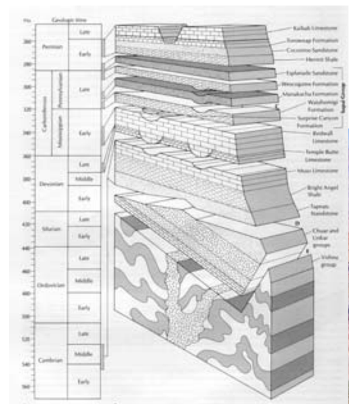
Figure 4. A simplified stratigraphic diagram from the Canadian Shield into the Rocky Mountains. Note the dramatic expansion of the stratigraphic section as the miogeosynclinal sequence is encountered west of the Front Ranges. The Mesozoic-Cenozoic boundary is the datum of the section. Also note the post-Mississippian to pre-Aptian wedge of multiple unconformities and the westward expansion of the Cretaceous foredeep sequence (from Ziegler, 1969).



Devonian reef building has been connected to basement-fault reactivations.

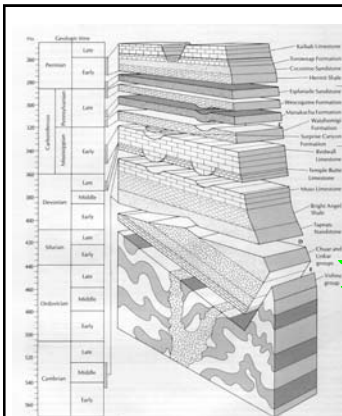


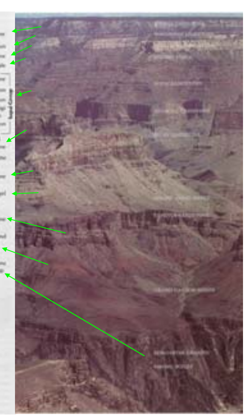


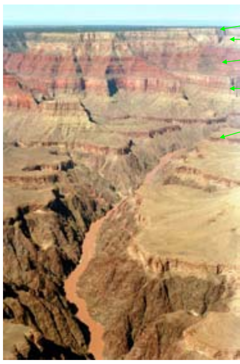


Grand Canyon Example

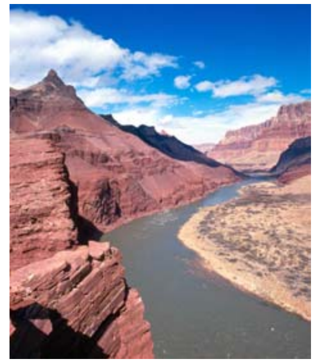
Grand Canyon, view from the West Rim







Colorado River carving out the Inner Gorge



Eastern end of the Grand Canyon

Marble Canyon, at the confluence of the Colorado and Little Colorado rivers.

Zoroaster and Brama temples from the South Kaibab Trail

Wotan's Throne

Paria Wilderness

ANTLER OROGENY

- Late Devonian - Mississipian
- Robert's Mountain Thrust Allochton
- Antler Foreland Basin

OVERVIEW (Review?)

- Early Eastward Thrusting
- Ocean Floor & Continental Slope Deposits
- Allochthon Pushed Over Passive Margin Rocks
- Associated with Arc Terrain Accretion

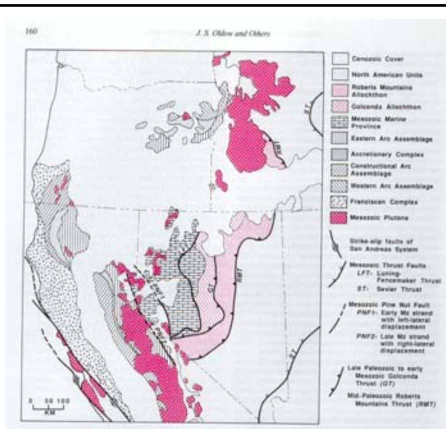
ROBERT'S MOUNTAIN UPPER PLATE

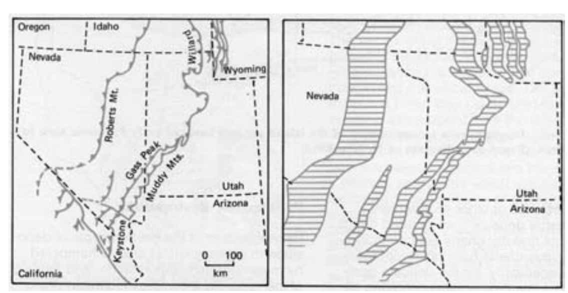
Sediments (Pelagic/Hemipelagics)

1. Turbidite Sequence
2. Graptolitic Shale
3. Radiolarian Chert
4. Carbonates and Siliciclastics

Volcanics

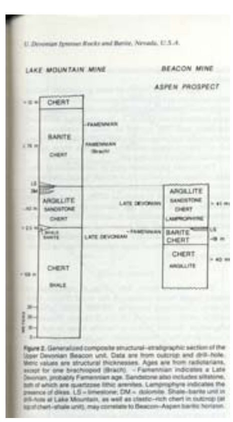
1. Ocean Floor Basalts
2. Tholeiitic Pillow Lavas & Dikes





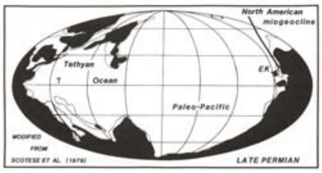
Boundary Thrust

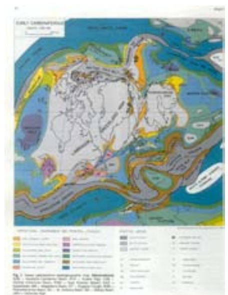
- Upper Plate
  - Cambrian to Ordovician
  - Basinal shales (pelagics), sandstones (turbidites)
  - Ocean Floor Volcanics
- Lower Plate
  - Ordovician/Devonian
  - Limestone and Shales (passive margin)
  - Telescoped Portions of Passive Margin



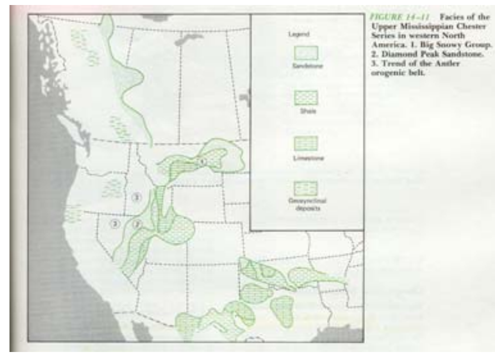
TIME OUT – flag on the play

How the hell does any of this relate?





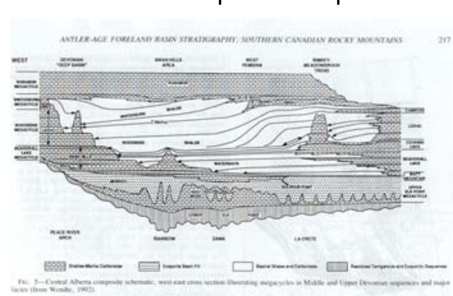
You have seen some abstract looking maps



We discussed the immediate, tangible results from tectonics

- Well Developed in Central Nevada
- Thick Black Shales Over Limestones
  - Chainman Shale (Miss) > 1.5 Km Thick
- Rapid Subsidence of Basins

…and looked at cross-sections that attempt to summarize depositional patterns

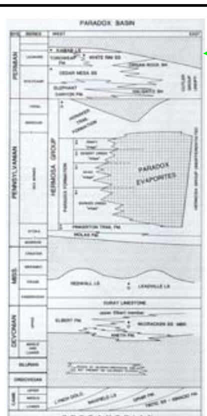


Proto/Paleozoic Summary

- PreCambrian – two major events that generated thick clastic deposits along the continental margin in a relatively narrow band.
- Mid Cambrian and Low-Mid Devonian experienced lower sea levels
- Overall passive margin, shelf – basin deposition.

Carboniferous revisited

- Antler orogeny generates clastic input for basins adjacent to the thrusts
- Another global lowering of sea level
- Generally passive margin deposition in the Cordillera, circulation is not open – resulting in evaporite deposition towards the southeast.

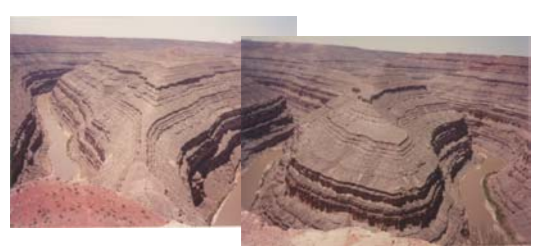


Top of the Grand Canyon

Monument Valley

Goosenecks of the San Juan River and Paradox Valley

Middle benches of the Grand Canyon



Goosenecks of the San Juan River
Pennsylvanian Hermosa Formation

Permian

- Uplift (reactivation of basement [protozoic] structures) of Ancestral Rockies and other “uplifts”
- Carbonate to evaporite basins towards the east lead to later salt- tectonics and the creation of small basins
- Non- marine clastics on the eastern extent of the Cordillera are derived from Ancestral Rockies and to some extent distal Appalachian and Ouachita orogenies.
- Change from open marine circulation to closed basins.

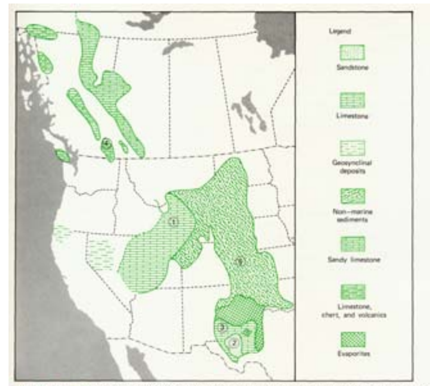
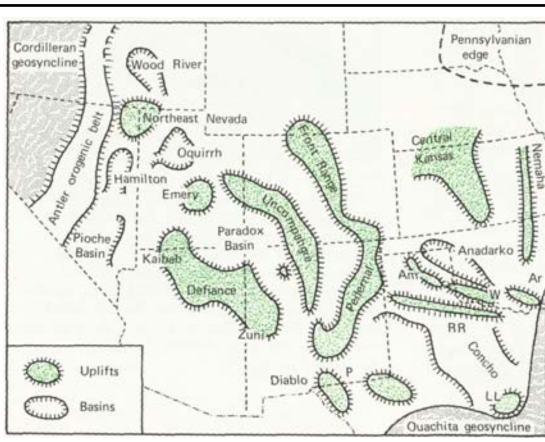


FIGURE 14-14 Facies of the Middle Permian Guadalupean Series in western North America. Note the many areas of limestone in the Cordilleran geosyncline. 1. Phosphoria Formation. 2. Delaware Basin. 3. Carlsbad Limestone. 4. Cache Creek Group. 5. Lykins Formation.



Boulder Flatirons, Co.

Fountain Formation,
arkosic alluvial fans
off the Ancestral
Rocky Mountains

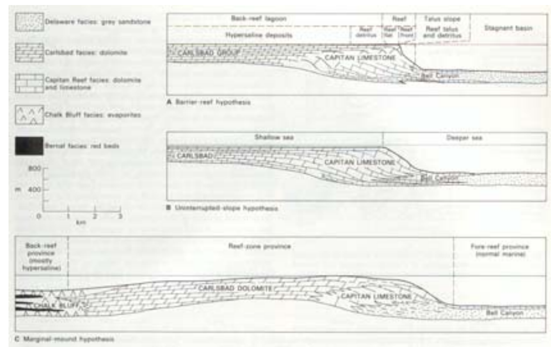
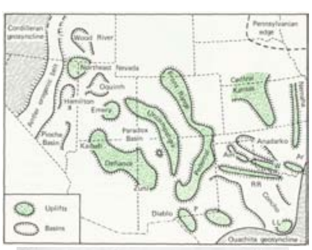
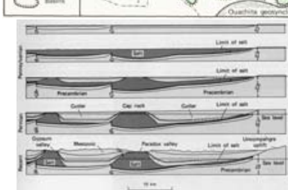
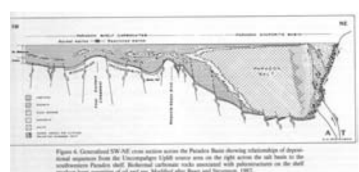
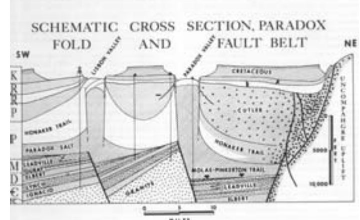


Fig. 10.61. Three alternative models of the Permian Reef Complex, West Texas and New Mexico (after Dunham, 1972).









Paradox Valley Basin

Cretaceous sediments form the valley walls, but tectonics modified by salt tectonics from Pennsylvanian through Triassic create the structure.

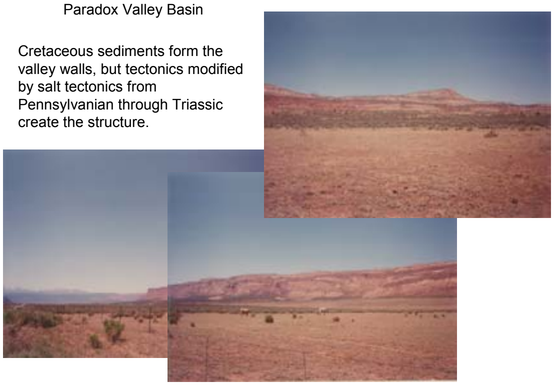


FIGURE 16-23 Basins and ranges of the central Rocky Mountains and the Colorado Plateau.

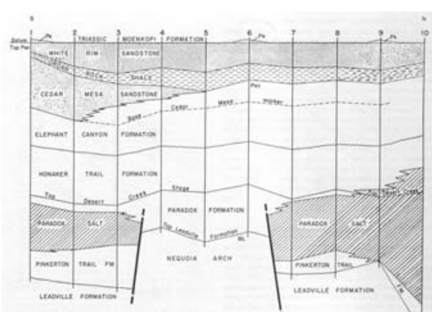


Figure 8. South to north cross-section across the Nequoia Arch west of Canyonlands. Major facies changes in the Pennsylvanian and Permian Systems are closely associated with the paleotectonic faulted structure, especially evident in the Paradox and Cedar Mesa Formations. Well spacing is diagrammatic. Wells used for control are: (1) Phillips French Seep #1, Sec.29,T.30S.,R.16E.; (2) Continental Hoover Fed. #1, Sec.20,T.29S,R.15E.; (3) Murphy Nequoia Arch #4, Sec.14,T.28S.,R. 14E.; (4) Texaco Nequoia Arch #6, Sec.32,T.27S.,R.15E.; (6) Continental Moonshine Wash #2, Sec.22,T.25S.,R.15E.; (7) General Petroleum #45-5-G, Sec.5,T.24S.,R.15E.; (8) Shell Chaffin #1, Sec.21,T.23S.,R.15E.; (9) Amax Petroleum Green River Desert #9-7, Sec.9,T.22S.,R.15E.; (10) Superior Grand Fault #14-24, Sec.24,T.21S.,R.15E. (From Baars, 1987.)

Monument Valley: Cliffs – mid Permian De Chelly Ss. (or White Rim Ss.
Slopes – mid Permian Organ Rock Sh.

Monument Valley
mid-Permian sediments

Butte

Mesa (Eagle Mesa)

Moki Dugway overlook
of Monument Valley

Carb-Permian Summary

- Antler – Sonoma orogeny create highlands west of the North America craton
- Ouachita/Marathon orogeny creates highlands along the southeast margin
- Uplift of the Ancestral Rockies create highlands along the western margin of the North American craton
- Uplift on NW trending structure (Uncompaghre etc…) create isolated basins.
- Basin is essentially closed, sediment supply is high and the water level is dropping.

Triassic

- Continuous transition from Permian to Jurassic of marine to non-marine
- Most notable deposits are in the Colorado Plateau – Moenkopi, Chinle, Wingate, and Kayenta formations (might sound familiar to anyone who was at the Steven's Canyon map site at UB field camp.

Facies of the Late Triassic

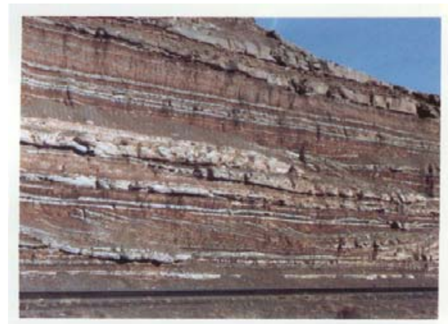
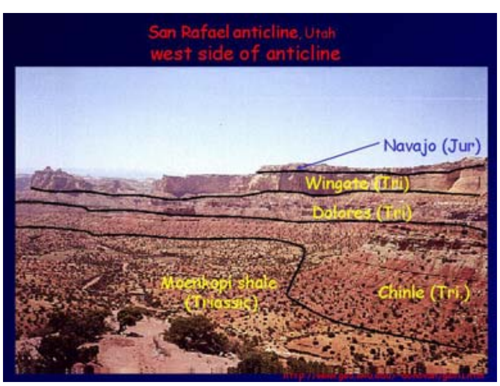


Fig. 46—Red fine-grained floodplain deposits of the Triassic Moenkopi Formation of Arizona. The whitish beds are caliche deposits and light-red sandstones at the top are crevasse splays. Many reduced green bands can be seen. A large swale or scour fill is present at the base. About 6 m of section is present.



Cathedral Butte,
Stevens Canyon
(Triassic)

Cedar Mesa Ss.,
Steven Canyon
(Permian)

Arches National Park, Utah
Jurassic Entrada Ss.

Canyonlands National Park, Utah Triassic Wingate and Moenkopi fms.

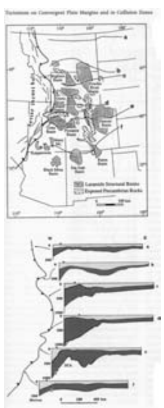
Triassic Alcova Ls.,
Williams Ranch Wyoming

Triassic-Jurassic
hogbacks
Williams Ranch, Wyoming

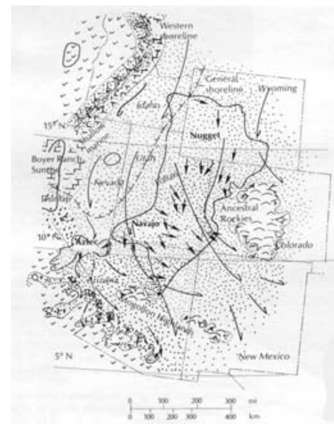
Dead Horse Point, Moab, Utah

Jurassic

- Non-marine Clastic sedimentation in full force
- Sevier orogeny uplifted central Cordillera continues the non-marine depositional environments from alluvial plains to eolian



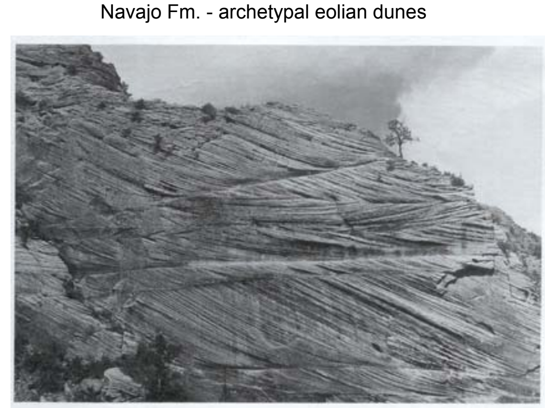
Sevier Thrust belt re-reactivates the old Antler Highlands and creates a narrow foreland basin that is predominantly non-marine. The location of the various highlands make eolian deposition quite dominant.

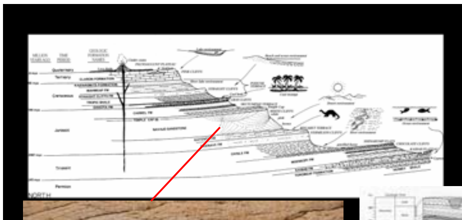


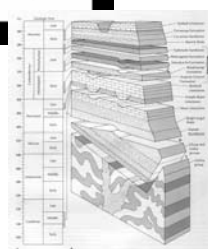
Eolian

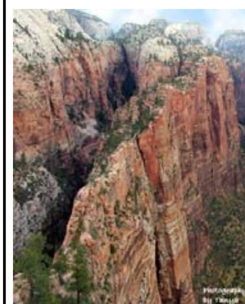
- Wind transported clastic sediments – generally looking at sand to silt size particles.
- Typically quartz grains as the mechanical wx is too harsh for other minerals
- 2^{nd} generation or higher sediments
- Colors are typically white-yellow: iron staining only on cements.

Navajo Fm. - archetypal eolian dunes

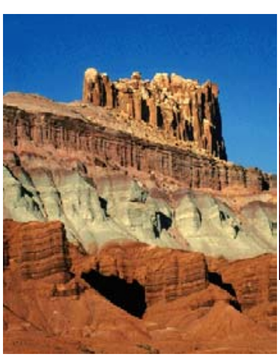






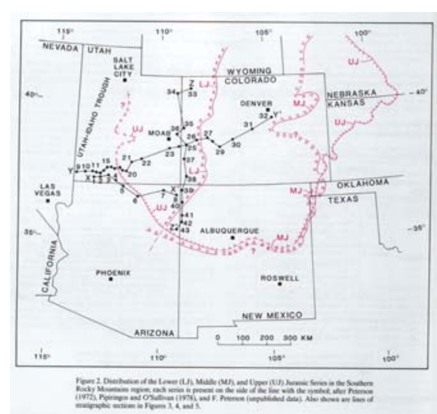


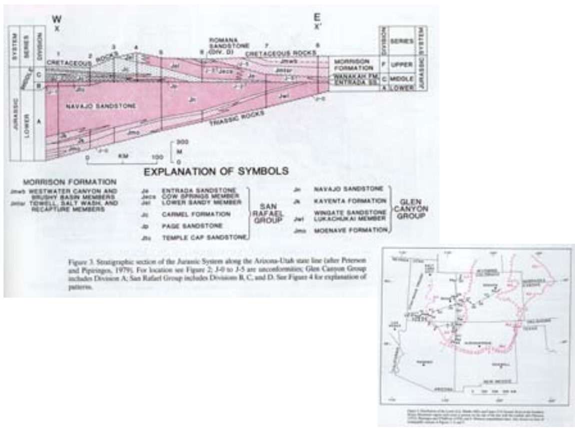
Zion National Park, Utah
Jurassic Navajo Sandstone.

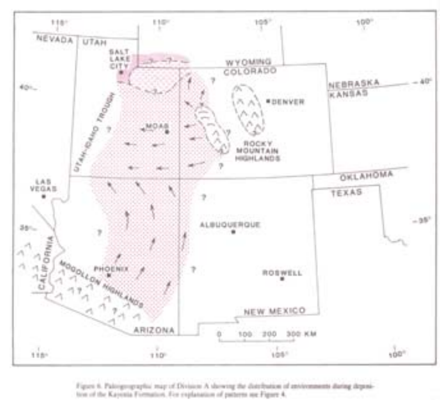


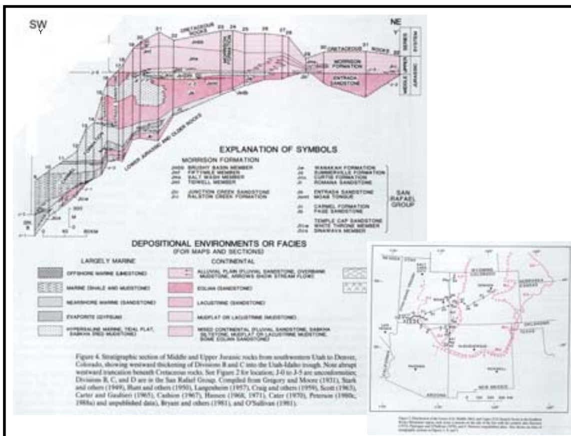
Capital Reef, Utah

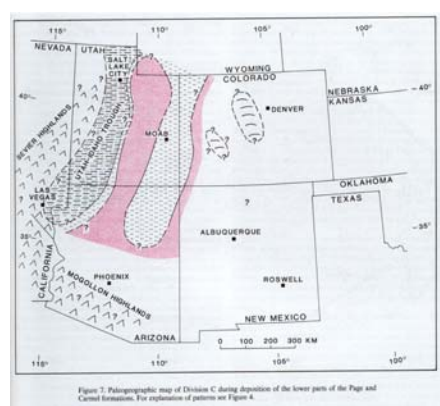
Usual suspects: Navajo - Chinle

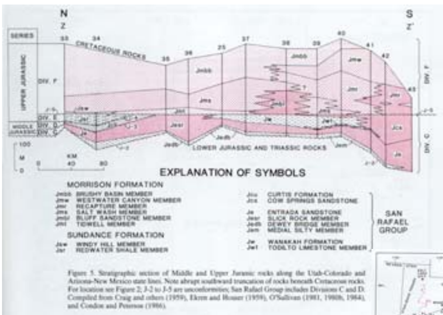


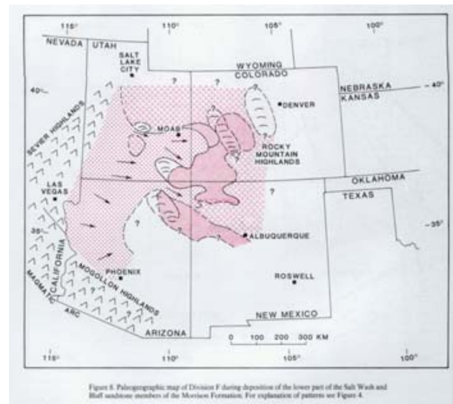

W
X
E
X'
SYSTEM
SERIES
DIVISION
ROMANA SANDSTONE (DIV. D)
CRETACEOUS ROCKS
MORRISON FORMATION
WANAKAH FM.
ENTRADA SS.
UPPER
MIDDLE
LOWER
JURASSIC SYSTEM
NAVAJO SANDSTONE
TRIASSIC ROCKS
EXPLANATION OF SYMBOLS
MORRISON FORMATION
WESTWATER CANYON AND BRUSHY BASIN MEMBERS
TIDWELL, SALT WASH, AND RECAPTURE MEMBERS
ENTRADA SANDSTONE
COW SPRINGS MEMBER
LOWER SANDY MEMBER
CARMEL FORMATION
PAGE SANDSTONE
TEMPLE CAP SANDSTONE
SAN RAFAEL GROUP
NAVAJO SANDSTONE
KAYENTA FORMATION
WINGATE SANDSTONE
LUKACHUKAI MEMBER
MOENAVE FORMATION
GLEN CANYON GROUP
Figure 3. Stratigraphic section of the Jurassic System along the Arizona-Utah state line (after Peterson and Pipiringos, 1979). For location see Figure 2; J-0 to J-5 are unconformities; Glen Canyon Group includes Division A; San Rafael Group includes Divisions B, C, and D. See Figure 4 for explanation of patterns.

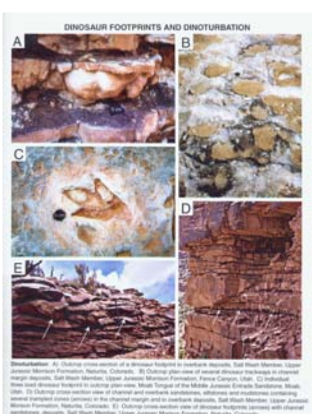

115°
110°
105°
100°
NEVADA
UTAH
SALT LAKE CITY
WYOMING
COLORADO
NEBRASKA
KANSAS
DENVER
MOAB
ROCKY MOUNTAIN HIGHLANDS
UTAH-IDAHO TROUGH
LAS VEGAS
OKLAHOMA
TEXAS
ALBUQUERQUE
CALIFORNIA
MOGOLLON HIGHLANDS
PHOENIX
ROSWELL
NEW MEXICO
ARIZONA
0 100 200 300 KM
Figure 6. Paleogeographic map of Division A showing the distribution of environments during deposition of the Kayenta Formation. For explanation of patterns see Figure 4.


SW
Y
NE
MORRISON FORMATION
ENTRADA SANDSTONE
LOWER JURASSIC AND OLDER ROCKS
EXPLANATION OF SYMBOLS
MORRISON FORMATION
SAN RAFAEL GROUP
DEPOSITIONAL ENVIRONMENTS OR FACIES
(FOR MAPS AND SECTIONS)
LARGELY MARINE
CONTINENTAL


115°
110°
105°
100°
NEVADA
UTAH
SALT LAKE CITY
WYOMING
COLORADO
NEBRASKA
KANSAS
DENVER
MOAB
SEVIER HIGHLANDS
UTAH-IDAHO TROUGH
LAS VEGAS
OKLAHOMA
TEXAS
ALBUQUERQUE
CALIFORNIA
MOGOLLON HIGHLANDS
PHOENIX
ROSWELL
NEW MEXICO
ARIZONA
0 100 200 300 KM
Figure 7. Paleogeographic map of Division C during deposition of the lower parts of the Page and Carmel formations. For explanation of patterns see Figure 4.







Jurassic Morrison Formation. Non-marine sediments noted for common occurrences of dinosaur remains and tracks. (From Hasiotis, 2002)

Triassic-Jurassic Summary

- “Basin” is closed and almost completely non-marine.
- Triassic – predominantly fluvial/alluvial with areas of marine – non-marine transitions.
- Jurassic – eolian for the memorable parts, Sevier thrust occupy the same location as the Antler/Sonoma highlands, and create a narrow foreland basin.