Early Tertiary Climate Change and its Impact on Matrix Mineralogy of the “auriferous gravels” in the Sierra Nevada Foothills

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Abstract

"Early Tertiary auriferous gravels" is a non-descript early mining term that remains in use on modern maps of both the USGS and the California Geological Survey (CGS).
Additional terms such as "lower gravel/upper gravel" and "channel gravel/bench gravel" all once held important economic connotations for 19th century miners but few modern geological studies have correctly characterized the physical and temporal nature of these important sedimentary deposits.

Recent field investigations and analytical data collected from several locations of the "auriferous gravels" throughout the Sierra foothills show this map unit to be a complex sedimentary assemblage comprised of at least two geologic units possessing drastically contrasting mineralogical and age relationships. Kaolinitic quartz-rich fluvial sandstones dominate the "lower or channel gravels" and represent the proximal Ione Formation fluvial system (≈50Ma). In contrast, the "upper or bench gravels" is a smectitic unit with complex sandstone matrix mineralogy and represents a much younger fluvial system (≥ 30 Ma). These smectitic sediments are best represented at Chalk Bluff in Nevada County. In addition, similar kaolinite/smectite mineralogical distinctions are observed in the paleosols buried immediately below these respective fluvial units. The mineralogical record contained in these sedimentary and pedologic units collectively forms an important addition to other climatic data indicating major global climate change at the end of the Eocene period. Thus, the 19th century nomenclature spawned during the heyday of gold mining in California should be abandoned in favor of a new classification based upon important differences in matrix mineralogy. Such revised classification will help more clearly define the character of these Early Tertiary sediments and their important role in understanding the complex geological evolution of the Sierran region as well as global climate change during this dynamic period.

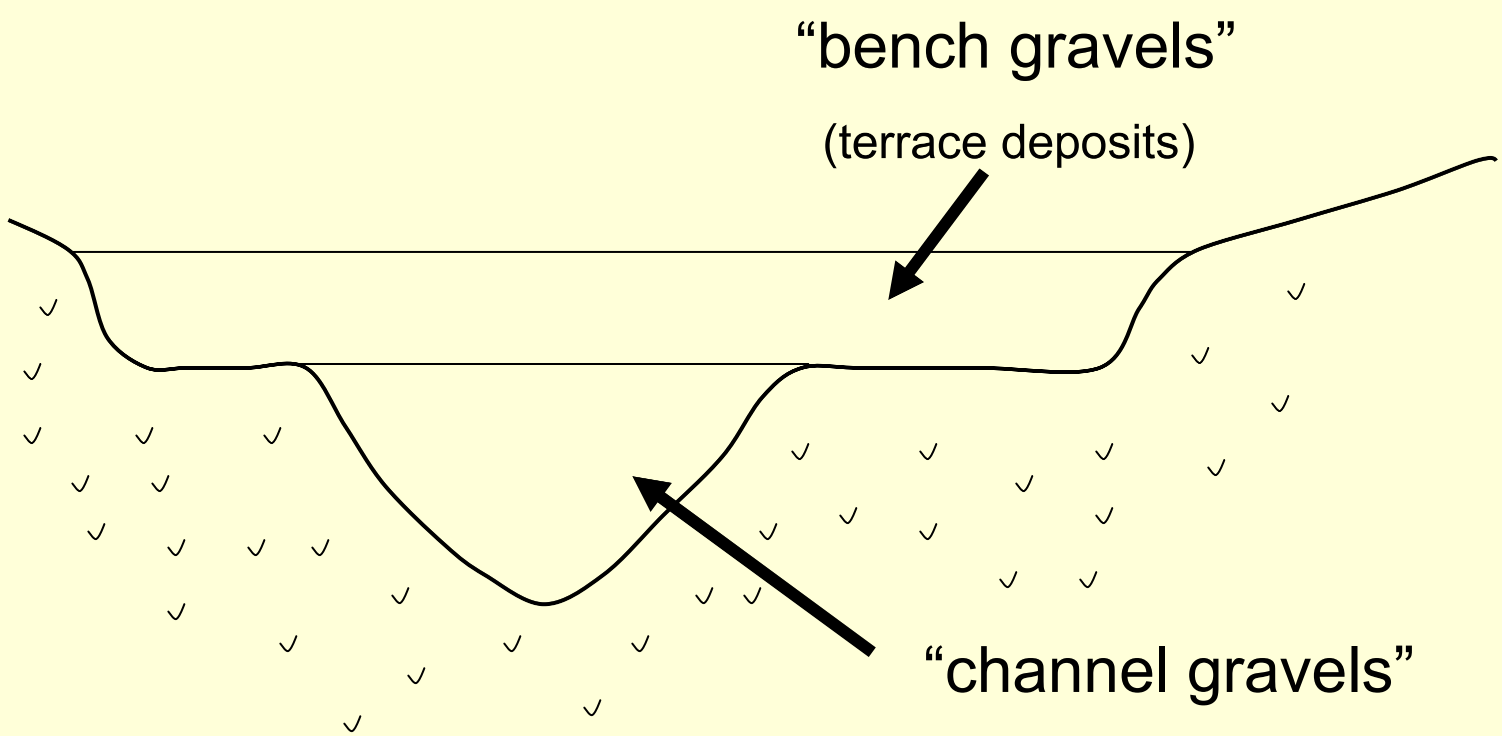
What are the “auriferous gravels”?
(prevailing understanding)

- River system sediments
- Middle Eocene age
- Quartzose sand with kaolinitic matrix clay
- Proximal deposits in Sierra foothills equivalent to Ione Formation
  - Coarse grained sandstone and conglomeratic sandstone
  - Gold bearing
- Distal fluvial/deltaic Ione deposits in fringe zone of Sacramento and San Joaquin Valley province
  - Finer grained sandstone and claystone
  - Ione and Lincoln are best known localities
  - Mined for kaolinite and quartz sand for glass

Earliest classification scheme of “auriferous gravels” was defined by miners

- Miners used gold content to define units:
  - Highest concentrations in “channel gravels or lower gravels”
  - Lower concentrations in “bench gravels or upper gravels”
- Early geologists adopted this mining nomenclature

Early Tertiary River System Architecture



Archaic 19th Century mining terminology is still in use today on USGS and CGS maps and in other geologic literature

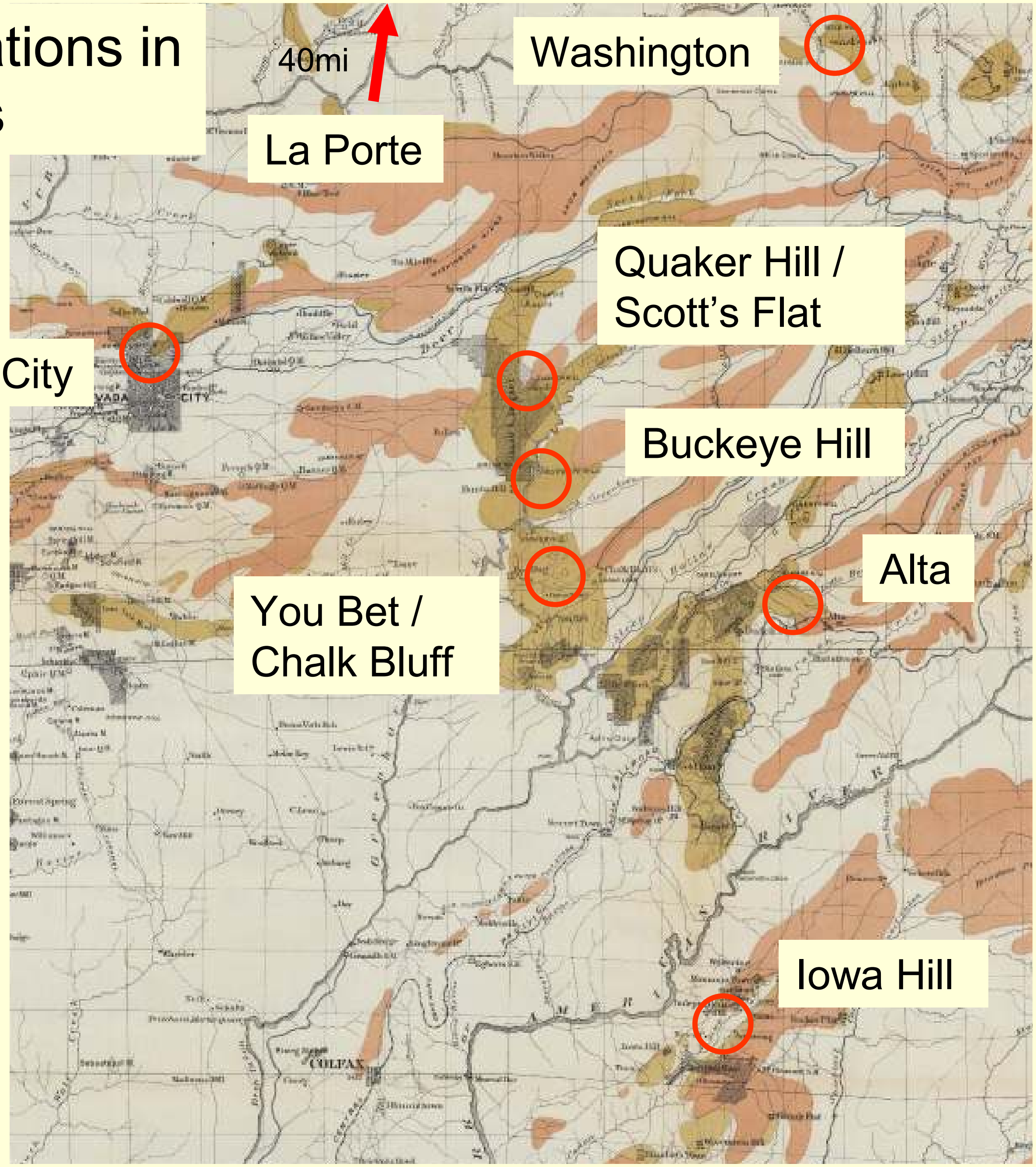
Continued usage has perpetuated various misconceptions and ignores important mineralogical distinctions that have implications for understanding Sierran Tertiary geohistory and paleoenvironments

History of Current Research

- Studies began in 1980's at UNOCAL Research Center
- Objective to gain better understanding of kaolinitic petroleum reservoir sands
- Conducted provenance study with Ione Formation fluvial system as a model

Principle study locations in Sierra foothill areas

J. D. Whitney (1873)

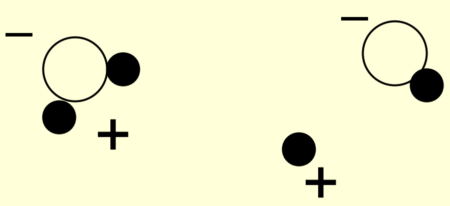


Global Early Tertiary Climates Were Very Humid and Warm

- Climate moisture and temperature regimen played an important role in determining the composition of soils and sediments
  - Weathering of primary minerals
  - Formation of secondary clay minerals

Chemical Weathering

- Hydrolysis is the principle agent of chemical weathering of minerals in soils
- Water forms a weak acid
  - H_2O molecule is bi-polar
  - dissociates into H^+ and OH^- ions

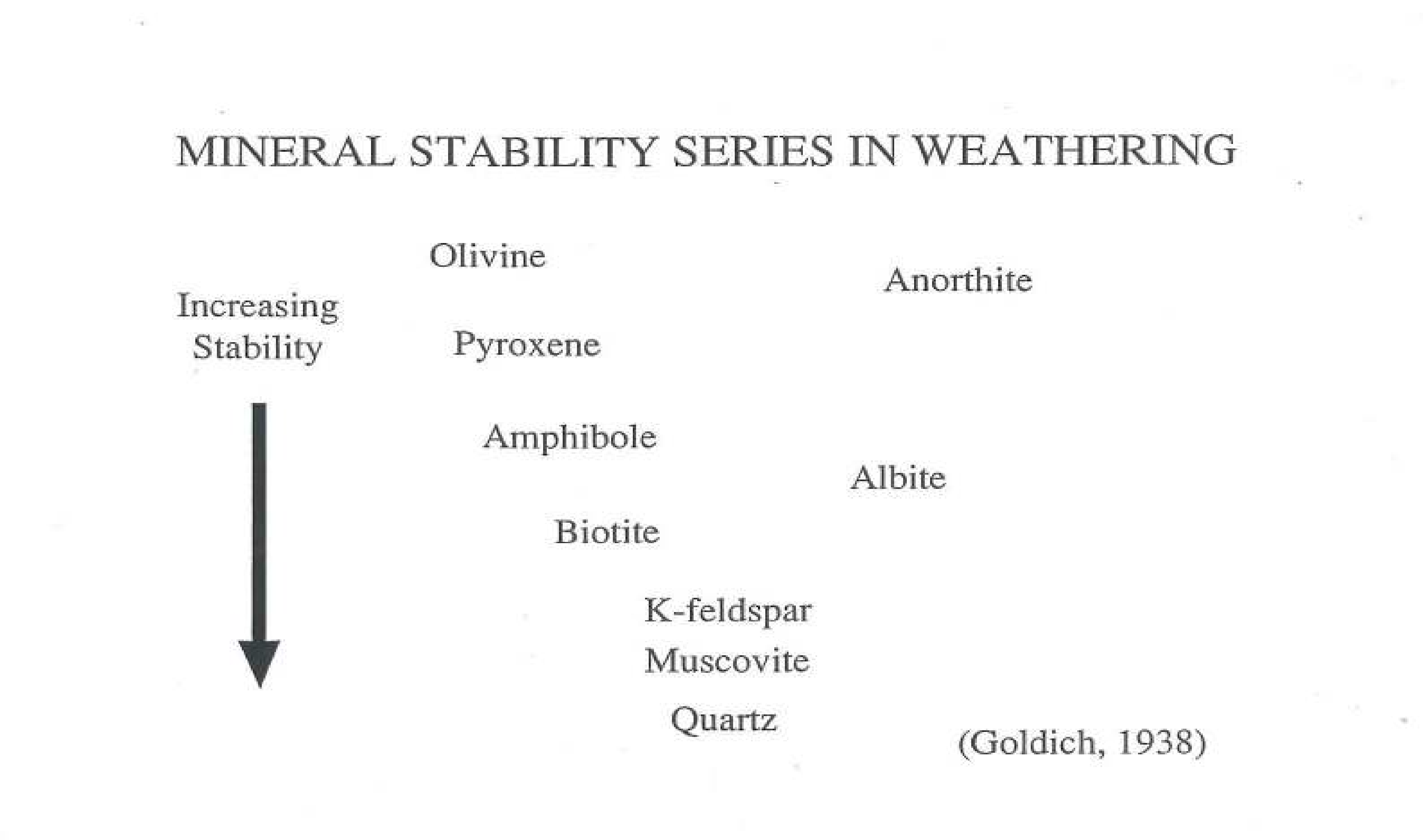


- Hydrolytic intensity depends on volume of water moving through the soil
- Higher temperature accelerates chemical reactions

Chemical Weathering

- Various minerals' susceptibility to weathering and decay depends on strength of bonding:
  - Ionic bonding more susceptible
  - Covalent bonding more resistant

- Silica polymerization (structure complexity)



Weathering Sequence Follows Bowen’s Reaction Series

Secondary clay mineral stability in soil determined by hydrolytic intensity

- Factors determining secondary clay mineral formation:
  - Availability of cations (K, Na, Ca, Fe, Mg)
  - Availability of Si determines the number of silica tetrahedral layers

HYDROLYSIS VS. WEATHERING PRODUCTS

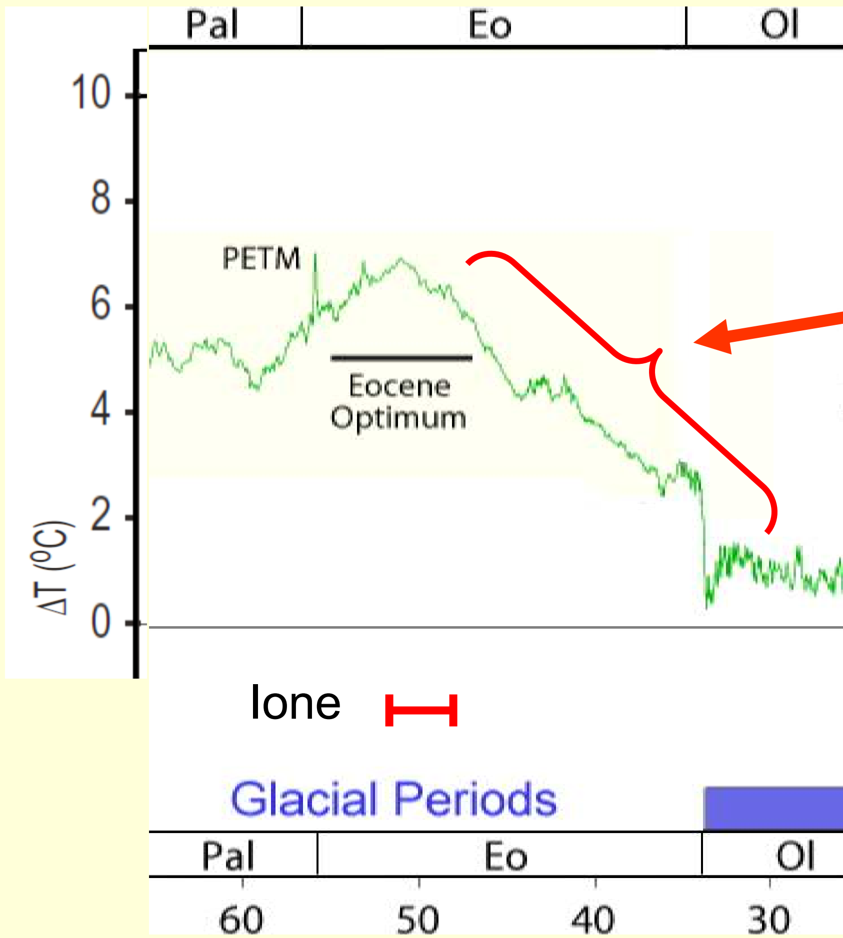
Increasing Hydrolytic Intensity ↓

# of Tetrahedral Layers	Secondary Minerals	
2	Sericite Smectite Vermiculite	2:1 clays
1	Kaolinite	1:1 clay
0	Gibbsite	

Increasing Cation Depletion ↓

(Chamley, 1989)

Early Tertiary Climate Trend

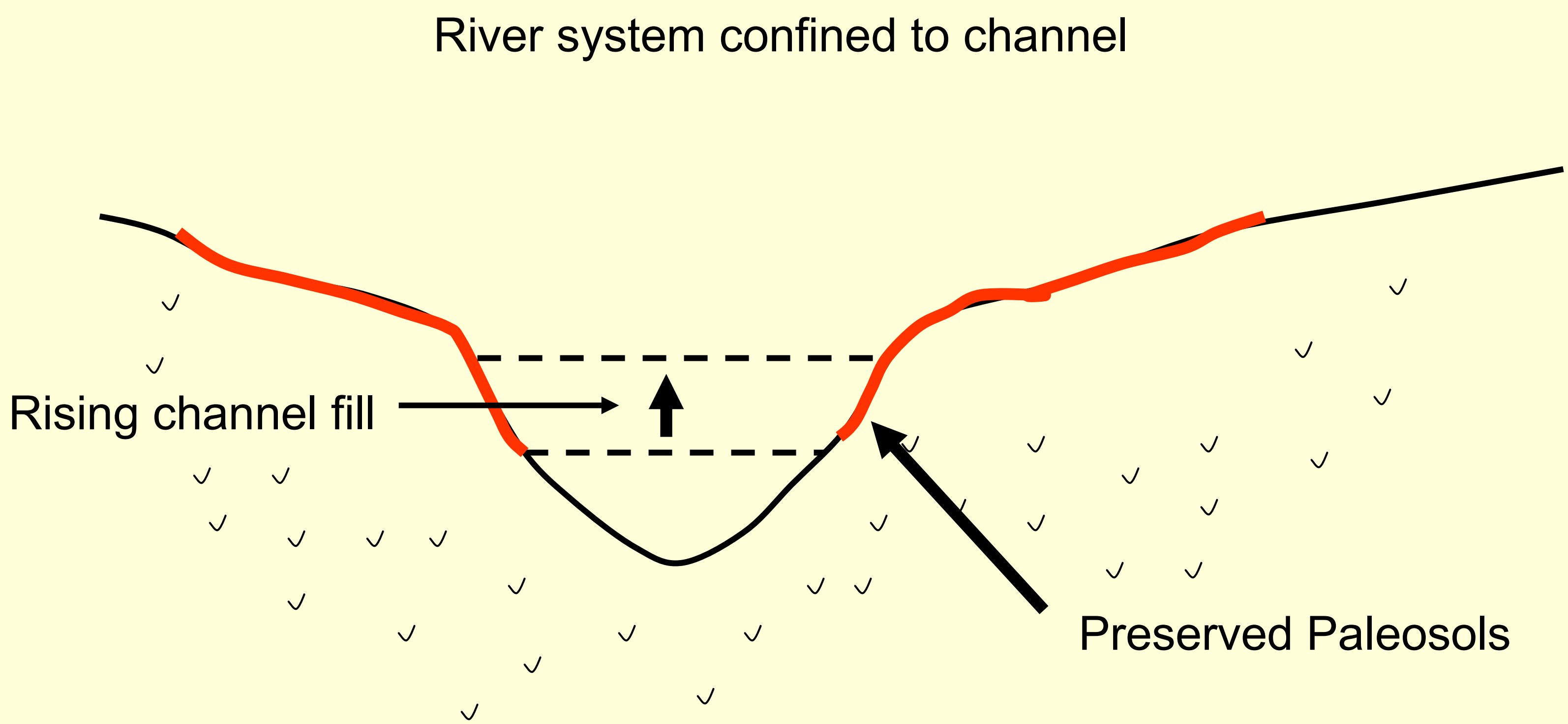


Increasing hydrolytic intensity

Should expect change in climax clay assemblage in soils and sediments

Modified from : Zachos, James, Mark Pagani, Lisa Sloan, Ellen Thomas, and Katharina Billups (2001). "Trends, Rhythms, and Aberrations in Global Climate 65 Ma to Present". *Science* **292** (5517): 686–693. doi:10.1126/science.1059412

Preservation of Early to Middle Eocene Soils

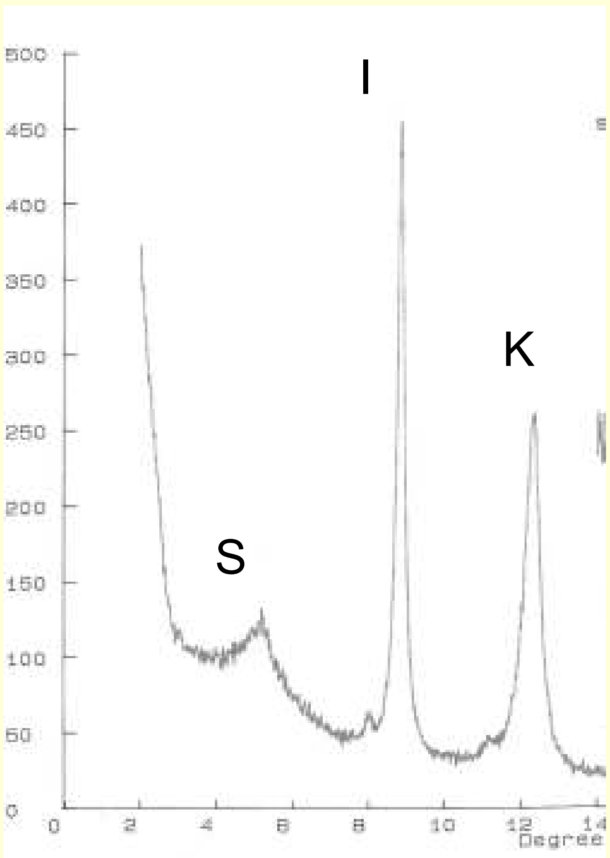


Mid-Eocene Regional Soils

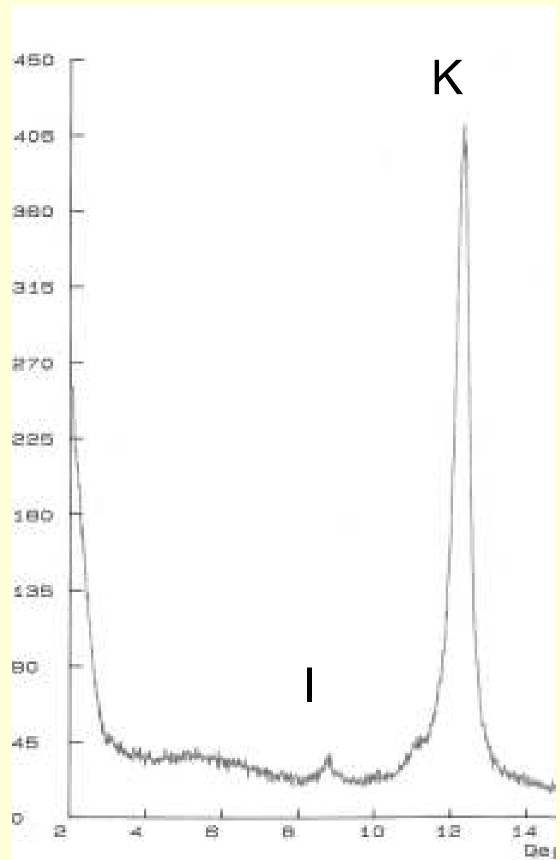
- Paleo “Oxisols” preserved below Ione Formation sediments in proximal and distal areas
- Kaolinite was the climax clay specie
- All weatherable minerals absent
- Ephemeral (transitory) clay minerals only in weathering front
- Example: paleo Oxisol — Nevada City

Oxisol Clay Mineralogy

Weathering front



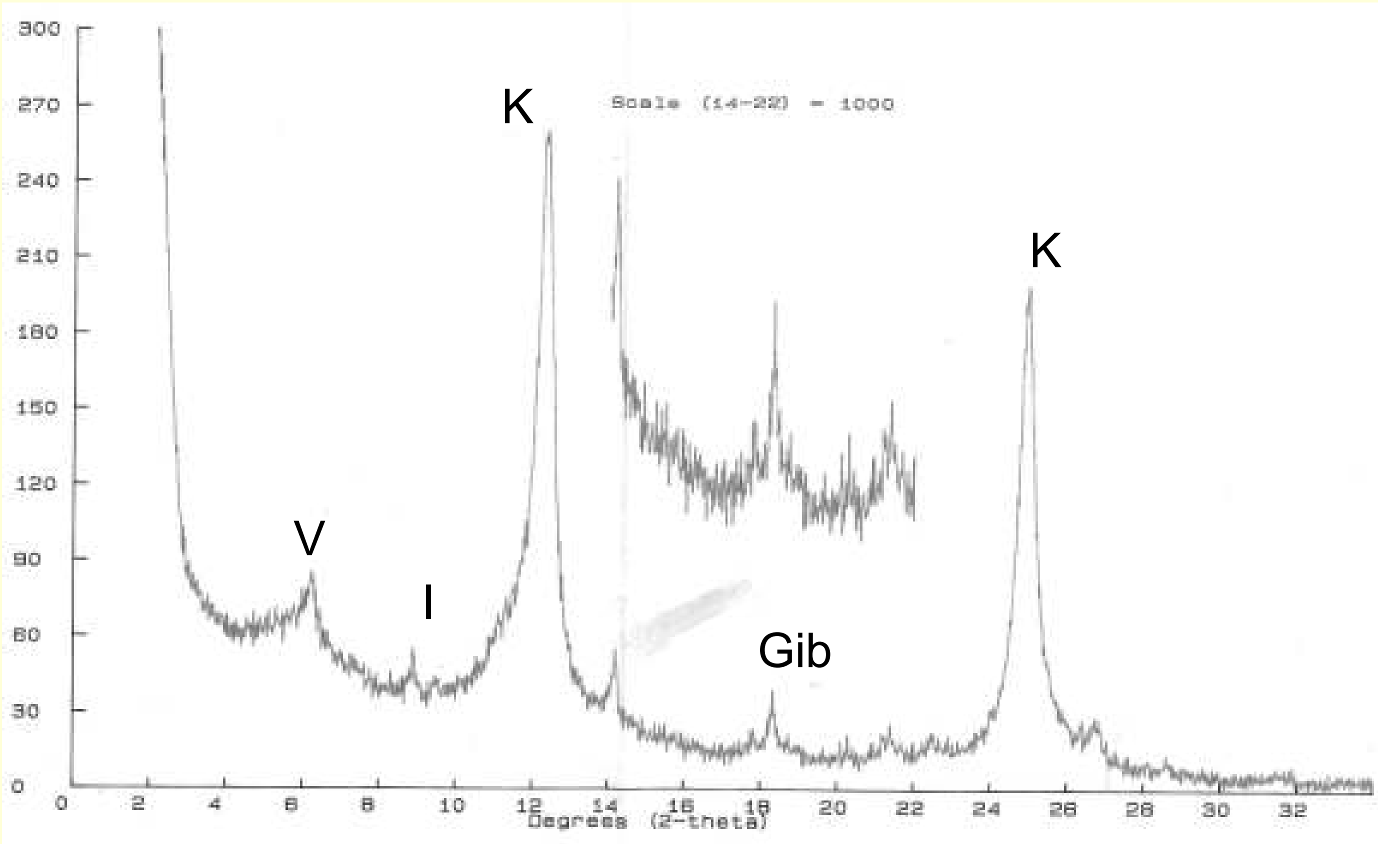
Saprolite



Oriented clay mineral XRD analysis (<2μm)

The matrix mineralogy of fluvial sediments that were derived from the erosion of regional soils should mimic the climax clay mineralogy of the soils

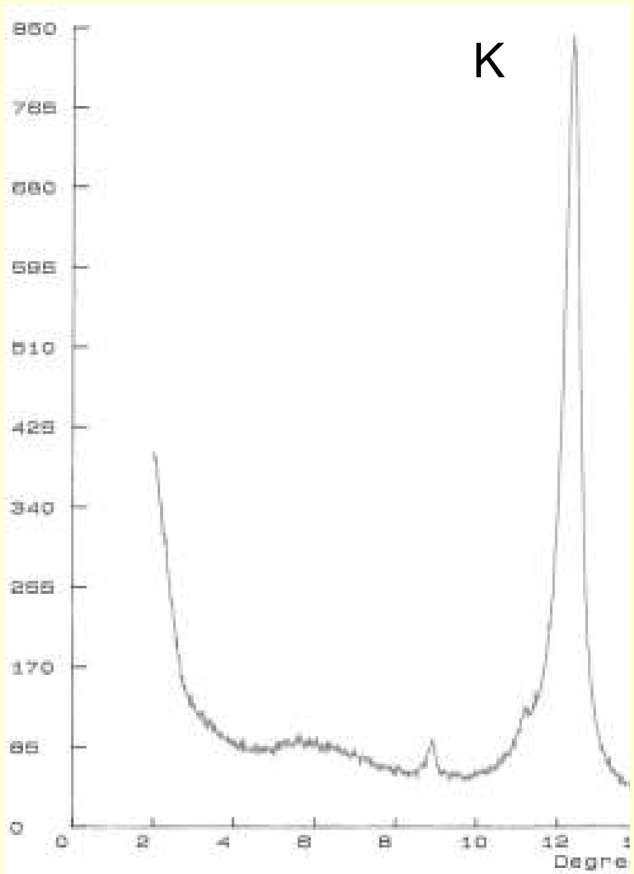
Ione proximal sandstone matrix clay assemblage (near Washington)



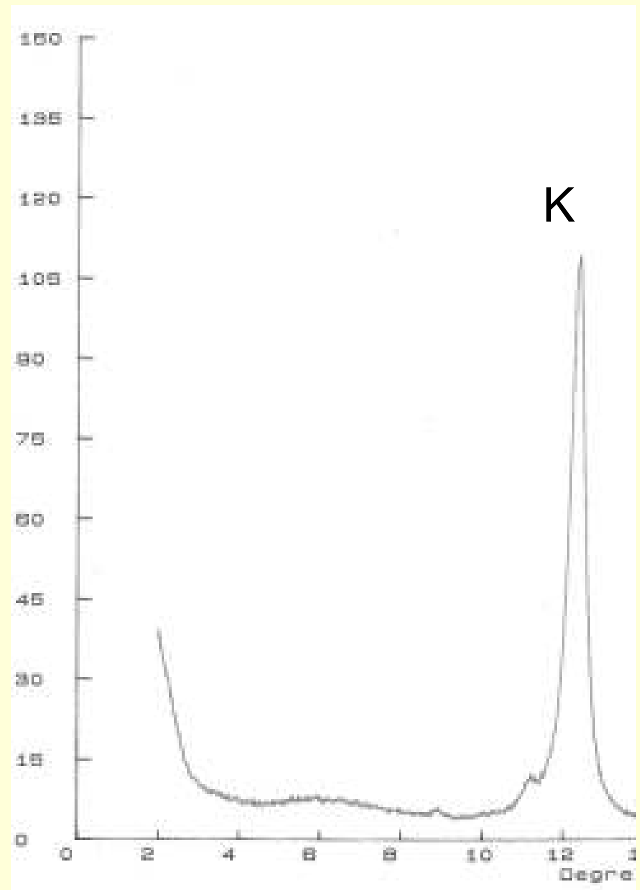
Kaolinite is dominant clay mineral

Distal Ione Sandstone

Lincoln



Ione



Kaolinite is dominant clay mineral

What happened in the last 10 meters of Ione claystone section?

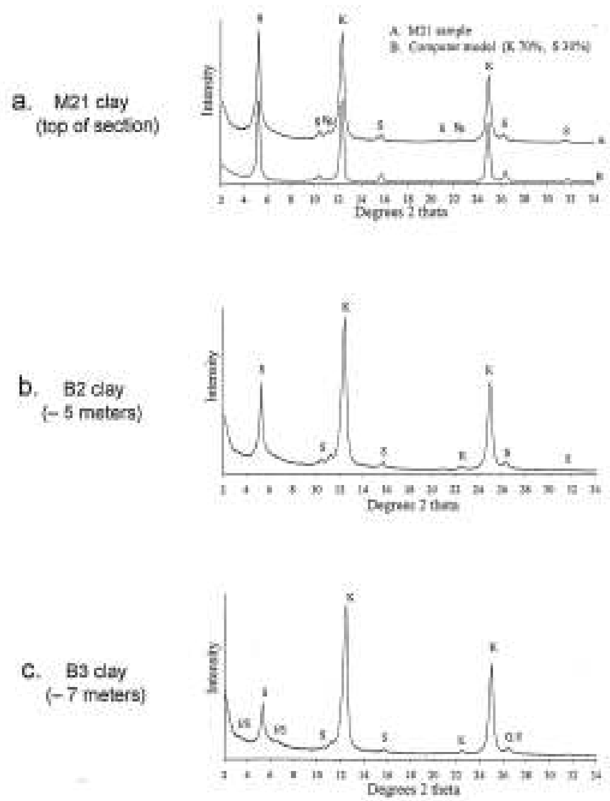


Figure 17. XRD analysis of the <2 µm fraction of M21 (a), B2 (b) and B3 (c) clays from the Bacon Pit. Oriented sample; Mg-saturated; glycol solvated. K = kaolinite, S = smectite, I/S = illite/smectite mixed-layered clay.

~30% S

Gradual increase in smectite content in top 10 meters

Same mineralogy in Lincoln claystone section

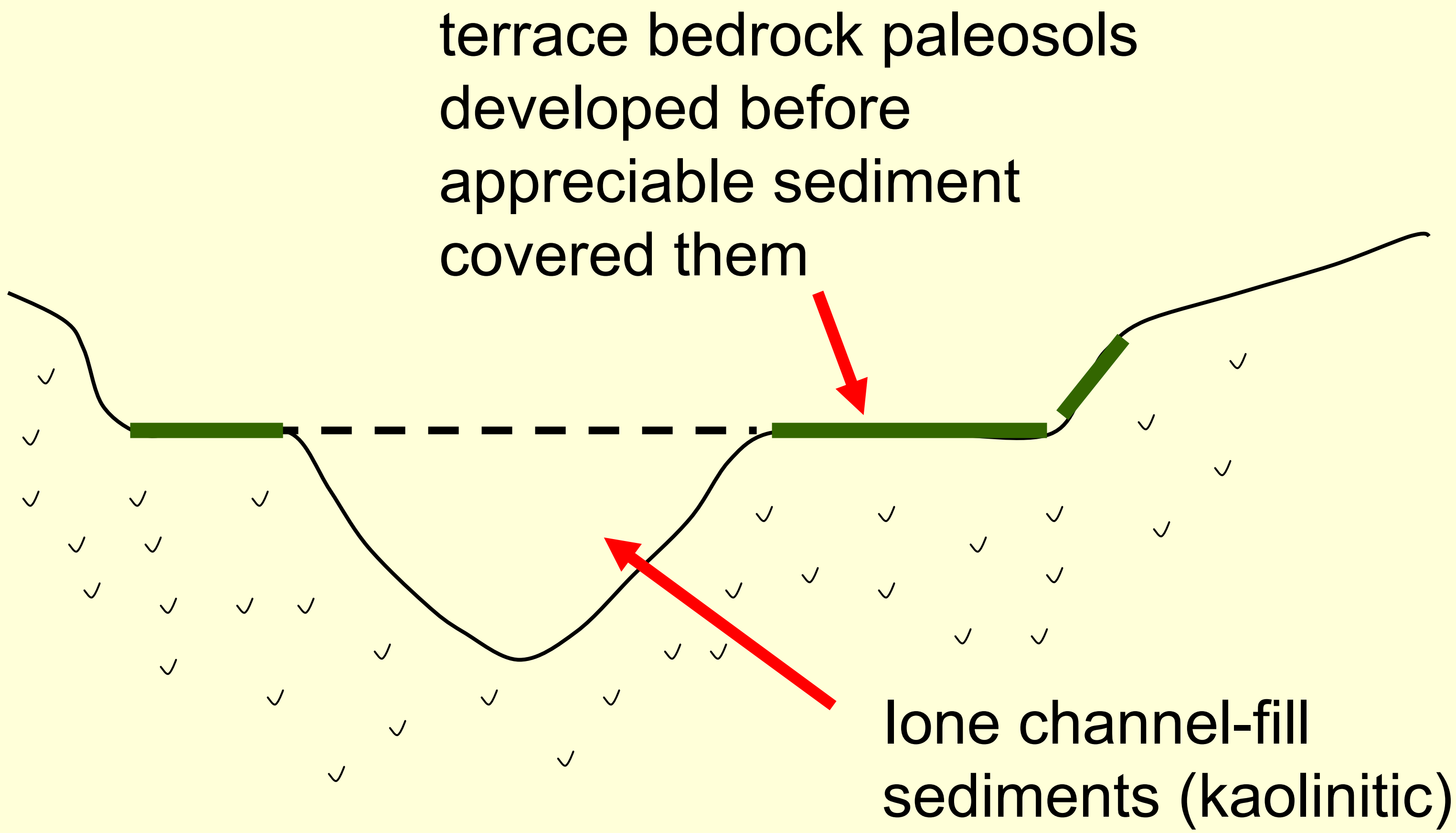
~5% S

(Wood, Glasmann, and Stout 1995)

What is the significance of the sudden appearance of smectite at the top of the Ione section?

Answer lies in the upper sedimentary section of the "auriferous gravels" — aka terrace or bench deposits

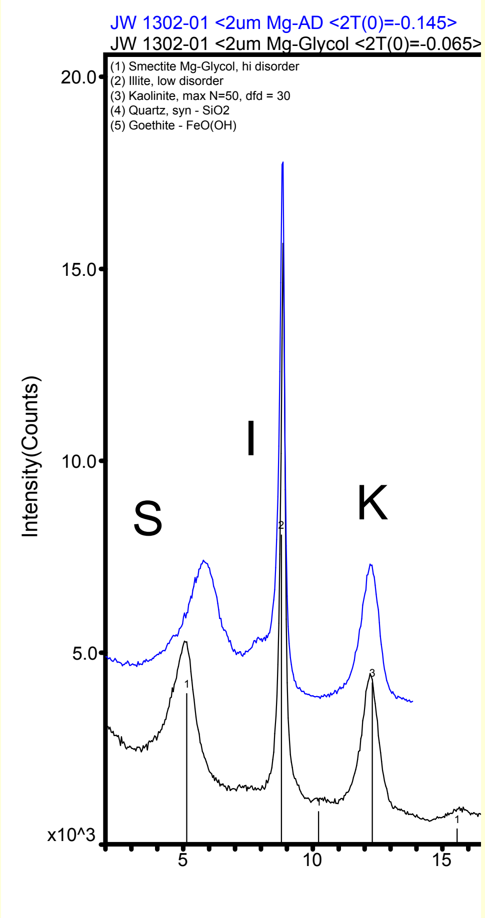
Early Tertiary River System



Soil and Sediment Sequence of Terrace Deposits at Chalk Bluff

photo from Howard Schorn, 2012

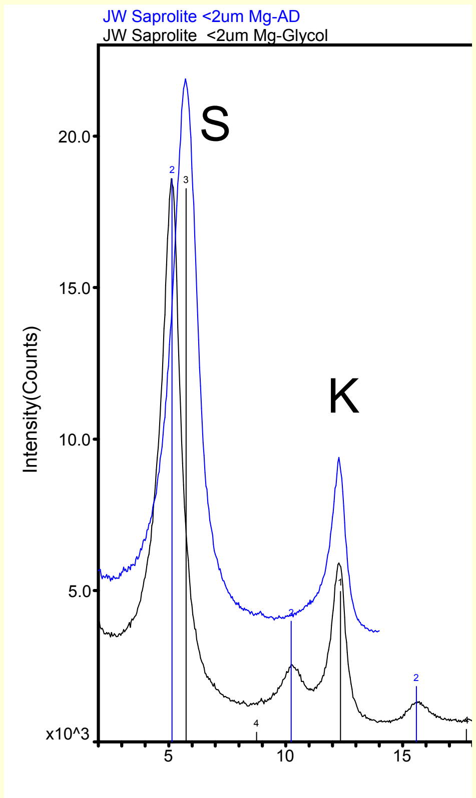
Weathering Front in Terrace Bedrock Surface



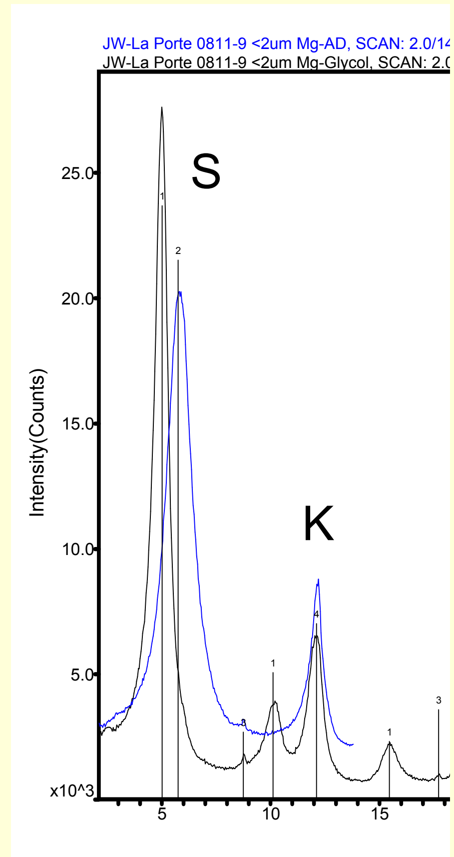
XRD shows incipient alteration of slate bedrock. Secondary minerals —smectite, kaolinite, and illite (sericite). The latter may be inherited from parent rock.

Paleosols on terrace bedrock surface

Chalk Bluff



La Porte

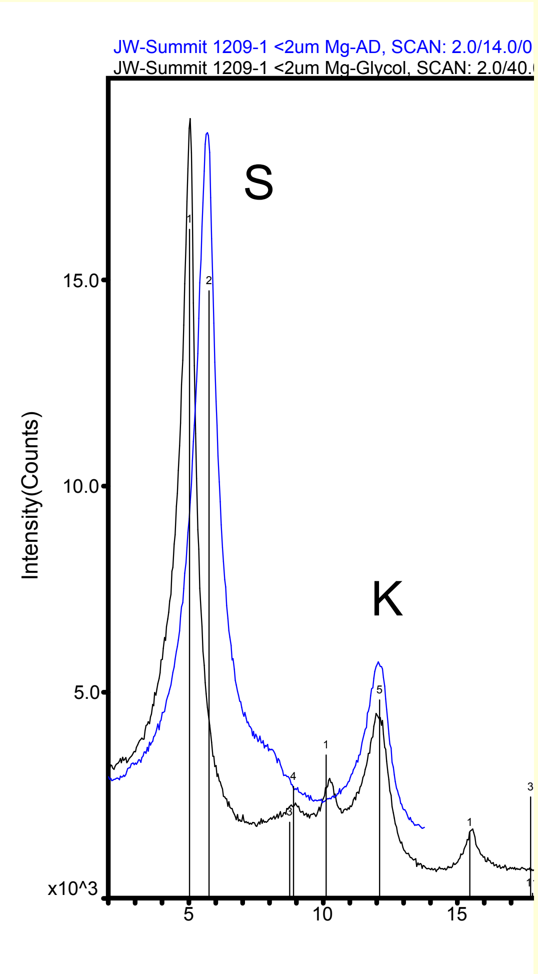


Shift to smectite as the dominant clay specie (1:1 to 2:1)

Paleosol buried by ash flow tuff ~30Ma

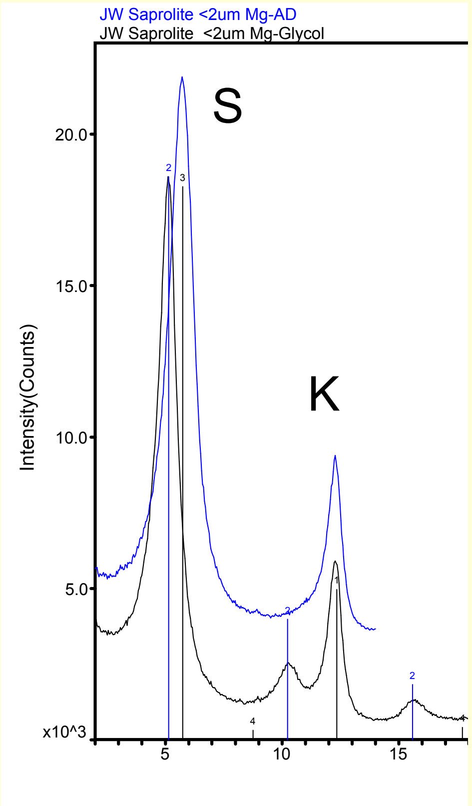
Donner Summit

Weathered granitic knoll entombed by ash flow

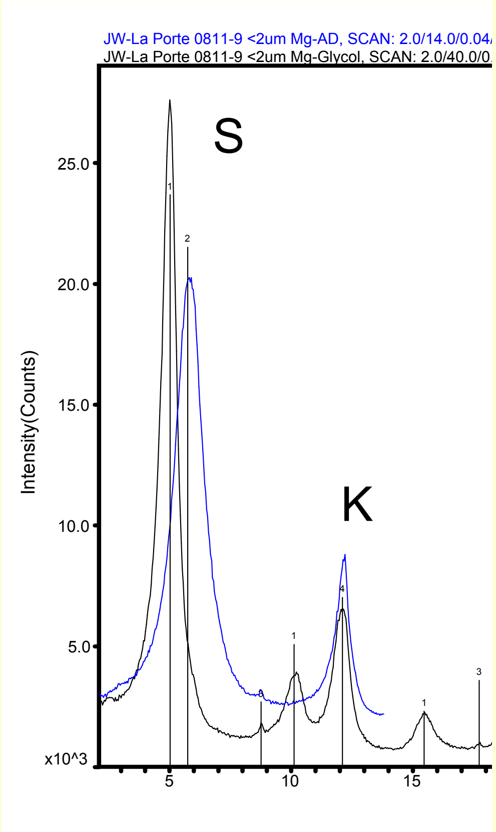


Is this the new climax clay mineral assemblage of regional soils after significant climate change?

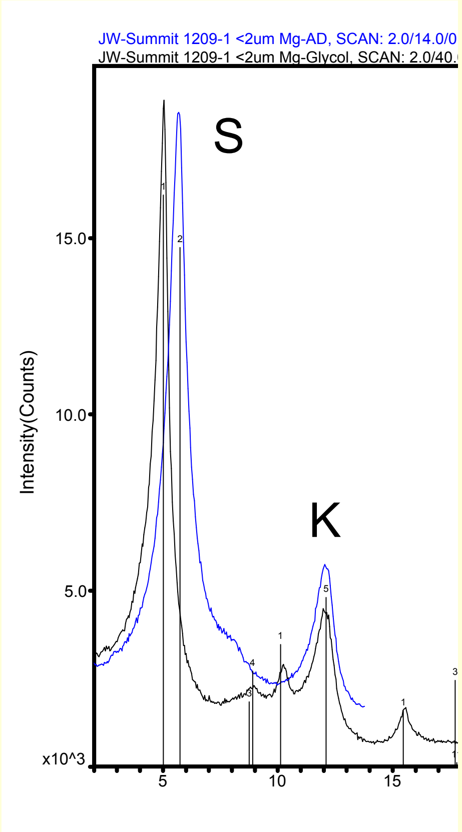
Chalk Bluff



La Porte

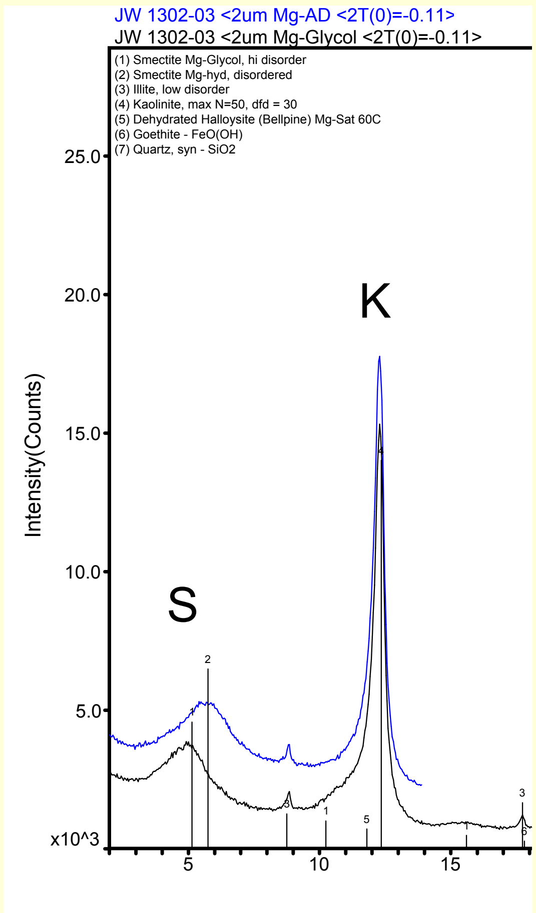


Donner Summit



Matrix clay assemblage in fluvial sediments should mimic the clay assemblage of regional soils

Chalk Bluff terrace sediments immediately above paleosol



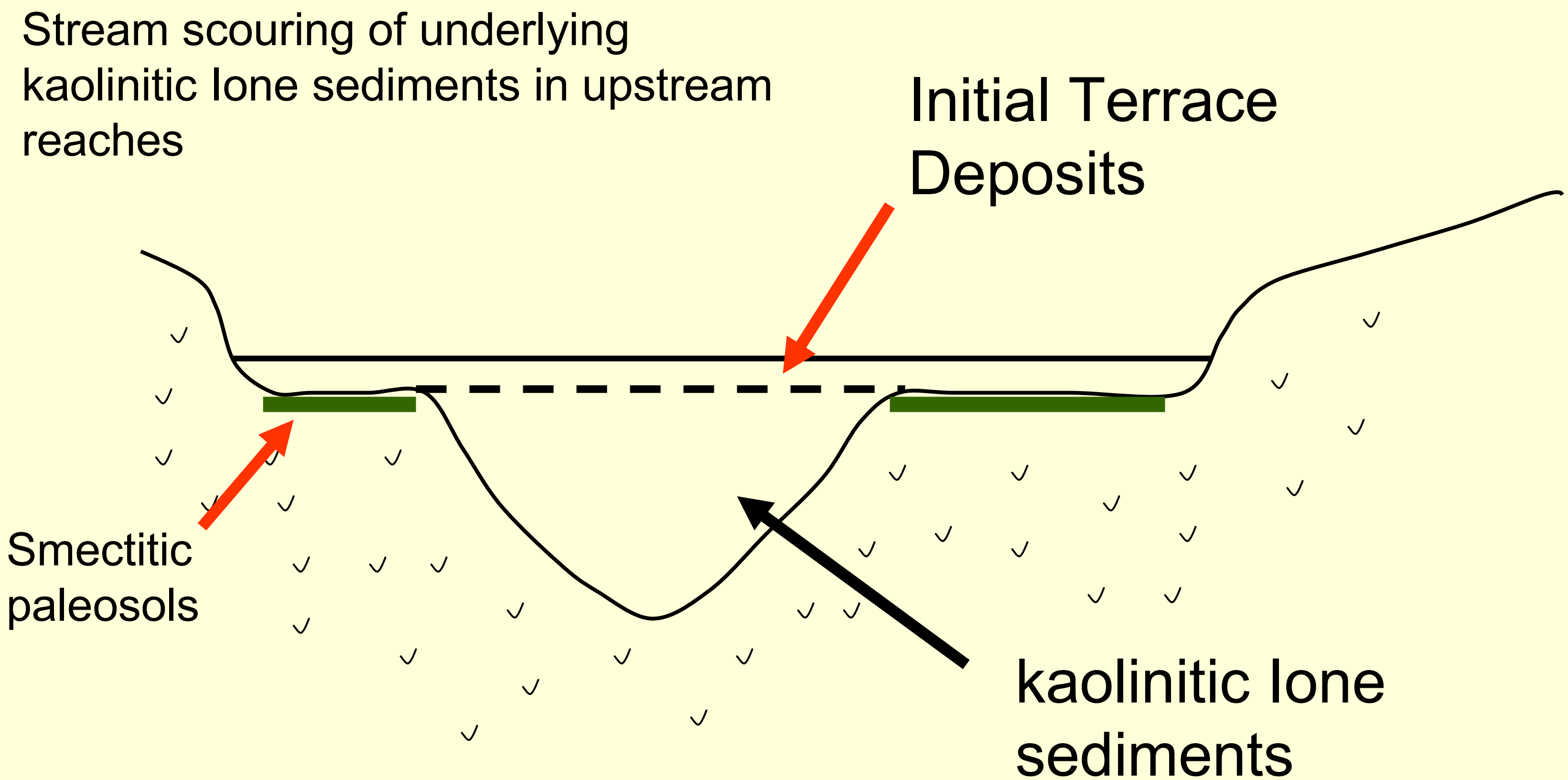
Kaolinite is still dominant

“Matrix Clay Mineral Response Lag”

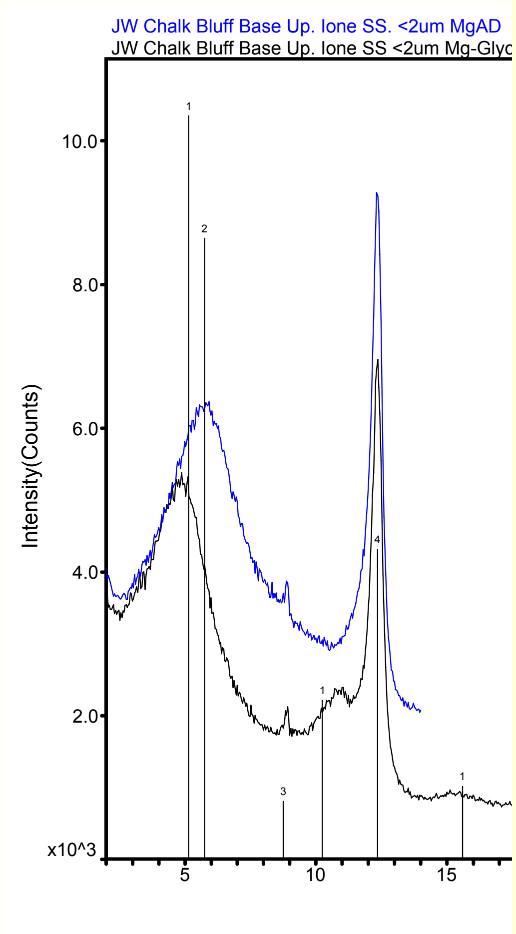
Cause:

Smectitic material eroded from contemporary soils was diluted by amalgamation of kaolinitic Ione sediment in the river channels upstream

Initial fluvial sediments deposited on terrace surface



Sandstone higher in the section

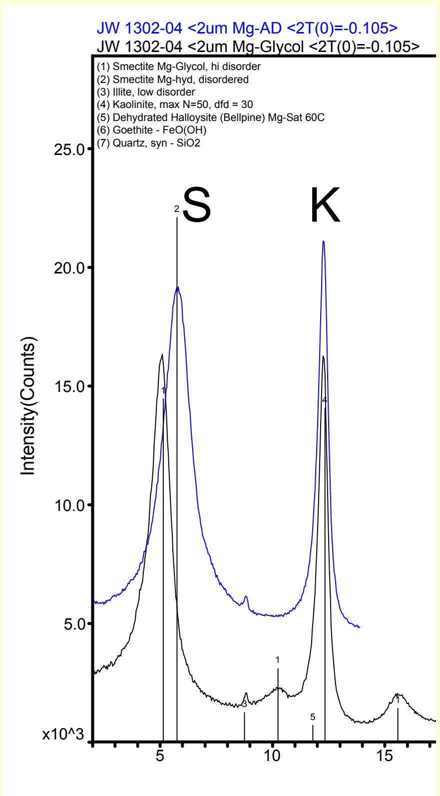


Smectite content increasing

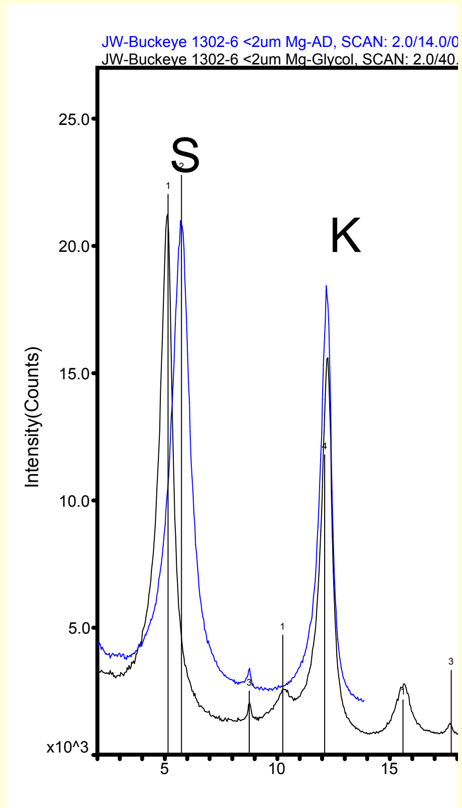
As underlying Ione sediments become covered, their influence on the sediment matrix composition diminishes

Terrace sandstones at yet higher stratigraphic level

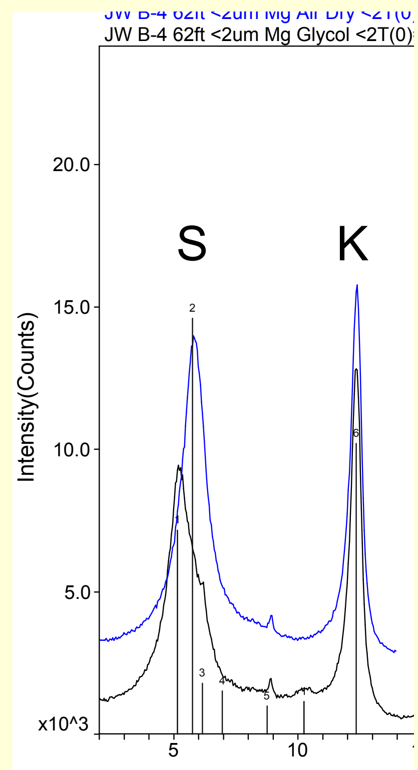
Chalk Bluff



Buckeye Hill



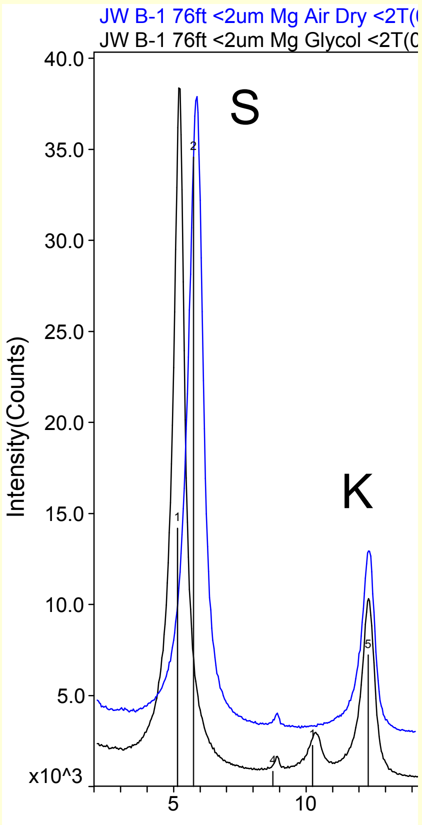
Quaker Hill



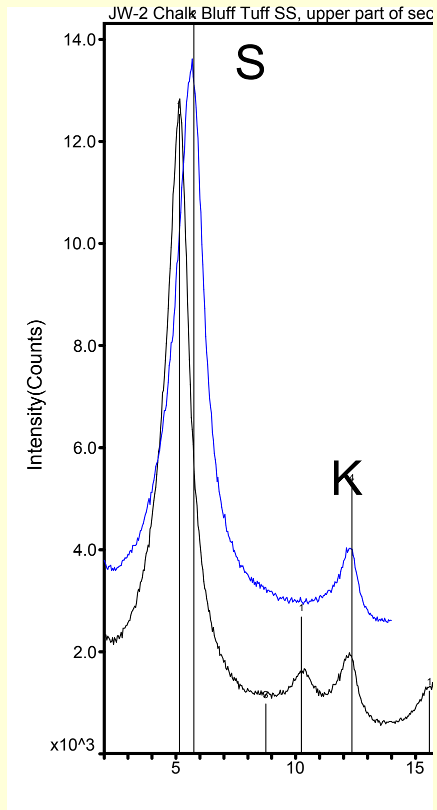
Smectite/kaolinite 50/50

Sandstones near the top of the Chalk Bluff section

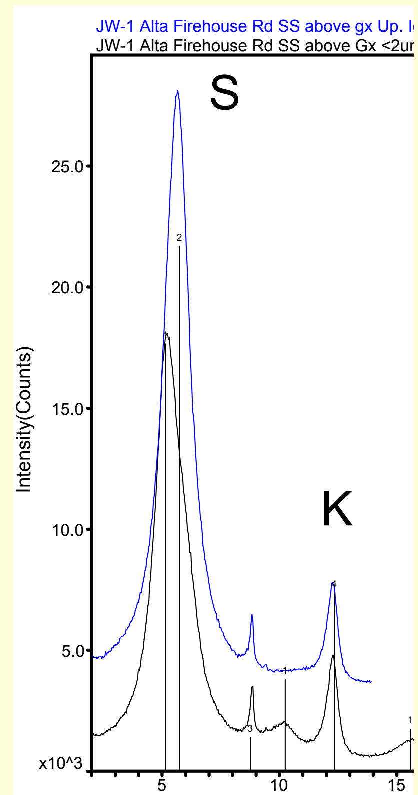
Quaker Hill



Chalk Bluff



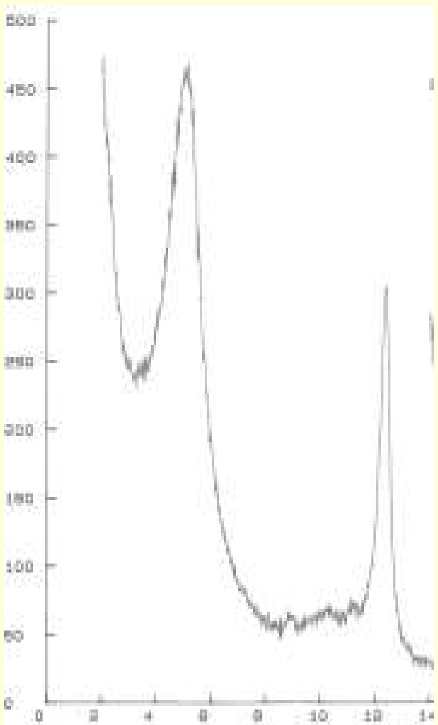
Alta



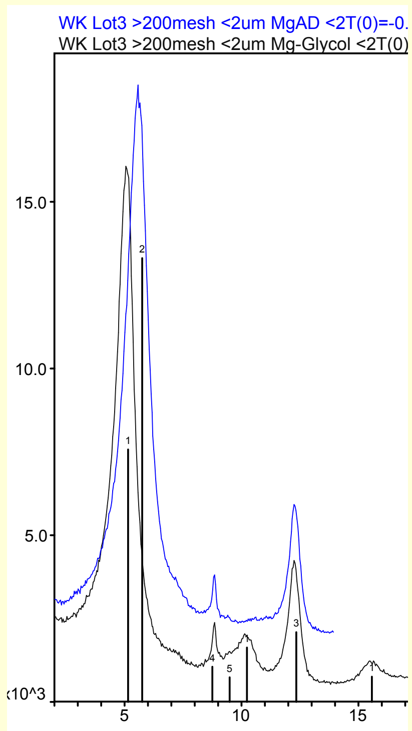
Smectite (2:1 clay) dominant

Smectitic Sediments in Distal Areas

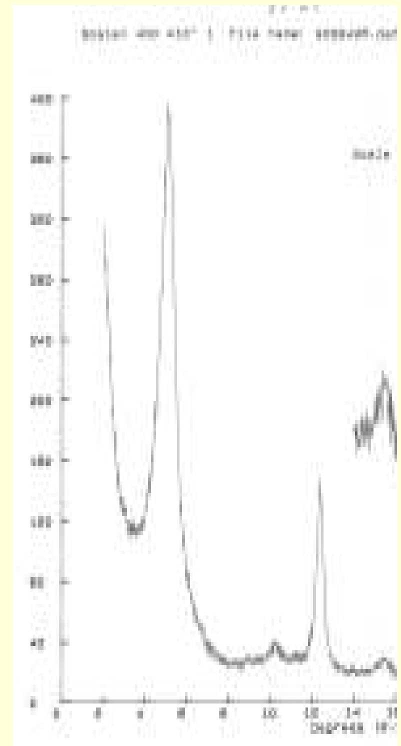
Lincoln



Sacramento Co



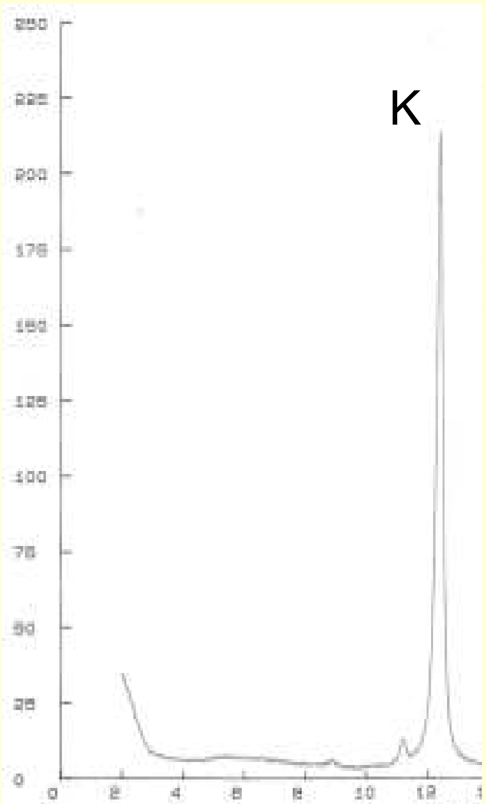
Ione



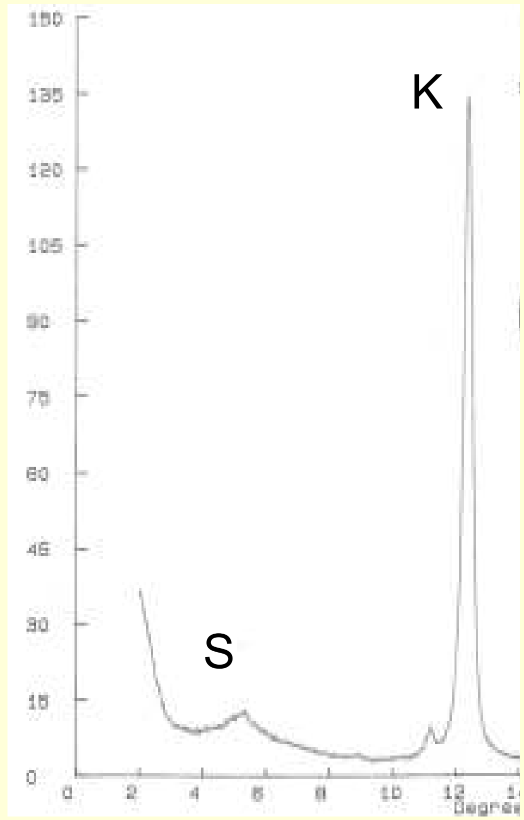
Sediment Matrix Clay Assemblage Mimics Regional Soil Mineralogy

Do we see same matrix clay trend in other regions?

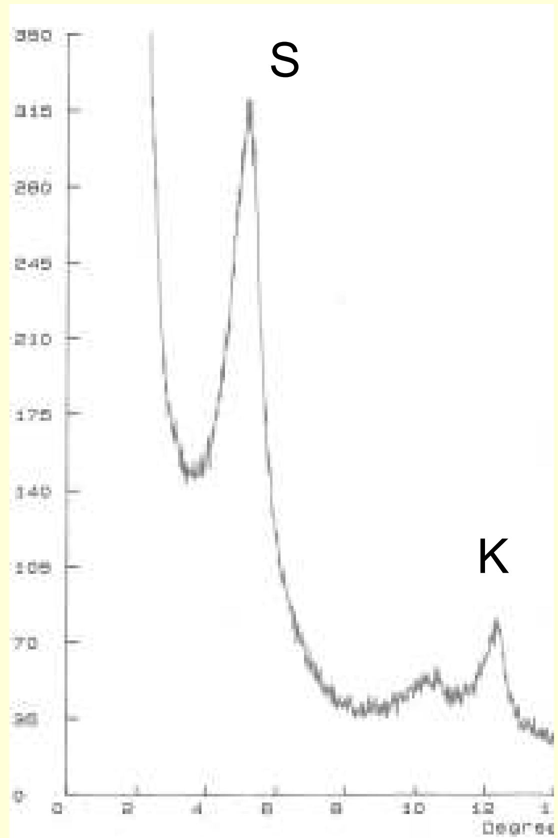
Mt Soledad ss



Upper Mt Soledad ss

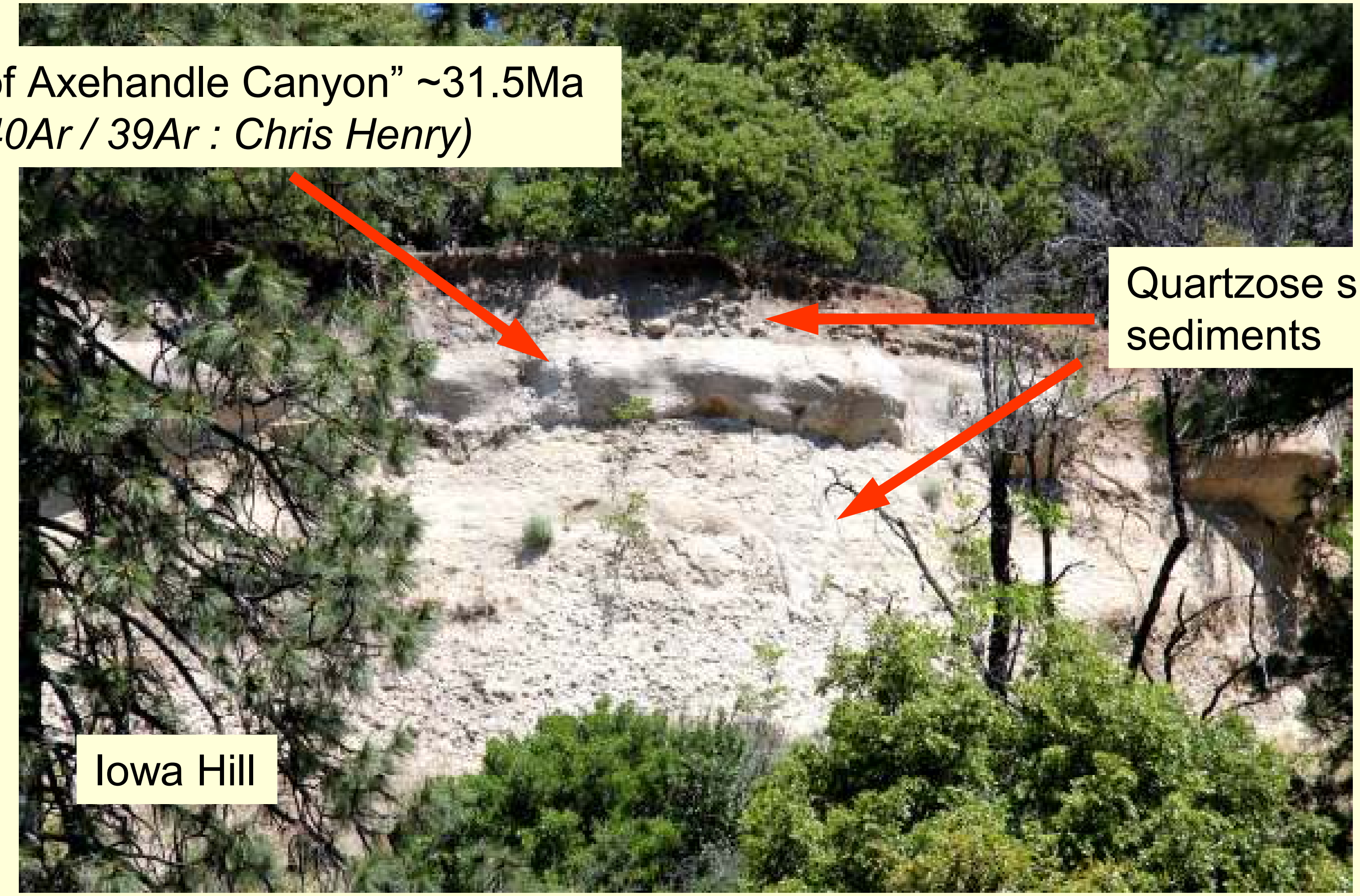


Ss unit above



Mt Soledad sandstone (50Ma) at Torrey Pines beach, San Diego

Rhyolitic Tuffs Interbedded in the Chalk Bluff Section Confines the Upper Age



Other examples: Alta, Chalk Bluff, Nevada City, La Porte, Lincoln

Rhyolitic tuff at the top of the Chalk Bluff sedimentary section

Rhyolitic tuff pebbles and boulders

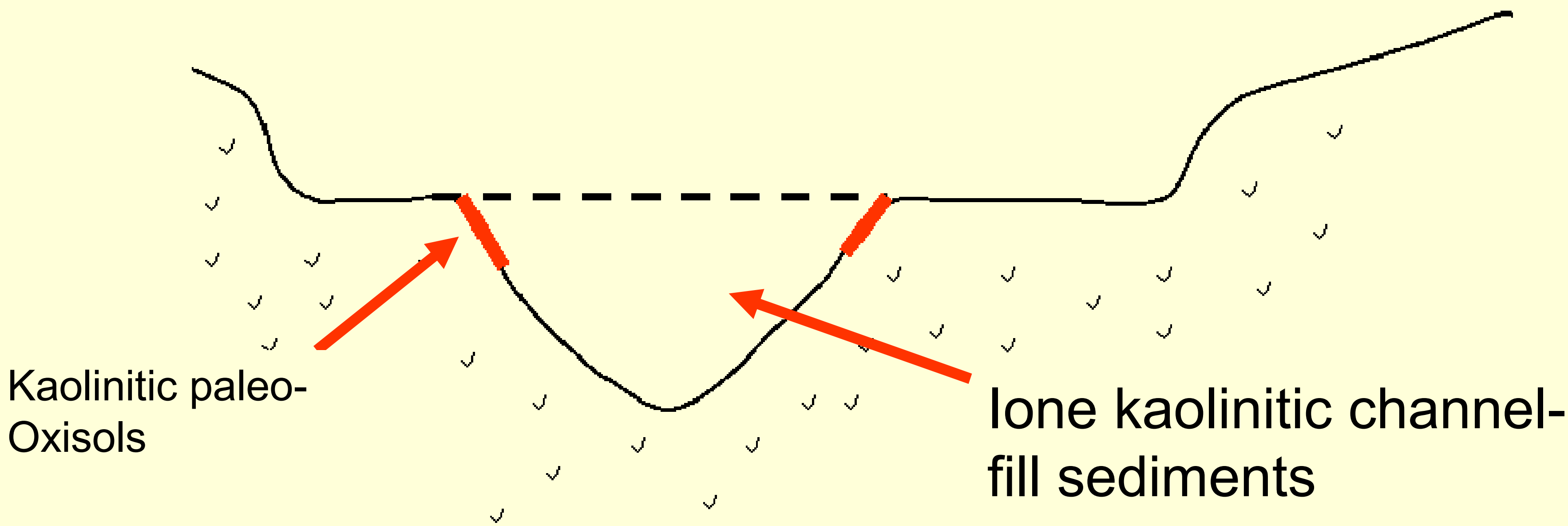
Conclusions

- The Middle Eocene to Early Oligocene transition was a time of drastic global climate change
- The Sierran Early Tertiary sediments and the fossil soils they bury collectively form a mineralogical record of decreasing hydrolytic intensity associated with such a change in the hydrologic regimen

Middle Eocene Soils and Sediments

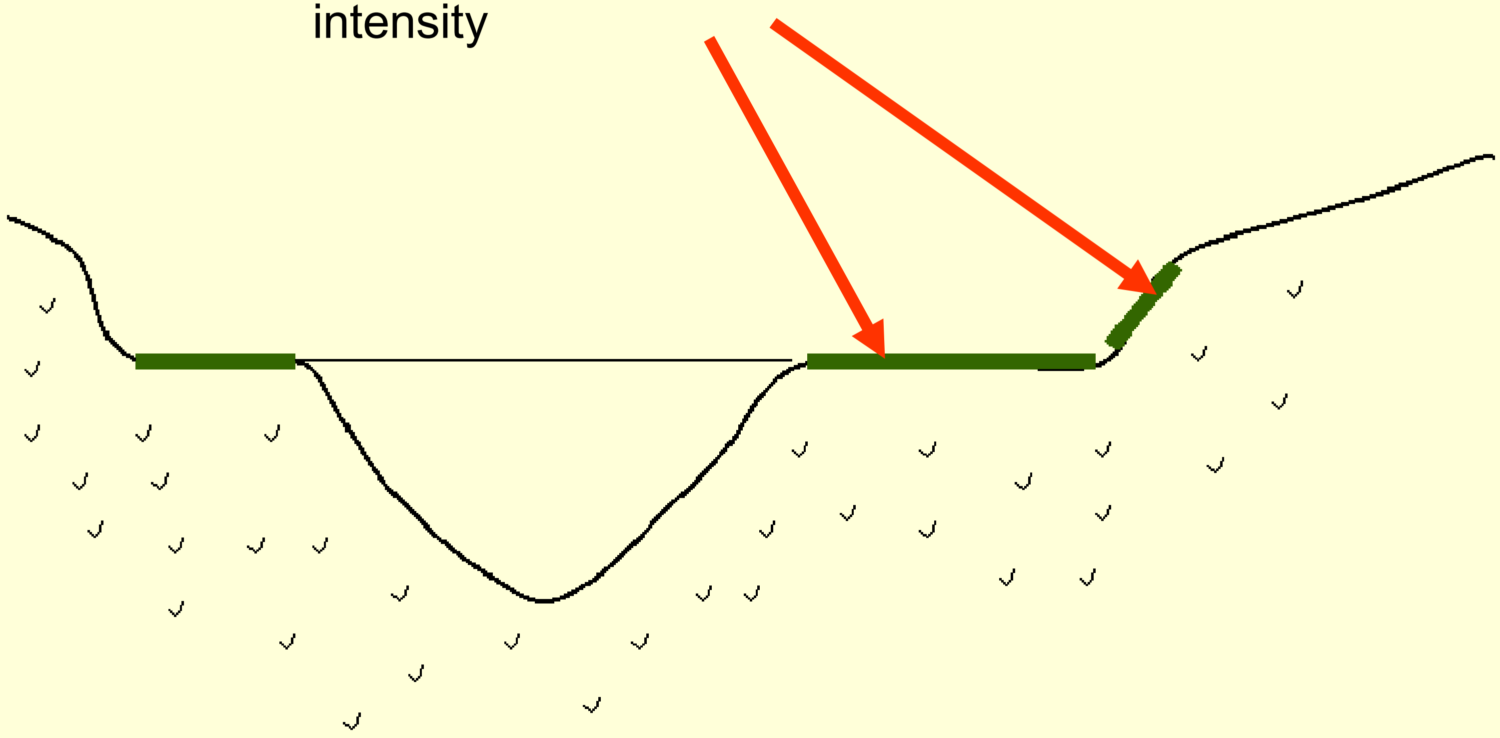
Paleosols below the Ione Formation are Oxisols with kaolinite being the dominant and climax clay mineral

Ione Formation sediments in proximal and distal areas reflect this regional kaolinitic soil mineralogy



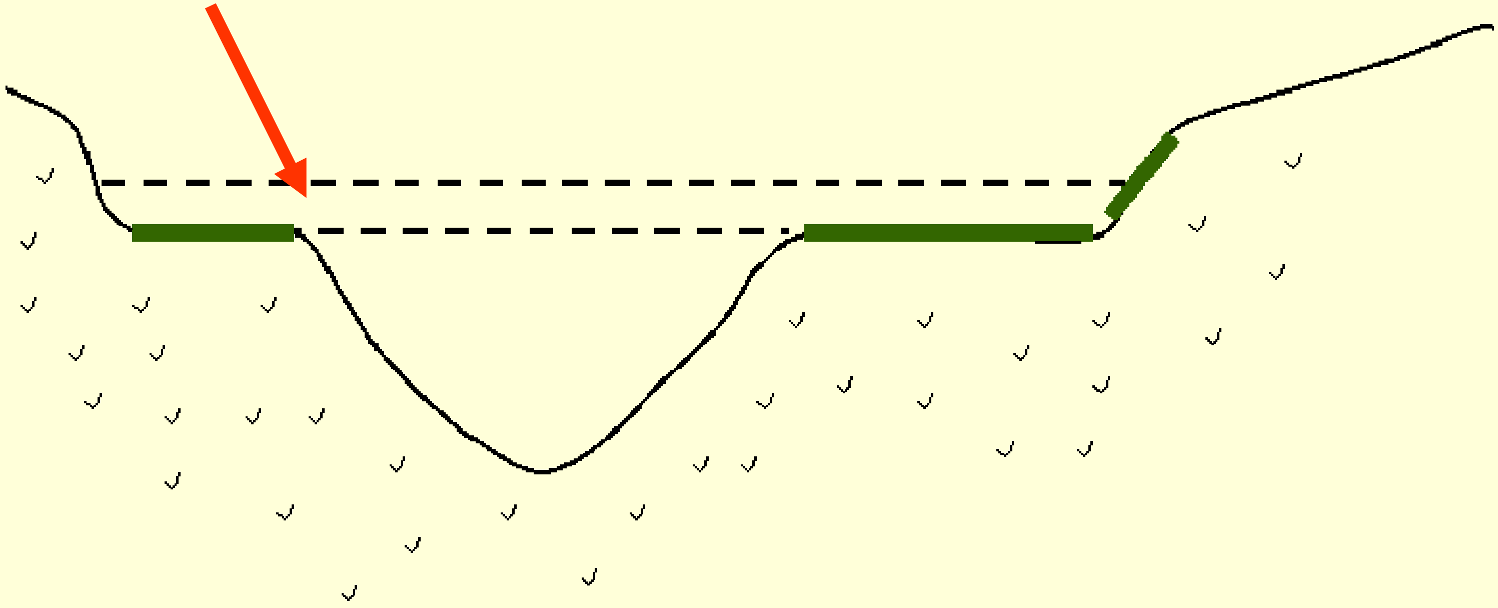
Terrace Bedrock Soils

Paleosols developed on the terrace bedrock surfaces and the regional landscape show a striking transition from kaolinite to smectite (1:1 clay to 2:1 clay) indicative of lower hydrolytic intensity



Transition Terrace Sediments

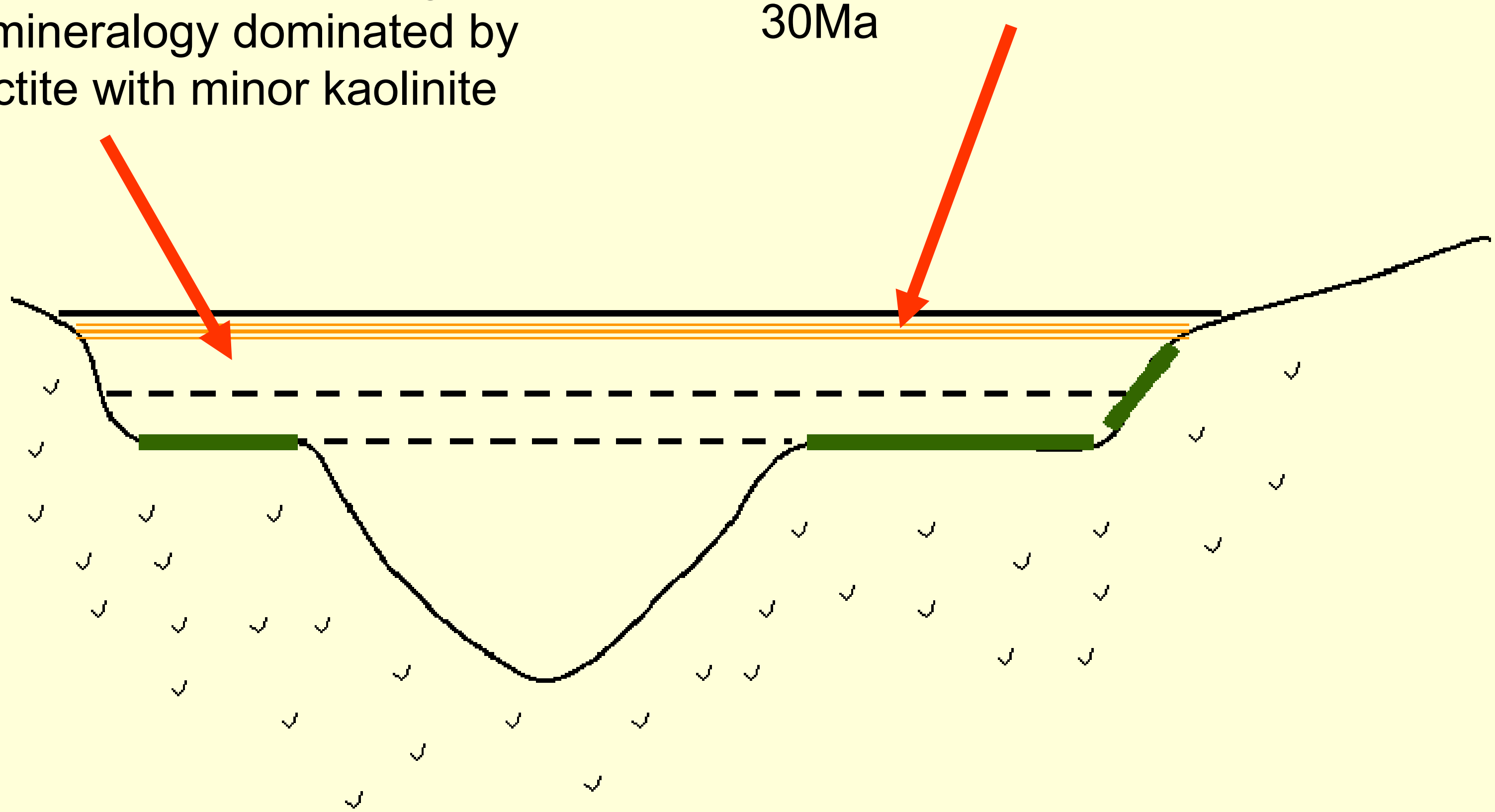
The clay mineralogy of the sediments above the bedrock terrace show a gradual transition to greater smectite content higher in the section



Upper Terrace Sediments

Sediments in the upper section of the terrace deposits as well as distal areas mimic the regional soil mineralogy dominated by smectite with minor kaolinite

Interbedded tuffs at the top of the Chalk Bluff section date to 33Ma to 30Ma

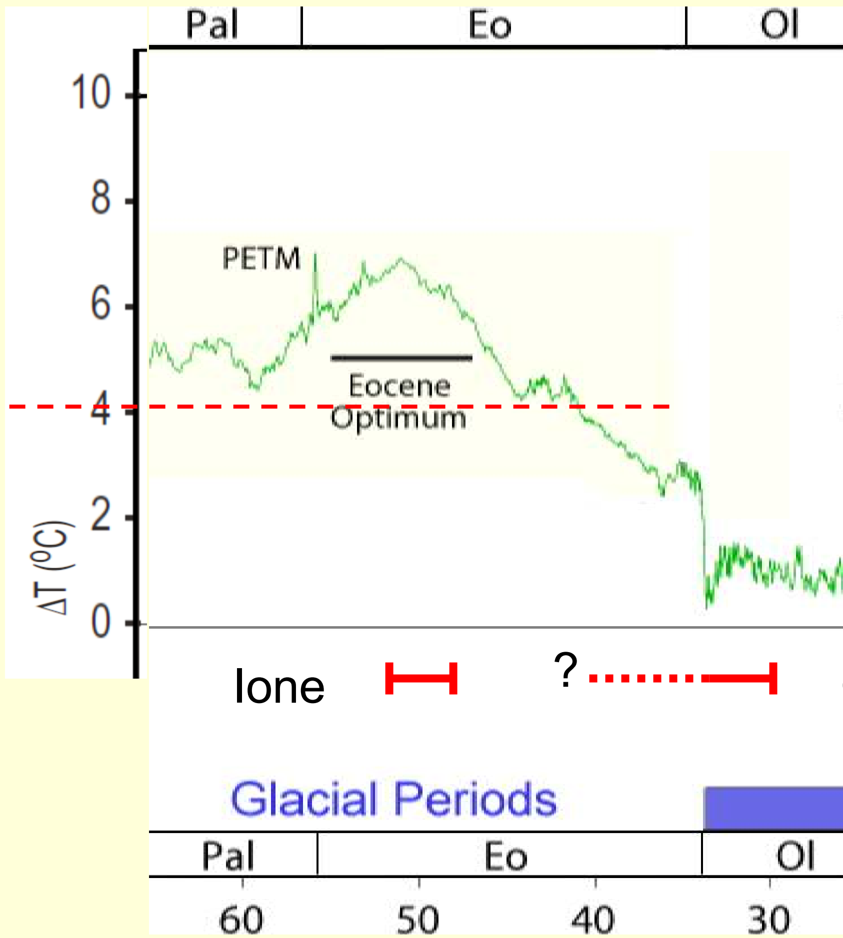


Age of Chalk Bluff sedimentary interval?

Decreasing hydrolytic intensity

K

S



Source : Zachos, James, Mark Pagani, Lisa Sloan, Ellen Thomas, and Katharina Billups (2001). "Trends, Rhythms, and Aberrations in Global Climate 65 Ma to Present". *Science* **292** (5517): 686–693. doi:10.1126/science.1059412

Need for New Nomenclature

- The sequence of smectitic terrace sediments known as the “bench gravels” or “upper gravels” and interbedded tuff beds at the top of the Chalk Bluff section was a sedimentary system that operated during a later time of distinctly different environmental conditions than those of the Middle Eocene.

Thanks to:

- Chris Henry (UNR) for $^{40}Ar/^{39}Ar$ dates
- The Brady family allowing access to their properties at Chalk Bluff
- Kathy Morgan allowing access to her mine property at Iowa Hill