The Nature of Early Tertiary Soils and Sediments — Mineralogy and Petrology

Slide Notes

Slide 1
This is an oral slide presentation delivered at the GSA Cordilleran Conference (Session T5: Critical Zone: Where Rock Meets Water and Life at Earth's Surface) in Fresno CA on May 20, 2013.

Slide 2
Abstract for the presentation

Slide 3
The work on this topic began through a reservoir quality research project at the UNOCAL Research Center in the late 1980's as well as for the preparation of a Clay Minerals Society Annual Meeting Fieldtrip to the Ione Formation in 1989.
Our research work has continued to the present through independent consulting for the geotechnical industry related to problematic soils and sediments encountered in the Sacramento Valley and adjacent Sierra Foothill areas.

Slide 4
Some of the sample locations in this discussion are plotted on this early economic geology map showing the Early Tertiary fluvial sediment localities where hydraulic mining was extracting gold in the Sierra Foothills areas of Placer and Nevada Counties.

Slide 5
This is the summary of the matrix clay mineralogy of the two sedimentary units that comprise the Early Tertiary "auriferous" gravels in the Sierra foothills and adjacent valley areas. The reader can review the other GSA Power Point slide presentation posted on the sierrageology.org website for additional information and specific details of that topic.

Slide 6
The mineralogy of the Early Tertiary fluvial sediments is similar to that of the paleosols that underlie those sediments. That begs the question…were the fluvial sediments completely derived from the erosion and transport of those soil materials? Or were some or all of the fluvial sediment constituents the product of tropical weathering of the primary fluvial sediments just as with the soils?

Soils are the product of a complex interaction of the surface environment with the minerals in the original parent rock. To recognize and know whether and how much influence transported soil materials had on the character of the fluvial sediments, the soil constituents of regional soils must be completely characterized as to their mineralogy and constituent morphologies.

Slide 7
Since there are no examples of active tropical soils in our temperate latitudes, the soils literature reporting research of tropical soils must be referenced to learn important characteristics of the mineralogy and micromorphology that should be found in local tropical paleosols.

The soil type formed as a result of an extended duration of chemical weathering under tropical conditions is the Oxisol family. Kaolinite is the dominant climax clay specie resulting from intense hydrolytic activity (see Wood and Glasmann, 2013 on this website). All minerals vulnerable to chemical weathering are absent. Quartz is the principle mineral inherited from the parent rock. The pedogenic activity has resulted in a sandy soil microtexture or soil clay aggregate particle arrangement.

Slide 8
In the course of the research work performed at UNOCAL extensive petrographic and geochemical analyses were performed on the soil constituents found in paleo-Oxisols associated with the kaolinitic Ione sediments as well as on examples from other regions. The important findings of that research were summarized in Wood (1994) and Wood and Glasmann (1995). Both documents are posted in pdf format in the Documents section of this website.

The major findings are listed here to be elaborated in the following slides.

Slide 9
The paleoOxisol example shown in this series of slides is of the chemically altered hornblend biotite granodiorite bedrock at Nevada City originally reported in Allen (1929). These two X-ray diffractograms show the clay mineralogy of the <2um fraction (oriented clay mounts; Mg saturated; ethylene glycol solvated). This X-ray technique plots the 001 clay peaks in the range of 0 to 14 degrees 2 theta.

The analysis of rock in the weathering front of the soil profile shows that the clay mineralogy in the zone of incipient weathering is controlled by the precursor mineralogy. Petrographic analysis of this material confirmed that K-feldspar altered to sericite (ie., coarse grained illite/fine grained muscovite). Other minerals with Ca, Mg and Fe cations altered to smectite. The kaolinite that shows up in this analysis likely formed directly from mica (pseudomorphously). This clay mineral assemblage in the weathering front follows the clay mineral stability chart of Chamley (1989)—See slide in Matrix Clay Mineralogy…. Wood and Glasmann (other GSA slide presentation in the Documents section of this website).

The XRD analysis of the maturely altered saprolite material in the soil column shows that all precursor clay minerals that were present in the weathering front are no longer detectable. This illustrates that with greater hydrolytic intensity all precursor clay minerals are ephemeral and altered to kaolinite with only a trace of one precursor clay mineral detectable (illite).

The following slides of petrographic and microprobe analyses show that the kaolinite textures observed in the mature soil material were largely determined by the pseudomorphous replacement of the ephemeral precursor phyllosilicate minerals including mica.

Slide 10
This is a plane polarized light (pl) thin section photomicrograph of the saprolite material from the paleoOxisol at Nevada City—the same material of the XRD (previous slide). The soil material was impregnated under vacuum with blue epoxy to show void space and microporosity of the porous clay constituents.

The only unaltered residual minerals that are seen in thin section are quartz and trace amounts of resistate minerals (ie, zircon in this view). The mica books in the original granitic rock are now kaolinized pseudomorphously (KM). The photo also shows that kaolinite occurs in variable textures such as coarse grained flakes (a) and fined grained massive texture (b).

This soil material also illustrates the presence of fracture voids known as packing voids in the soils nomenclature. These voids result from repetitive cycles of moist/dry soil conditions timed with seasonal rain fall that result in shrinking and swelling of the soil fabric. The packing voids also serve as conduits for ground water transfer through the soil column that would otherwise have poor drainage. Packing voids are a common and inevitable soil micromorphology observed in soil development.

The dark opaque material that occurs throughout the soil material in thin section is explained in the following slides.

Slide 11
This group of four photos shows SEM and microprobe analyses of various textures of kaolinite observed in the thin section view of Slide 8 and Photo 1 of this slide. The coarse grained kaolinite flaky texture (a) of Photo 1 is shown in SEM Photo 4 and the fine grained massive appearing texture (b) is shown in SEM Photo 3. Using the SEM photo scale bars as a reference, these SEM analyses of the two zones of disparate kaolinite grain size show that the fine grained zone (b) possesses kaolinite plates and flakes in the 1 to 5 um range while the coarser grained zone (a) is in the >10 um range with vermicular forms commonly occurring.

The Photo 2 is a microprobe view of the grain boundary between the two zones of kaolinite grain size (a) and (b) in Photo 1. The coarser grained kaolinite texture is at the upper right and fined grained massive texture at lower left of the photo. The boundary of these kaolinite textural zones has the ghost remnant texture of myrmakitic quartz shown at (a) in Photo 2. This delicate quartz microtexture occurs at the grain boundary of K-feldspar and plagioclase feldspar in granitic and some gneissic rocks. In the original rocks the delicate blebs of quartz are an exsolution texture imbedded in the plagioclase crystals close to the mineral grain boundary noted above.

Careful examination of the myrmakitic quartz texture in Photo 2 reveals that it occurs within the finer grained massive kaolinite texture. Thus, in this example, the precursor plagioclase minerals ultimately altered to very fine grained kaolinite through a smectite intermediary phase while the precursor K-feldspar minerals altered to coarser grained kaolin texture through a sericite phase. The diversity of kaolin textures resulting from the pseudomorphous replacement of intermediary clay mineral morphologies is discussed in more detail in Wood (1994).

Slide 12
This is another thin section view of the granitic saprolite from the paleoOxisol at Nevada City. The quartz crystals (white) retaining their original position of the parent rock illustrates that this soil material is truly a saprolite—the rock structure is intact but all weatherable minerals are altered to clay, in this case, kaolinite. The network of packing voids delineates numerous micropeds or sand-sized clay aggregates (a). The labels (c) and (d) point out opaque pedogenic cement coatings that are commonly associated with the micropeds. In other areas, opaque cement appears to uniformly saturate the clay fabric such as the zone KM and center right in the photo.

The opaque coating at (d) appears to be effective cement as it isolated the clay interior from epoxy impregnation. The clay fabric interior to the cement coating (d) appears a brownish color and remains porous following the thin section preparation. The inability of epoxy to infiltrate beyond the cement coating to reach the interior of the micropeds indicates that the cement coating is actually spherical in the third dimension.

Other details of the micromorphologies depicted in this photo are found in Wood (1994)

Slide 13
Zones of opaque cement are transparent to intense light from below the microscope stage (photos top and bottom left). These zones of cementation fluoresce with blue light irradiation (top and bottom right). These optical phenomena are explained below.

Slide 14
Close up view of cement fluorescence in Slide 13.

Slide 15
This thin section view is of the soil material in the oxic horizon of the paleoOxisol at Nevada City. The oxic horizon is generally called the laterite horizon. Here, micropeds are very well developed between packing voids. Various morphologies of pedogenic cements are visible such as pale colored coatings (a), opaque coatings (b) and saturations at the interior of the micropeds (c). Again, the cement coatings are spherical in nature as they have prevented the epoxy impregnation from reaching the interior of the clay micropeds. Application of red dye following thin section preparation shows that the

interior clay fabric remains porous (d). Within the oxic horizon, bioturbation and soil processes disrupt the original rock fabric found in the saprolite below. Quartz no longer appears in its original parent rock orientations.

Slide 16

This fluorescent view of the microped (left photo) shows that the various cements fluoresce with variations in tone and hue (right photo) suggesting variations in chemical composition. Compare fluorescent colors of (a) and (b) in right photo.

Slide 17

The dissolution of all silicate minerals vulnerable to chemical weathering results in the release of silica and other cations in solution. For example, with the leaching of K-feldspar to produce kaolinite in an Oxisol, substantial silica as well as K are released to soil solutions.

Slide 18

The advantage of analyzing the microchemistry of kaolinite with the aid of the electron dispersive spectrometer (EDS) equipped microprobe is that the ratio of aluminum to silicon is approximately 1:1. Therefore, a significant deviation from equal peak heights of Al and Si in the analysis of kaolin is due to the presence of excess silicon. The EDS analysis of these pedogenic cements (coatings, saturations, etc) consistently show that in addition to kaolinite (the substrate), the cement coatings and saturations are largely composed of silica (amorphous) as well as trace amounts of other cations that were derived from the dissolution of various silicate minerals.

The pale and opaque concentric coatings at (a) and (b) are symmetrically arranged to others in the same position in micropeds on the opposite side of packing voids. This symmetry indicates that these cements originated by the infiltration of saturated solutions into the soil clay aggregates and later solidified to form the various cement coatings.

Slide 19

In another example of a paleoOxisol developed on granitic rock near Friant, north of Fresno, CA, the amount of pedogenic silica cement in the kaolin soil material is substantial. An opal-A "hump" appearing in the XRD analysis indicates that the total amorphous silica is in excess of 20% of the soil material. See Wood, 1994 and Wood et. al., 1995 for additional discussion on this topic.

Slide 20

The various pale and opaque manifestations of the silica cements in thin section are merely optical effects of the respective cement microfabrics that saturate the clay fabric. The pale coatings are produced when the cement completely fills the interstices between the clay particles. Thus, the exclusion of colored epoxy in those cemented zones appears pale with transmitted light. In contrast, the microprobe views of the opaque coatings show that the infill of the cement between the clay particles is incomplete and leaves a frothy/spongy microfabric with entrained microvoids throughout the cement. As diffuse substage transmitted light in the microscope passes through these cemented zones with microbubbles, the light is refracted away from the direct light path to the microscope ocular and the cemented zones appears opaque. See Wood, 1994 for further discussion.

Slide 21
This is a thin section view (pl) of a sandstone sample from the fluvial sediment at Quaker Hill near Nevada City. The thin section was stained to show K-feldspar and plagioclase . This view shows that quartz, K-feldspar (K) and plagioclase feldspar (plag) comprise the durable sand clast constituents. Up to 50% of this sediment is composed of kaolinite. This view shows that the kaolinite occurs in the form of transported clay micropeds stabilized by amorphous silica cement that inhibited clay dispersion during fluvial transport. The micropeds show signs of being squashed between durable sand grains to form pseudomatrix. The various forms of pedogenic silica cement in these clay clasts are virtually identical to similar cements seen in the clay micropeds of the paleoOxisol fabric shown in Slides 10 and 12. The weatherable feldspar clasts do not show little signs of leaching. This indicates that the sediment was buried by subsequent sediment accumulation before significant surficial weathering of the sediment could occur.

This view also shows that interstitial pores are free of other clay debris indicating that this sand was clean and devoid of suspended clay sediment at the time of deposition. Thus, the substantial amounts of kaolinitic clay in this sediment occur largely, if not entirely, in the form of silica stabilized sand-sized clasts (micropeds) that were transported as bedload sediment along with the durable sand constituents.

Slide 22 and 23
These illustrations show the concept of the formation of pseudomatrix by the compression of plastic detrital clay clasts as a consequence of sediment consolidation and compression due to the pressure of the overlying sediment package. The plastic clay clasts are squashed between the rigid durable sand clasts and largely fill the interstitial pores. This process does not necessarily occur immediately after deposition but may occur over time due to long term overburden pressure.

Slide 24
This is a thin section of a kaolinitic Ione Formation sandstone at Apricum Hill near Ione. The outline of remnant silica cement coating the sand sized clay clasts in the plane light view (pl) shows the residual spherosity of some of the clay clasts that form the pseudomatrix. Variable birefringence noticeable in the clay clasts in the xpl view is due to variations in kaolinite microcrystalline texture. Thus, the xpl view shows that adjacent clay clasts have different microtextures. This is a principle criterion to identify the occurrence of detrital clay in the form of sand sized clay clasts in sandstones that now form pseudomatrix. A kaolinized mica “book” clast occurs in the upper right of the view.

Slide 25
Thin section view of another Ione sandstone at Ione. The variable microtexture of various clay clasts can be seen throughout this view with dramatic examples visible at (a) and (b). Trace amounts of weatherable minerals occur in Ione sandstones such as K-

feldspar (K) and amphibole (A). The amphibole grain retains its pristine rhombohedral crystalline form with no signs of post-depositional leaching. The uniform size of quartz sand indicates this sediment is very well sorted.

Squashed clay clasts occur in much larger grain size than the durable sand fraction due to their inherent microporosity and lower bulk density. The occurrence of the larger sized clay clasts forms "clay-filled gaps" in the sandstone fabric. Thus, the larger clay clasts were hydrodynamically equivalent to the smaller quartz and other durable mineral grains in this well sorted sandstone. See Slide 27. This grain size difference demonstrates one of the principle criterion for the occurrence of detrital clay in the form of sand-sized clasts in sandstones. Also note the interstitial pores are free of suspended clay debris where no clay clasts occur (bottom center of view).

In these views of kaolinitic Ione sandstones (Slides 24 and 25) there are no indications of packing voids that would be present if significant post-depositional soil processes had been operating.

Slide 26

This microprobe backscattered electron view shows the dramatic microtextural difference of adjacent clay clasts at grain boundaries (a). This view also shows that the plastic clay clasts are squashed into the narrowing openings between the rigid sand clasts. This latter observation is another principle criterion for the identification of detrital clay in the form of sand sized clasts that form pseudomatrix. The brighter sand grains in the bottom of the photo are denser heavy minerals (illmenite, magnetite, etc.) in a laminae of black sand.

Slide 27

This chart plots the average grain size difference of quartz sand clasts vs kaolinite clay clasts in six well- to very-well sorted sandstones collected from an east to west transect in the Ione basin. The clay clasts are consistently a larger grain size than quartz (one whole phi size separation) due to their lower bulk density.

Slides 28 and 29

These two thin section views—plane light and cross polarized light— of a sandstone at Ione show that mica (in this case muscovite) and abundant kaolinized mica are major constituents. The kaolinized mica has very low birefringence in the xpl view compared to the muscovite. Both unaltered mica and kaolinized mica are of a consistently larger grain size than the quartz clasts due to their lower bulk density. The darker streaks among the kaolinized mica platelets are zones of amorphous silica cement that stabilized the altered mica grains. These kaolinized mica grains show signs of rounding due to abrasion and being deformed by post depositional compression between more rigid quartz grains.

Slide 30

This review of the saprolite fabric of the paleo Oxisol from Nevada City (Slide 10) demonstrates the origin of the abundant kaolinized mica observed in the kaolinitic sandstones of the Ione Formation and other associated up-stream proximal equivalents, ie., the auriferous lower or channel gravels.

Slide 31
Thin section photo (xpl) of claystone deposits at Ione. This view shows that the Ione Fm claystones are composed of clay and silt-sized particles of kaolin clay originating from the suspended fluvial sediment load.

Slide 32
The last 10 meters of sediment in the claystone deposits at Lincoln and Ione have increasing amounts of smectite. The thin section view (xpl) shows that the smectite is in the form of smectitized mica flakes that were carried with the suspended sediment constituents. The smectite clay has higher birefringence (orange colors) than the kaolinite clay (gray colors) in this cross polarized light view.

Slide 33
This is a thin section view of a smectitic Chalk Bluff lithology sandstone at Quaker Hill. Squashed smectite clay clasts comprise a substantial portion of these smectitic sands. The squashed clay clast shown here demonstrates some of the principle criteria of the occurrence of detrital sand-sized clay clasts in sandstones: clay clasts (as well as mica clasts) are of a larger grain size than adjacent durable sand grains (quartz and feldspar); plastic clay clasts are squeezed into narrowing orifices between adjacent rigid sand grains; and any laminar microstructures visible in the fabric of the clay clasts also reflect this plastic deformation.

Slide 34
Thin section view of another smectitic Chalk Bluff lithology sandstone at Baxter. The mixed clay mineralogy of kaolinite and smectite in this sediment is caused by the occurrence of both of those clay constituents if the form of detrital sand-sized clay clasts. Pedogenic silica cement prevented these clay clasts from dispersion during fluvial transport. The smectite clay clast at right is enveloped by a pale silica coating (a). The larger kaolin clast at left was squashed between other rigid sand grains (b) and (c).

Slide 35 and 36
Thin section views of a smectitic sandstone of Chalk Bluff lithology at the residential development of Rancho Murieta, eastern Sacramento County. The expansive soils and sediments there are mapped as kaolinitic Ione Fm sandstone and claystone and Valley Springs Fm sediment. Both are rock types that should be relatively benign for use as engineered soil. However, many homes in the neighborhood have experienced substantial home foundation damage…costly structural repairs…perpetual lawsuits leading to home builder and geotech company bankruptcies as a consequence of the prolonged episode.

Petrographic examination shows that the sandstone is approximately 80% smectite clay. Reflected light view shows that the clay is stabilized (temporarily) with silica cement and discrete sand sized clay clasts are visible with very high concentrations of pedogenic cement.

Slide 37
Compounding the problem of misdiagnosis of the expansive nature of the soil at Rancho Murieta due to incorrect mapping, laboratory testing by competent geotechnical consulting firms over the years have characterized these soils as having low plasticity and low expansion potential. The small amounts of silica cement required to inhibit dispersion of the smectite clay during fluvial transport also inhibits dispersion of the clay during the standard ASTM test methods—the industry standards for geotechnical soil characterization. This chart illustrates how soil samples collected from homes that experienced substantial soil heaving are characterized as soils with low expansion potential (CL) in ASTM tests performed by one of the myriad of geotechnical consultants that have worked at the residential development. Similar ASTM testing by other consultants over the years have achieved the same misleading results.

Unfortunately, the stabilizing silica cements are ephemeral and begin to disperse (dissolve) incrementally over time sometimes over a period of years. Gradually with repetitive landscape irrigation and seasonal rainfall, the cements eventually dissolve and the soil clay becomes completely reactive but long after the homes were built. The operative word for this phenomenon is “latent expansion”.

Slide 38
This latent expansion issue has become recognized as a regional problem and the California Geological Survey issued a Geologic Hazard Notice for Smectite Clay Sediments to warn city and county building agencies of this building hazard in areas throughout the region. This photo of a smectitic Chalk Bluff lithology sandstone from a home site in Orangevale, Sacramento County, shows the retention of substantial smectite clay in the form of sand-sized clasts following the standard ASTM sieve analysis which is designed to characterize the amount of potentially expansive clay material within the soil.

Slide 39
Clay mineral XRD analyses of the sieve separates (ie. sand fraction vs silt/clay fraction) shows that the >200 mesh sand fraction contains nearly as much smectite clay as the <200 mesh fines fraction.

Slide 40
Conclusions