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

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Abstract

The mineralogy and petrology of soils and sediments in the Early Tertiary section of the Sierra Nevada foothills of Northern and Central California were influenced by global tropical and subtropical climatic regimens. Kaolinitic soils and sediments formed during the extremely warm/humid tropical climate of the Paleocene to Early Eocene, while smectite clay dominates the later Eocene to Early Oligocene soils and sediments. Micromorphological and micro-chemical investigations of both kaolinitic and smectitic sediments show that large volumes of clay-rich materials were transported in these paleo fluvial systems as sand-sized aggregates derived from fluvial erosion of deeply weathered mature soils. The clay microfabric of the Early Tertiary paleosol clasts was stabilized by amorphous silica cement that precipitated in association with the intense chemical weathering in the warm/humid environment of the Early Tertiary. This pedogenic silica protected clay-rich aggregates from dispersion during fluvial transport in Early Tertiary rivers.

Today, the pedogenic silica cement that stabilizes the granular smectitic sediments creates problems for soil engineers that design for construction on the exposed smectitic soils and sediments. The silica-stabilized smectitic clay in soils engineered from Late Eocene/Early Oligocene deposits can not be characterized by conventional ASTM soil test methods. The standard soil engineering tests classify the smectitic sediments as having low expansion potential. Following placement in engineered soils for construction, the paleo silica cement in these clay materials is prone to incremental dissolution allowing the expansive clays to freely interact with cyclic soil moisture conditions. Failure to properly classify these potentially highly expansive soils has contributed to widespread cases of structural damage throughout the urbanizing Sierra foothills and adjacent Sacramento Valley areas.

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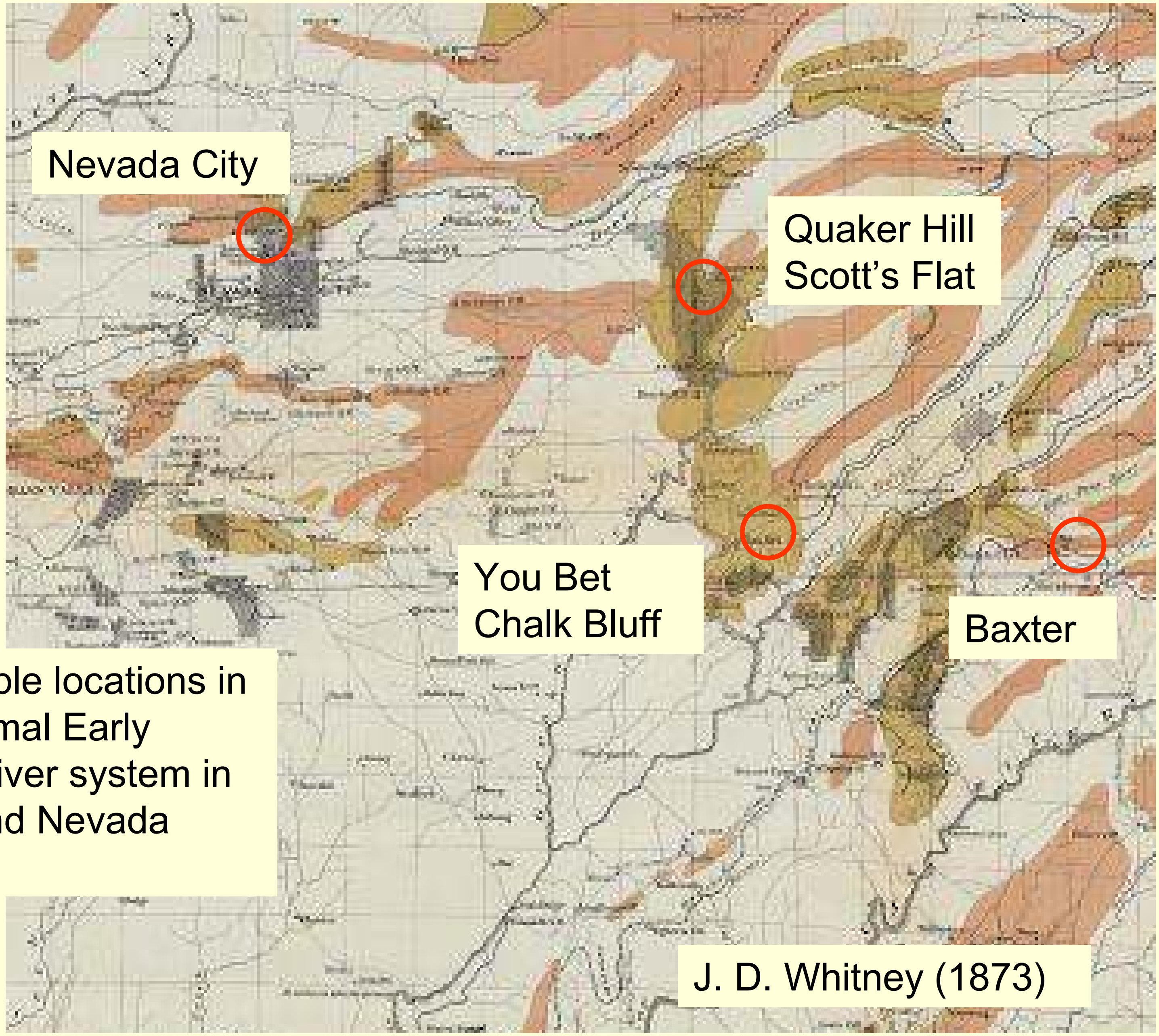
History of Current Research

- Work began in 1980's at UNOCAL Research Center as part of a reservoir quality research project

- Subsequent work over the last 10 years related to consulting work on geotechnical problems in the Sierra foothills and Sacramento Valley areas



Key sample locations in the proximal Early Tertiary river system in Placer and Nevada Counties

Matrix mineralogy of Early Tertiary river sediment mimics the contemporary regional soil mineralogy

- Ione Fm proximal and distal sediments and the underlying paleo Oxisols (ie., mature tropical soils)
  - kaolinitic and quartzose

- Chalk Bluff sedimentary section immediately above the Ione Fm. unit has similar clay mineral assemblage as smectitic terrace bedrock paleosols and other regional soils*

*see Wood and Glasmann, 2013—*Early Tertiary Climate Change and its Impact on Matrix Mineralogy of the "auriferous gravels" in the Sierra Nevada Foothills*—on this website for greater detail on soil and sediment mineralogy

The key to recognizing soil constituents in fluvial sediments is to know and understand the textures and morphologies of the pedogenic constituents of the original source soils from which the sediments were derived

From the soils literature describing mineralogy and micromorphology of Oxisols (Stoops, 1983):

- All weatherable minerals are absent
- Quartz is the dominant residual mineral of the parent rock
- Kaolinite is the dominant climax secondary clay mineral
- The soil fabric is comprised of granular arrangement of clay aggregates (ie., micropeds). The soil fabric called "sapro-sands".

Pedogenic features revealed by soil petrography

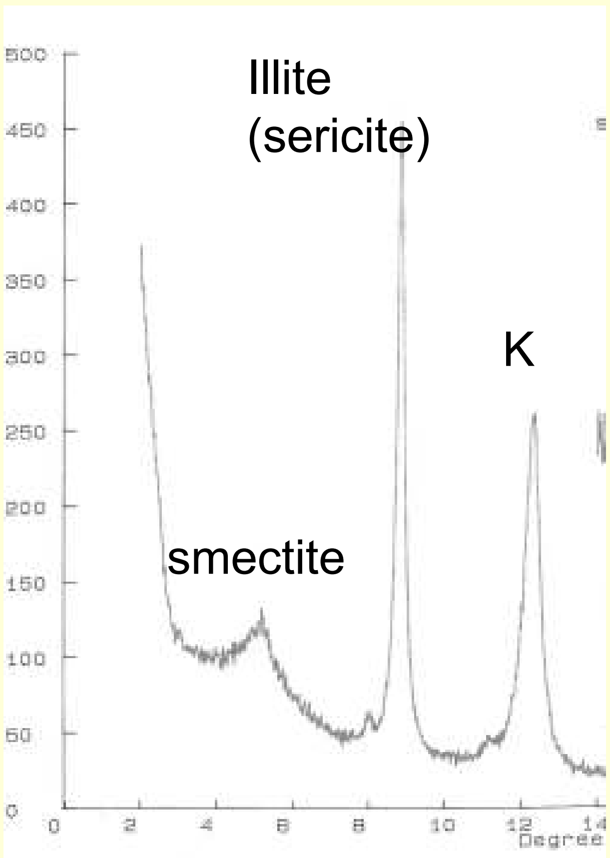
- Kaolinite occurs in numerous textures and arrangements
  - Largely determined by textures of precursor transitory clay minerals that form in the weathering front

- Micropeds (ie., sand-sized clay aggregates) are well developed

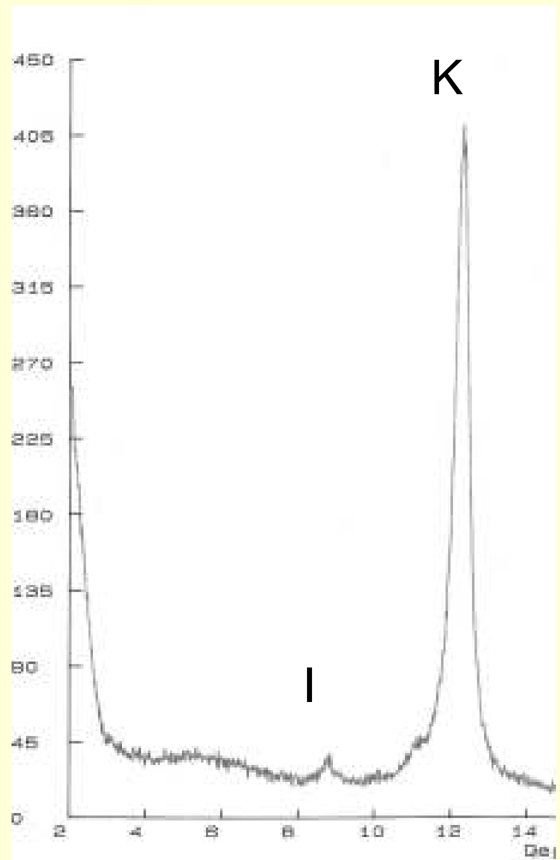
- Pedogenic cements are prevalent.

Oxisol Clay Mineralogy

Weathering front

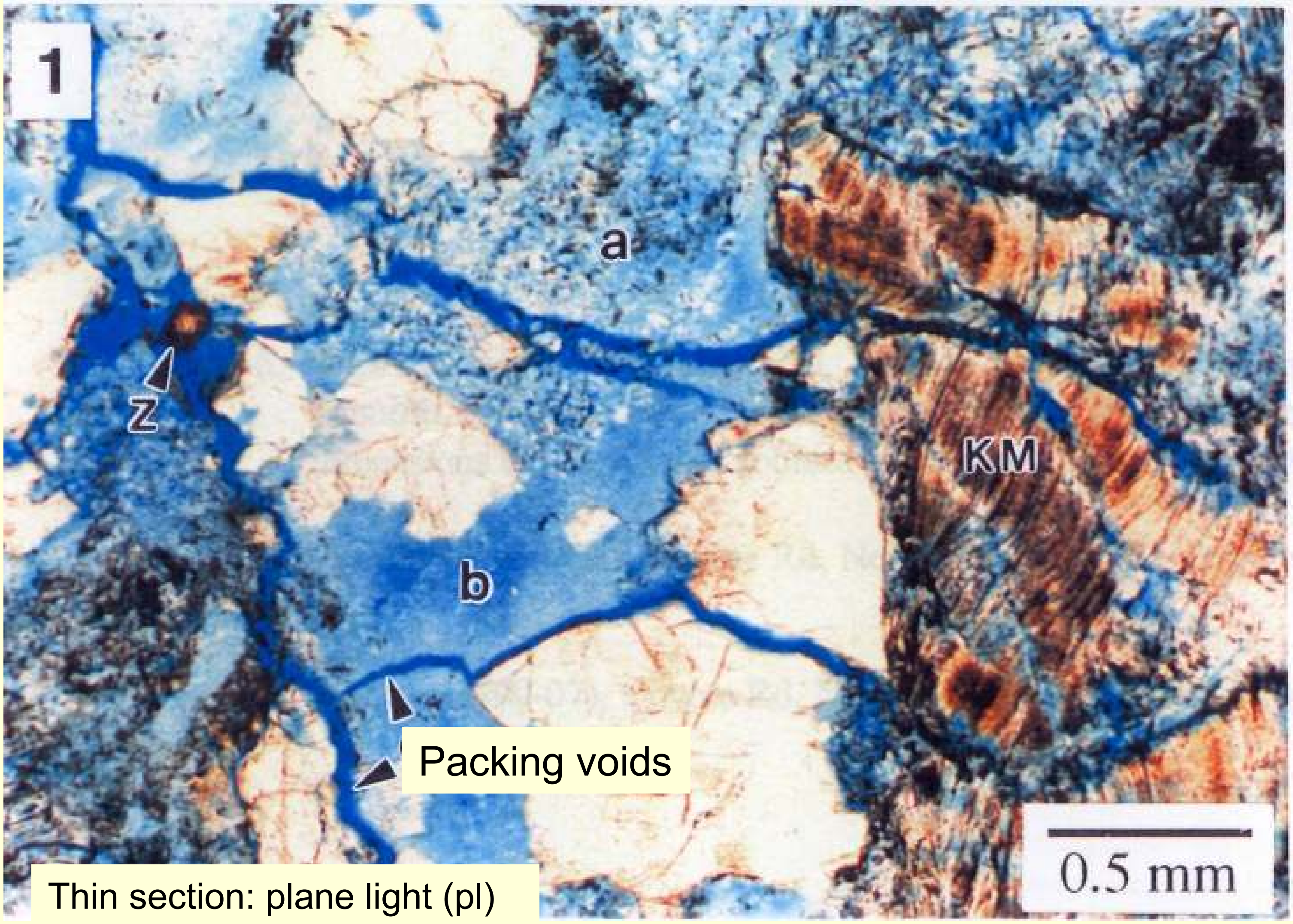


Saprolite

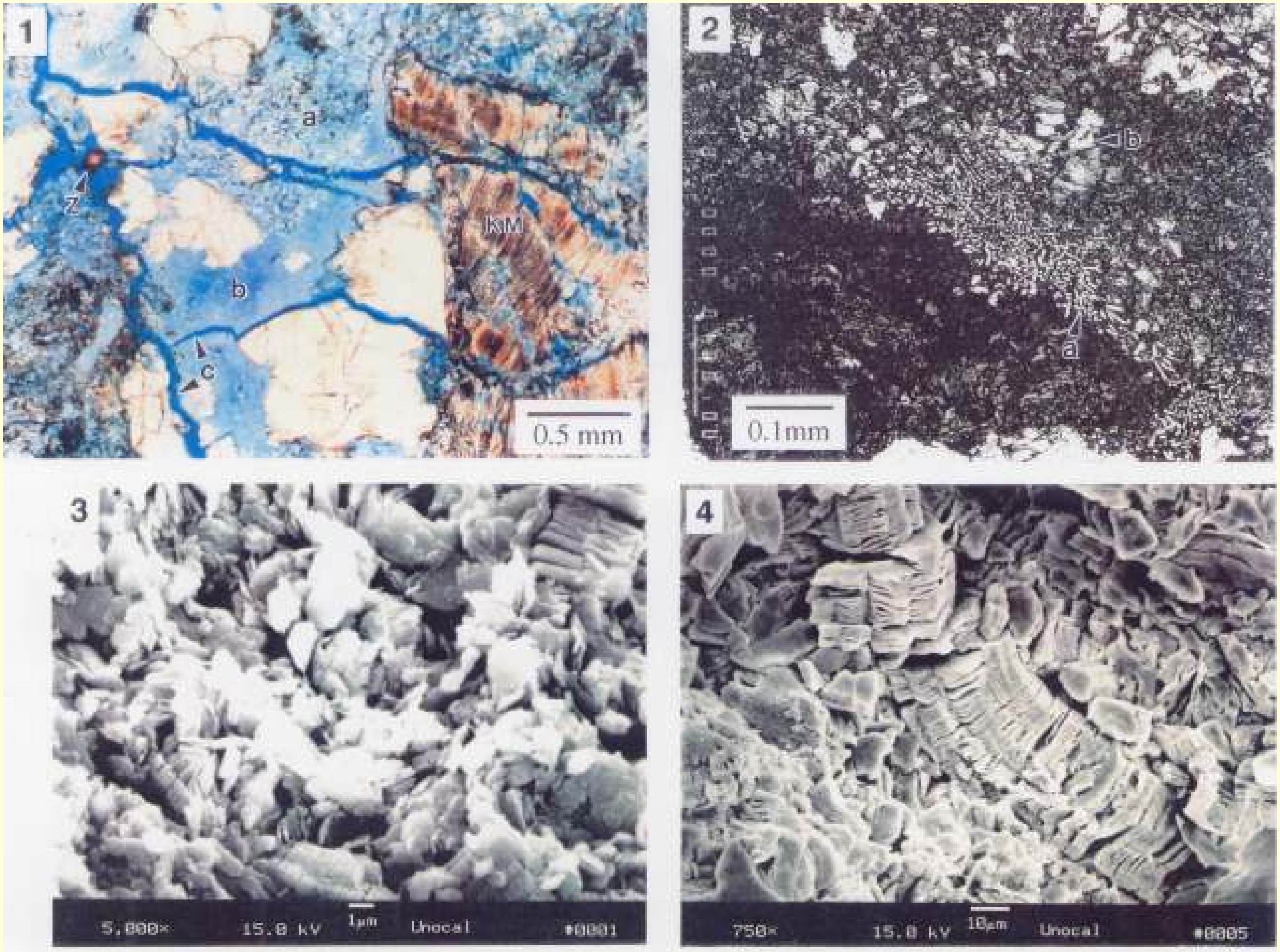


Kaolinite pseudomorphously replaces precursor clay minerals

Paleo Oxisol — Saprolite

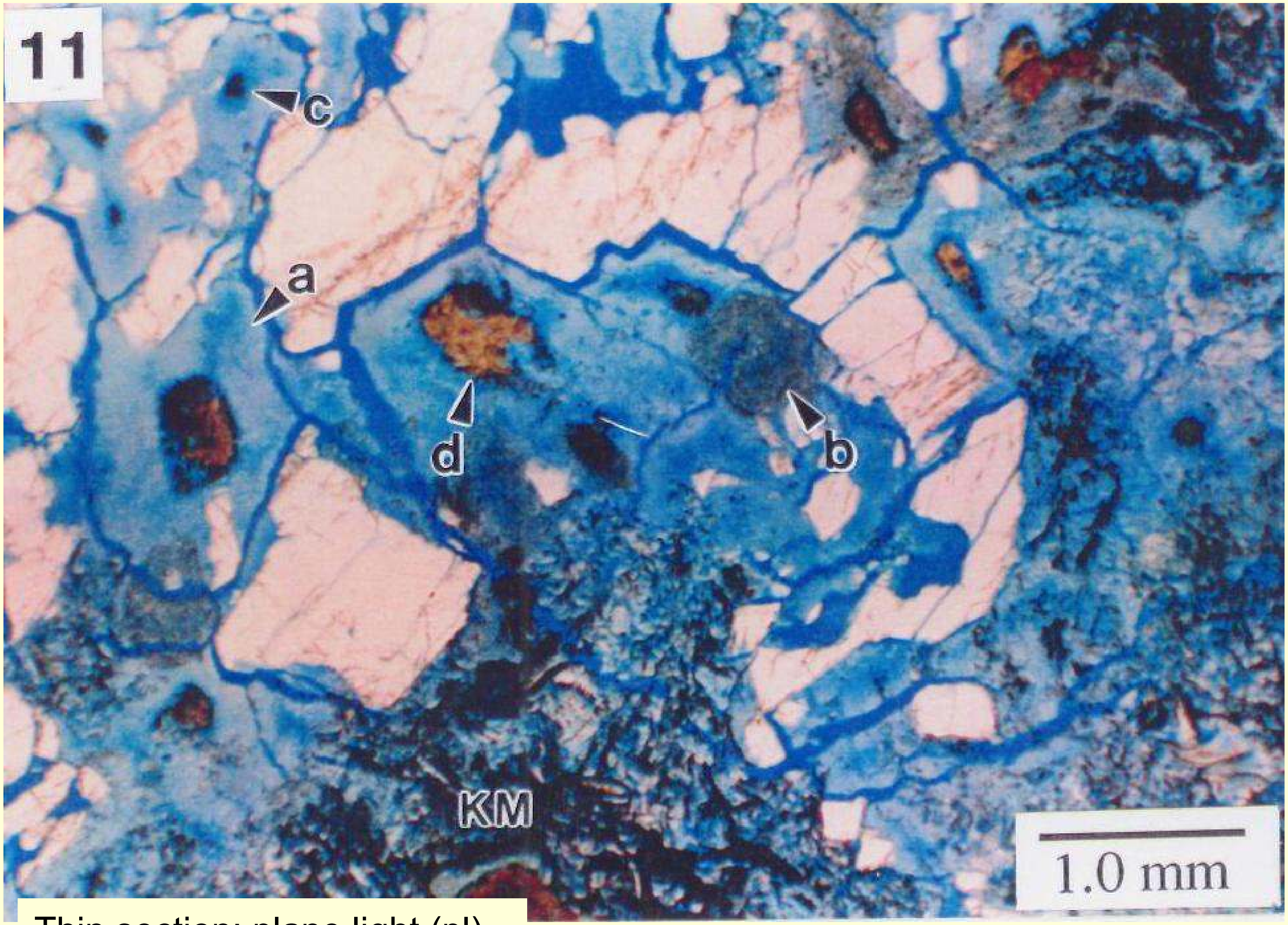


Wood 1994


1
a
z
KM
b
c
0.5 mm
2
b
a
0.1mm
3
5,000×
15.0 kV
1μm
Unocal
#0001
4
750×
15.0 kV
10μm
Unocal
#0005

Wood 1994

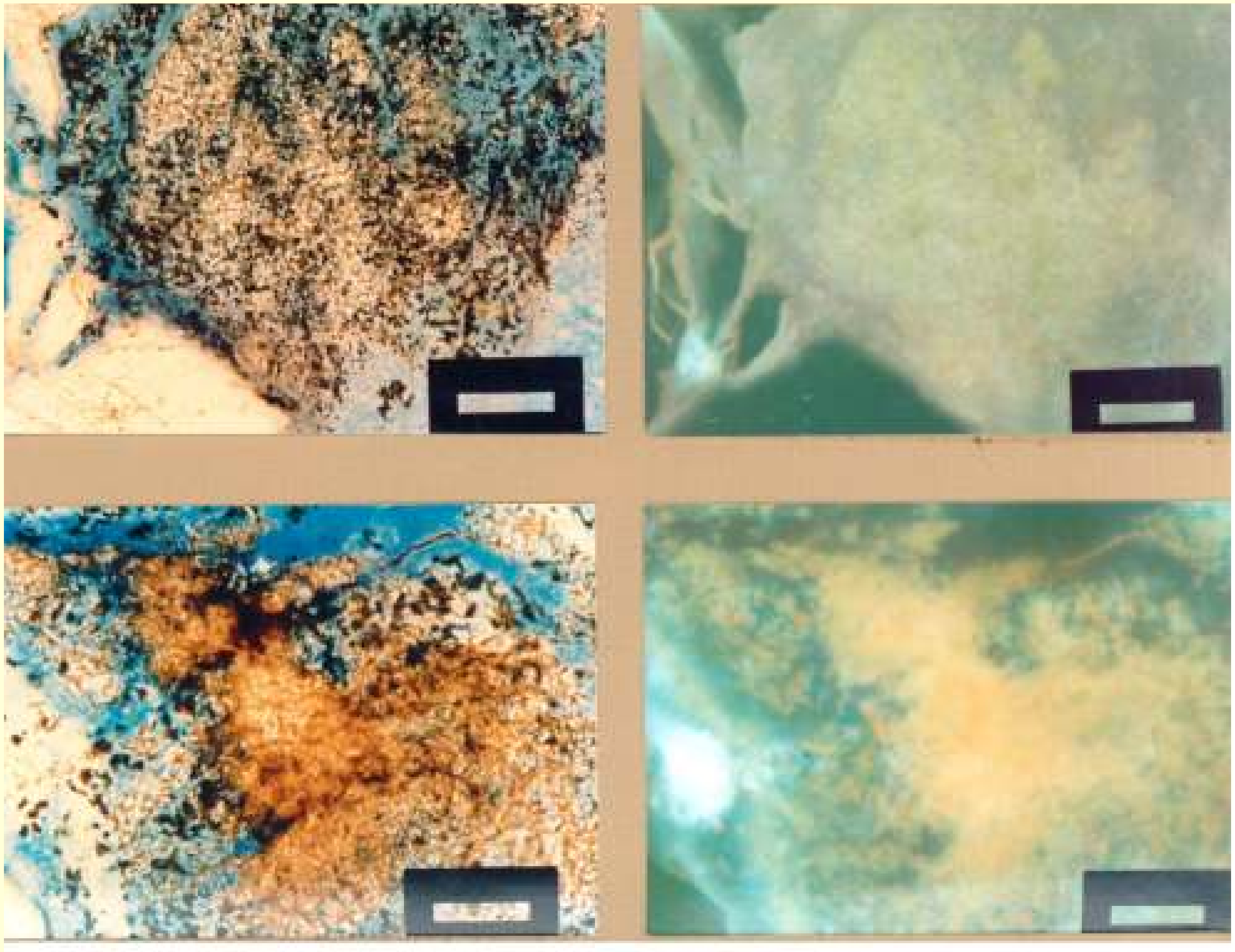
Paleo Oxisol — Saprolite



Thin section: plane light (pl)

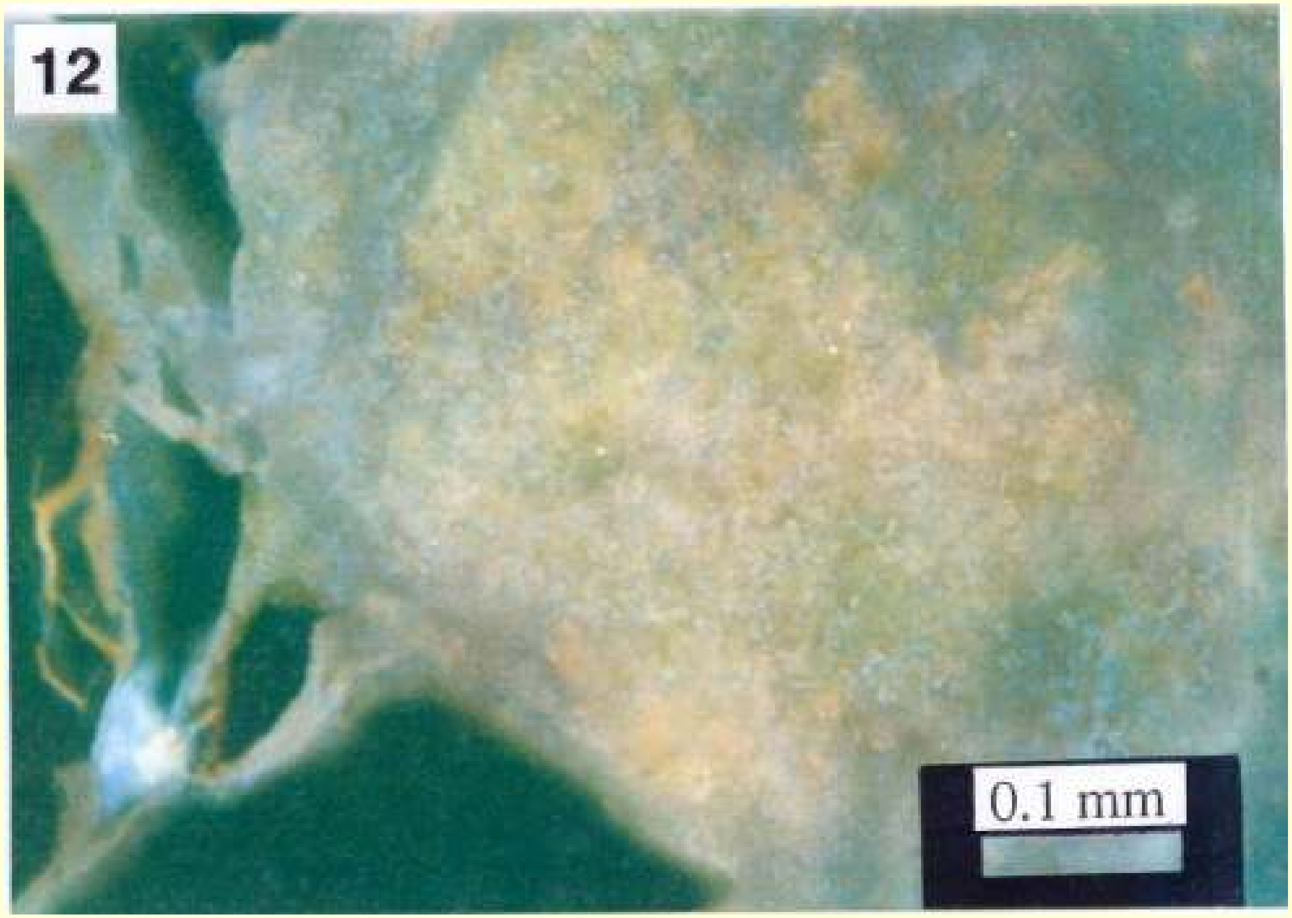
Wood 1994

Soil Cement Fluorescence



Irradiated with blue light

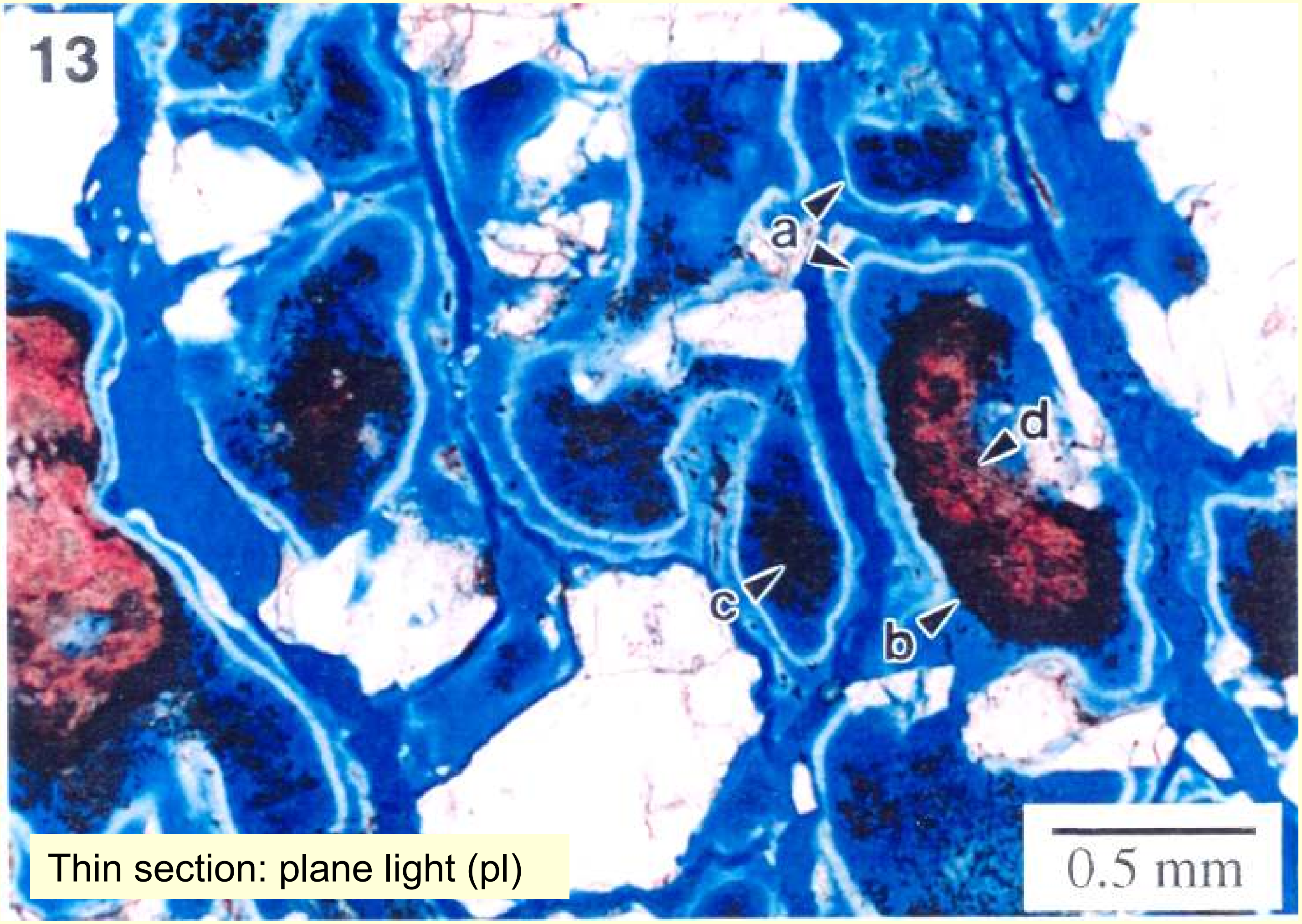
Soil Cement Fluorescence



Wood 1994

paleo Oxisol — oxic horizon

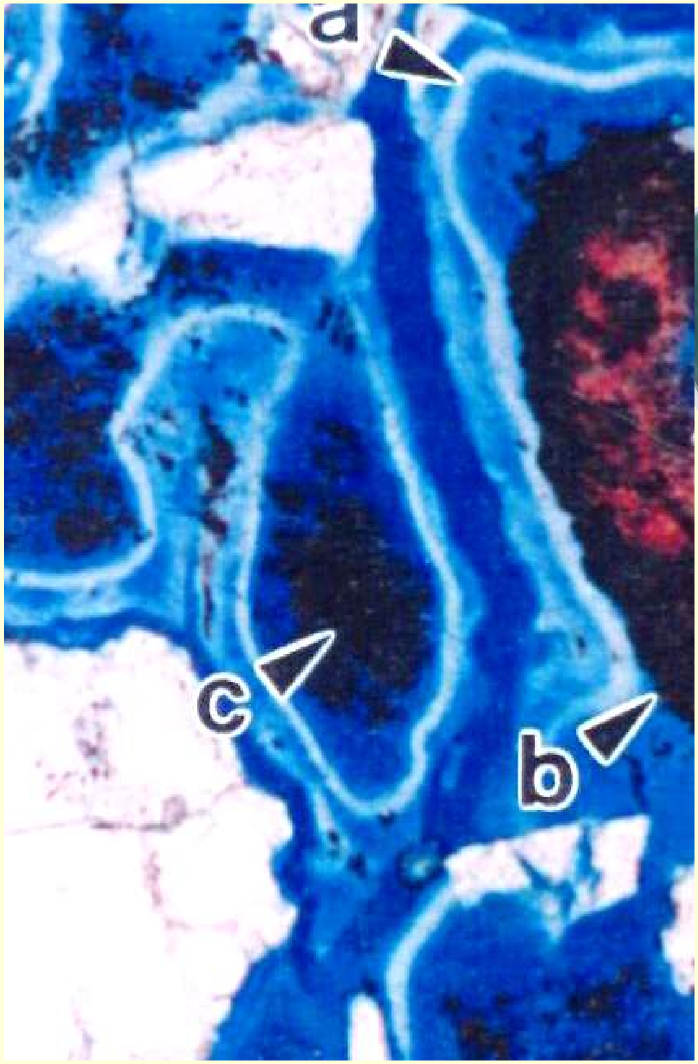
sand-sized clay aggregates with cement coatings

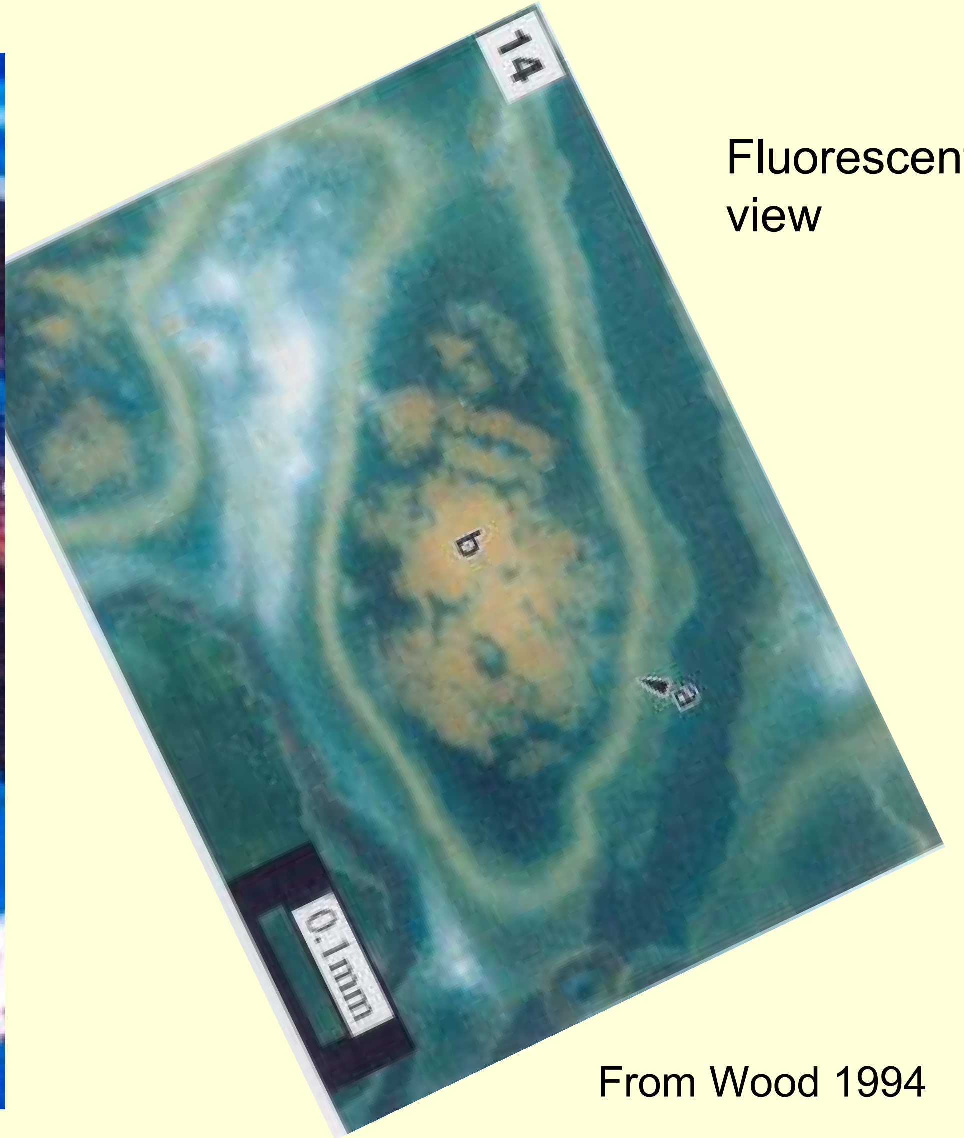


Red dye fills porous clay fabric

from Wood 1994

Cement Coatings





Fluorescent view

From Wood 1994

Chemical Weathering of Silicates Produces Excess Silica in Solution

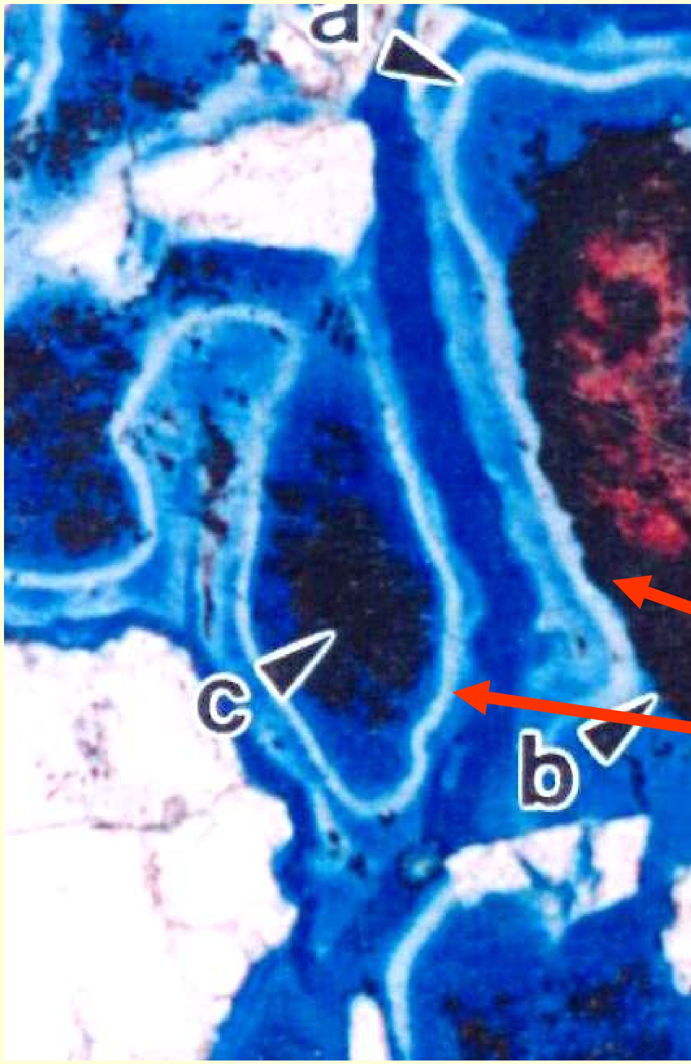
$$4\ KAlSi_3O_8 + 4\ H^+ + 2\ H_2O \longrightarrow$$

K feldspar

$$\longrightarrow 4\ K^+ + Al_4Si_4O_{10}(OH)_8 + 8\ SiO_2$$

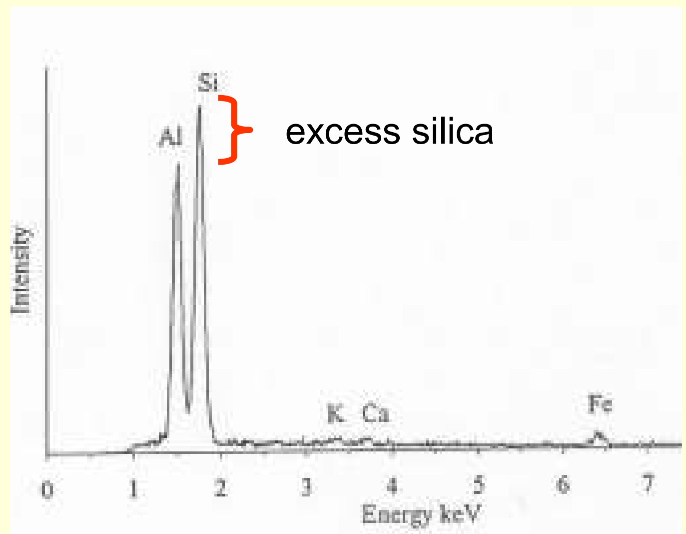
Kaolinite

Cement coatings are siliceous

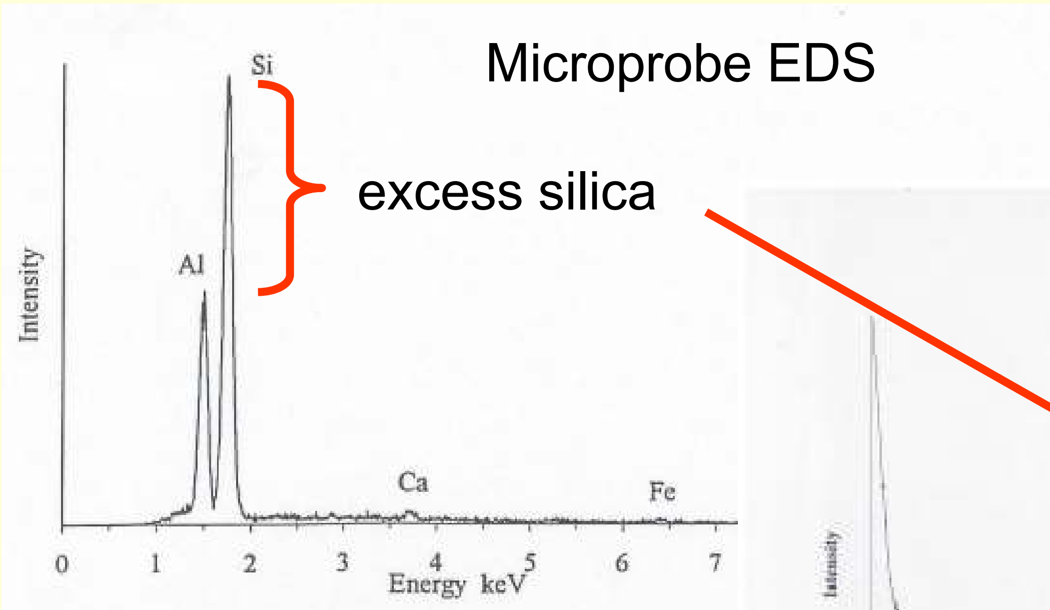


Microprobe EDS analysis:

kaolinite + excess silica + other cations



Pedogenic silica in another paleo Oxisol near Friant

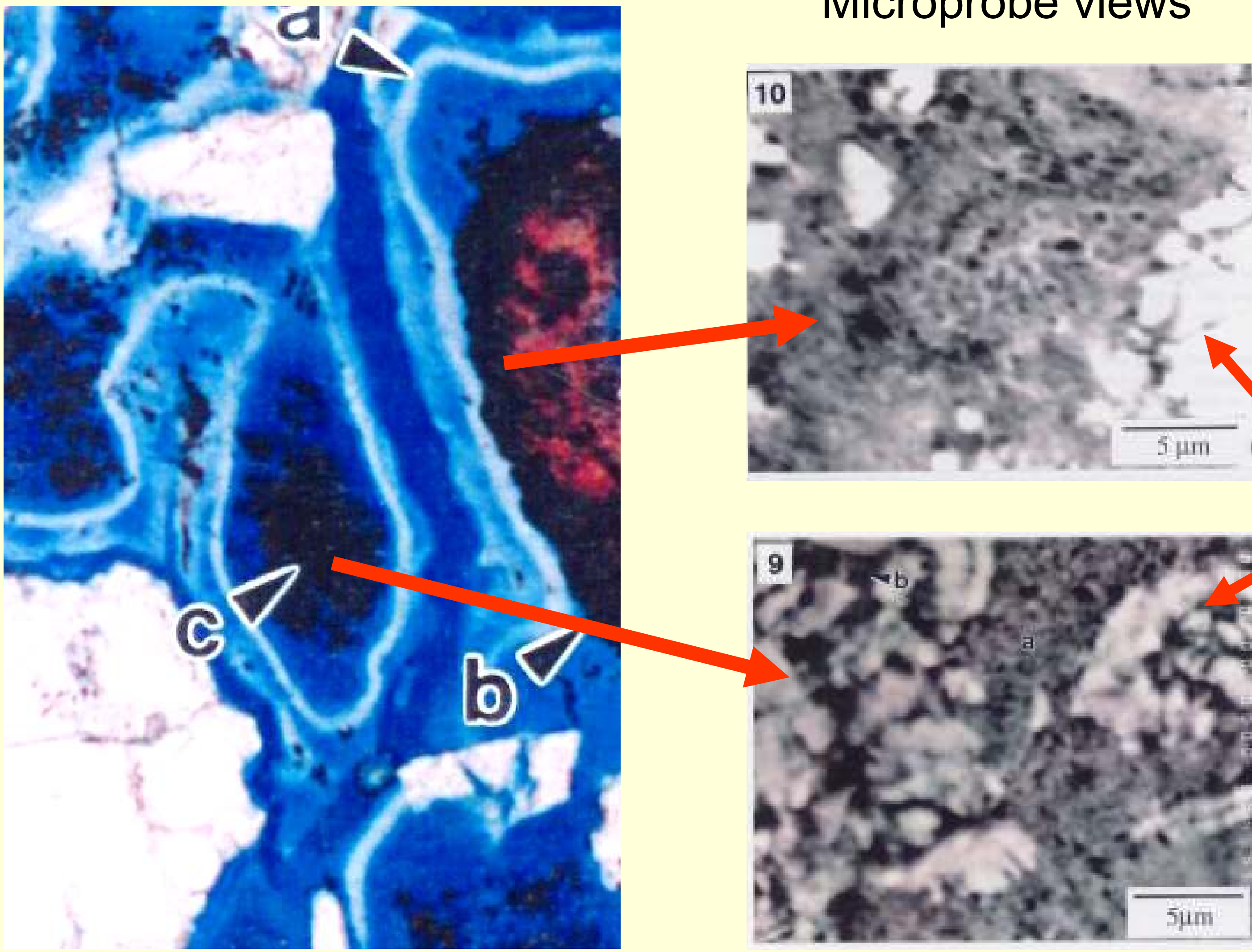


opal A peak = >20% amorphous silica

Wood et. al. 1995

Spongy microfabric of opaque cement coatings causes refraction of light

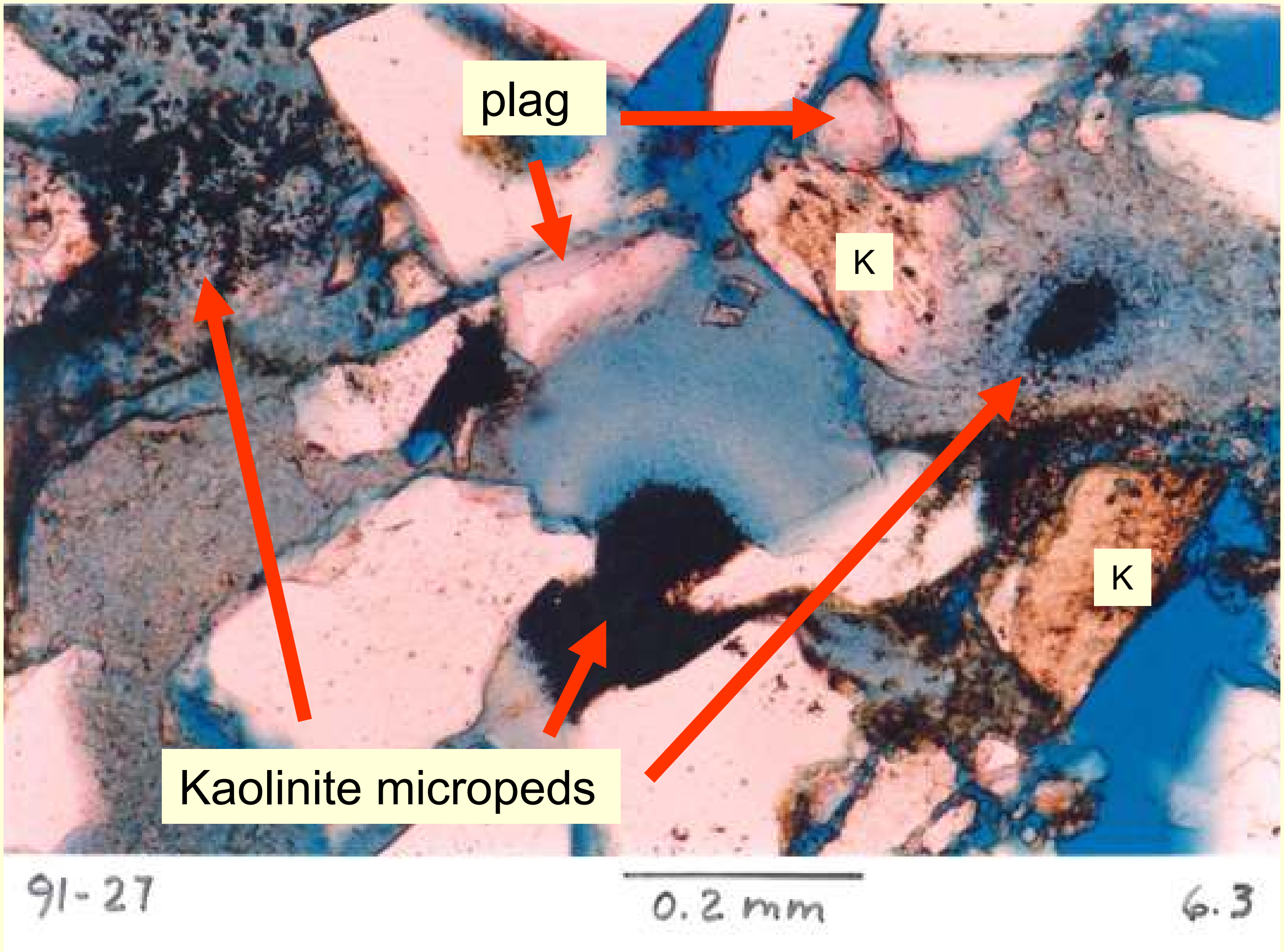
Microprobe views



kaolinite platelets

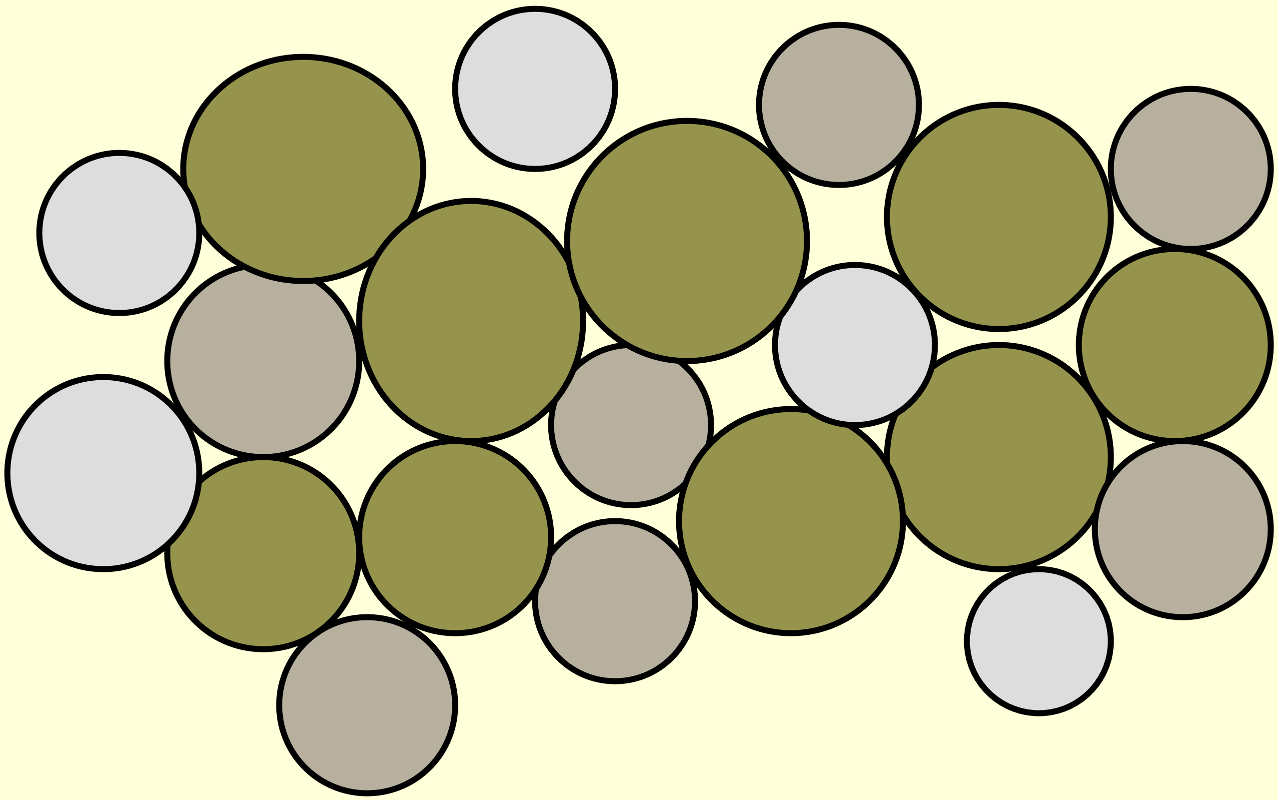
Wood 1994

Ione kaolinitic sandstone (Quaker Hill)

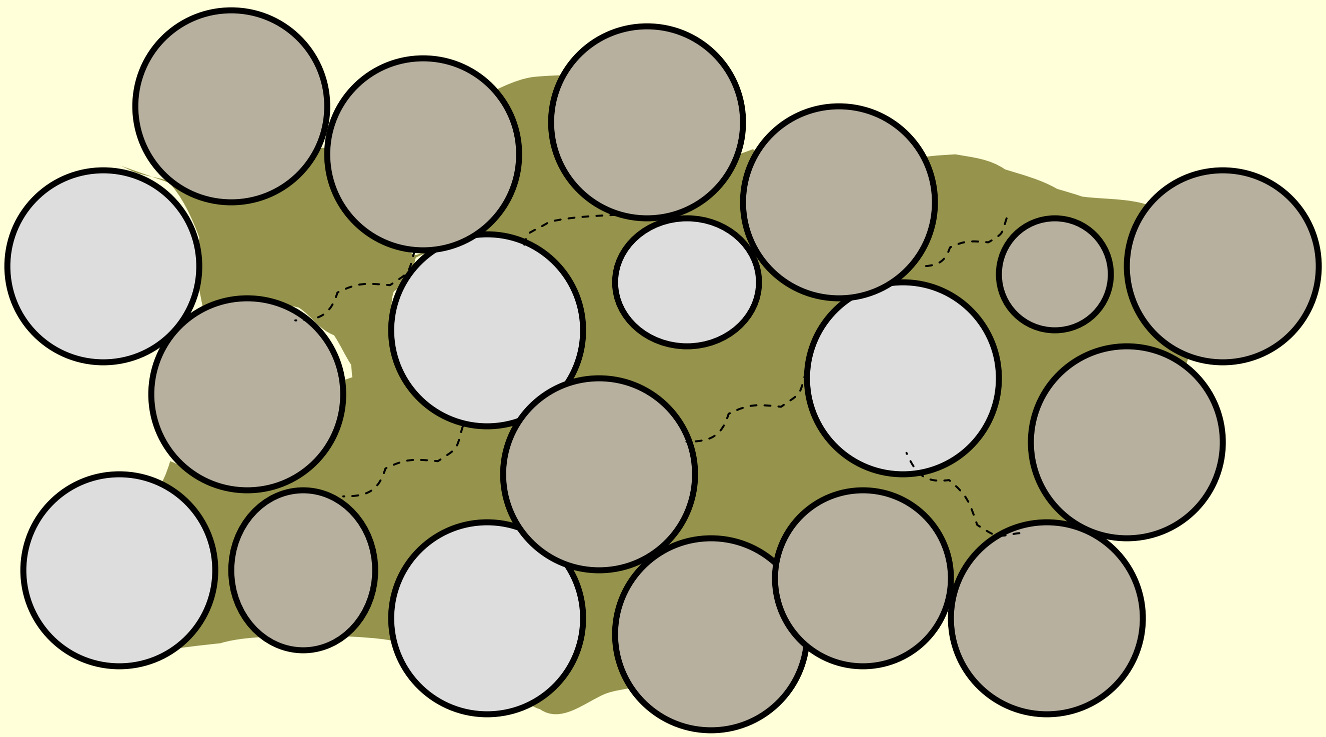


Transported Clay Clasts to Pseudomatrix

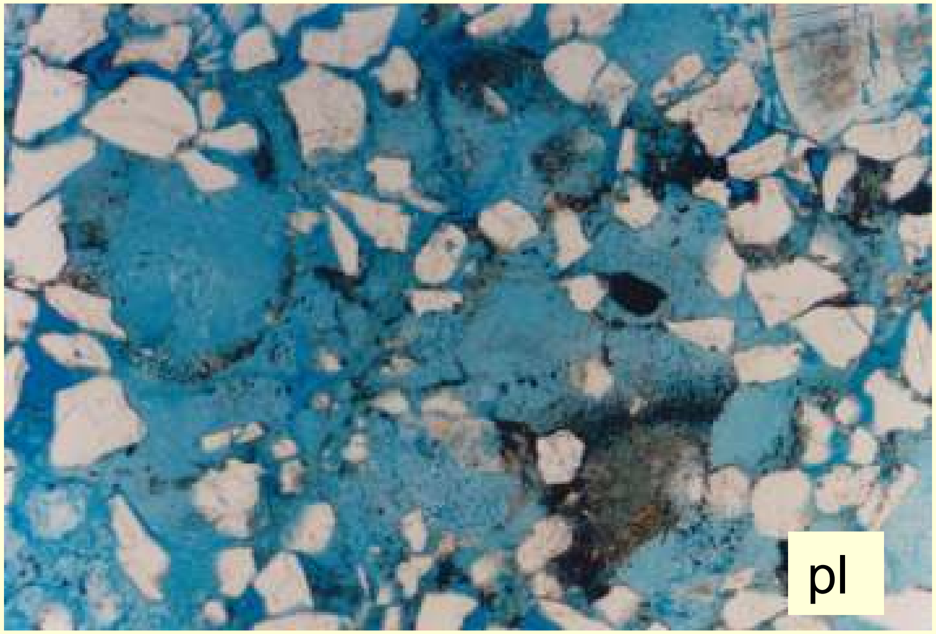
Initially, the sandy sediments with transported micropeds posseses substantial intergranular porosity at the time of deposition

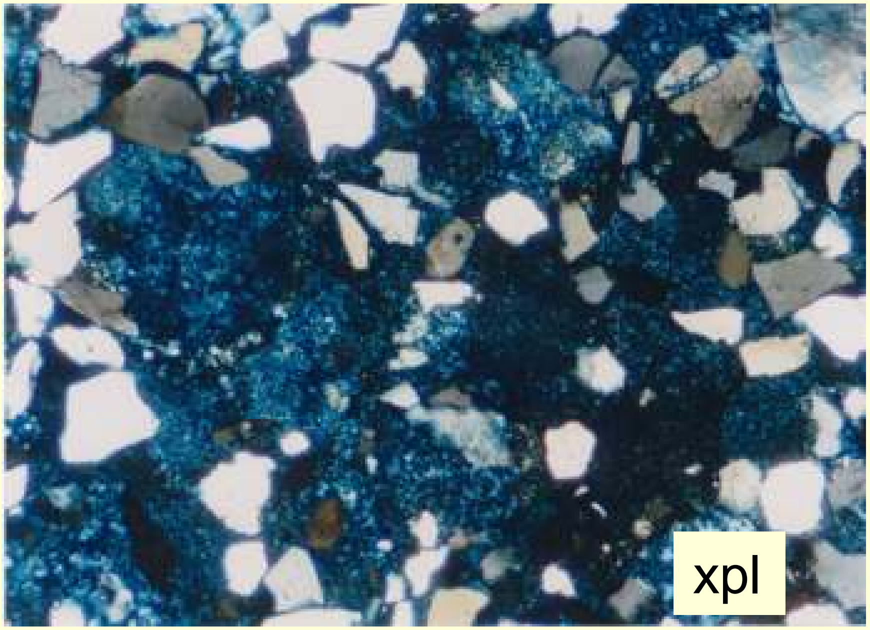


Consolidation and compaction from overburden pressure caused plastic clay clasts to deform and form pseudo-matrix



Ione Sandstone – Apricum Hill

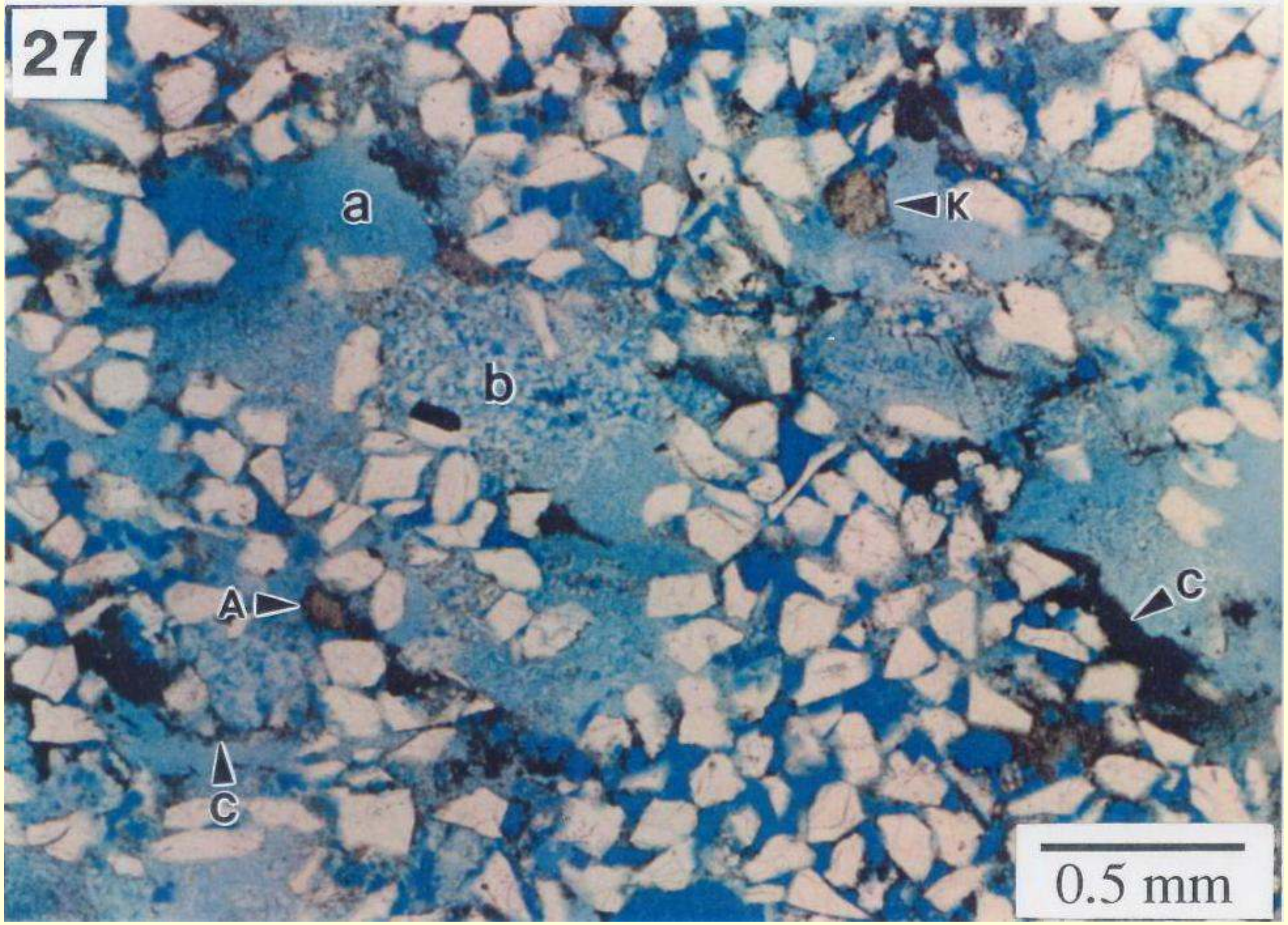




Squashed clay clasts comprise ≈ 50% of sand constituents

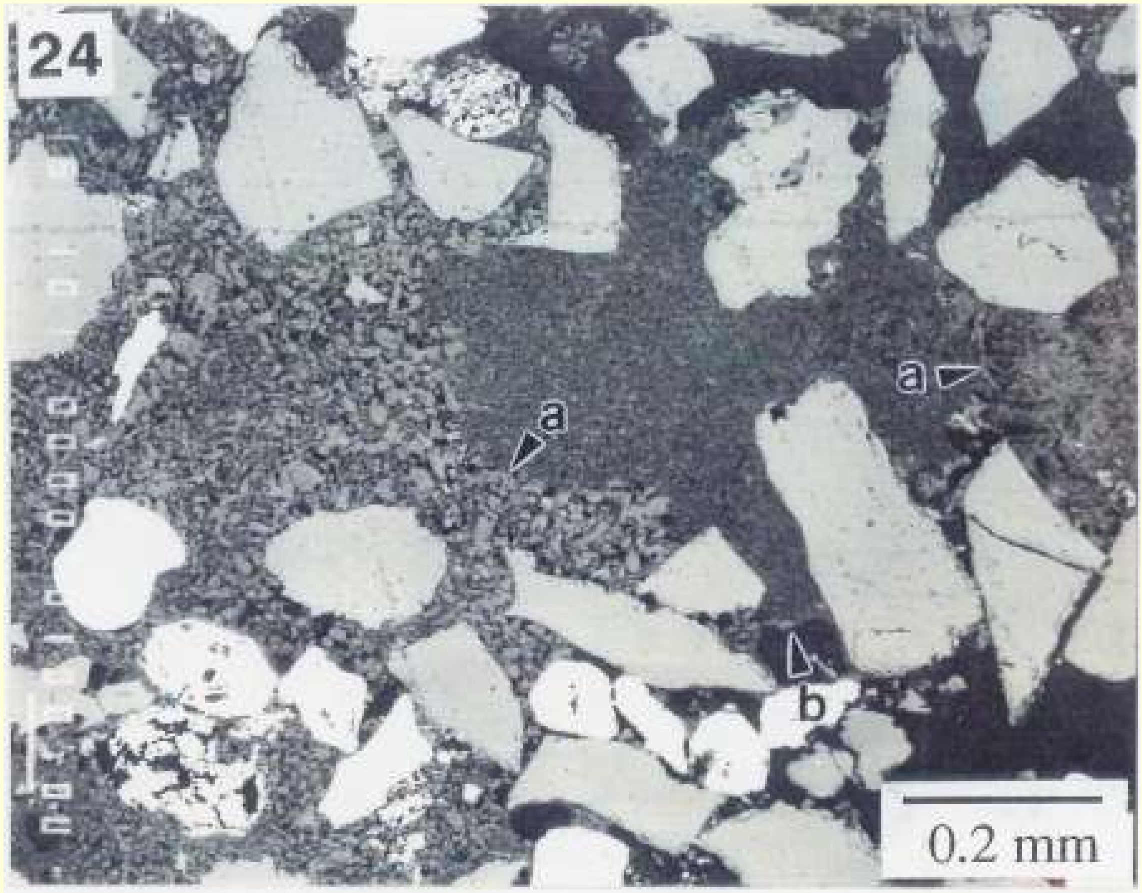
From Wood, 1994

Ione sandstone



Weatherable minerals present in trace amounts — amphibole (A), K-feldspar (K), adjacent squashed clay clasts have variable clay textures (a verses b); prominent silica cements lining clay clasts (c) (from Wood, 1994).

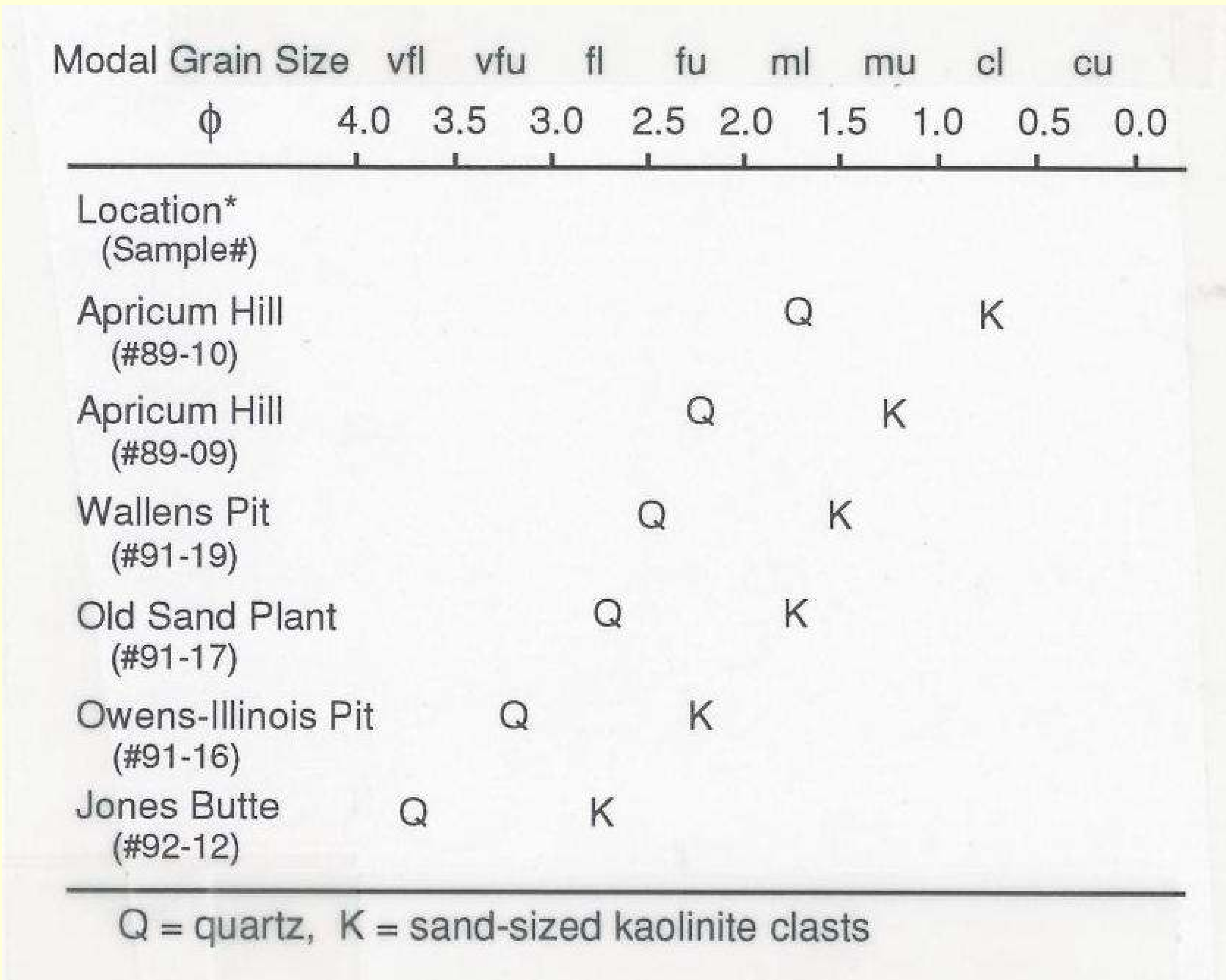
Squashed clay clasts form pseudomatrix



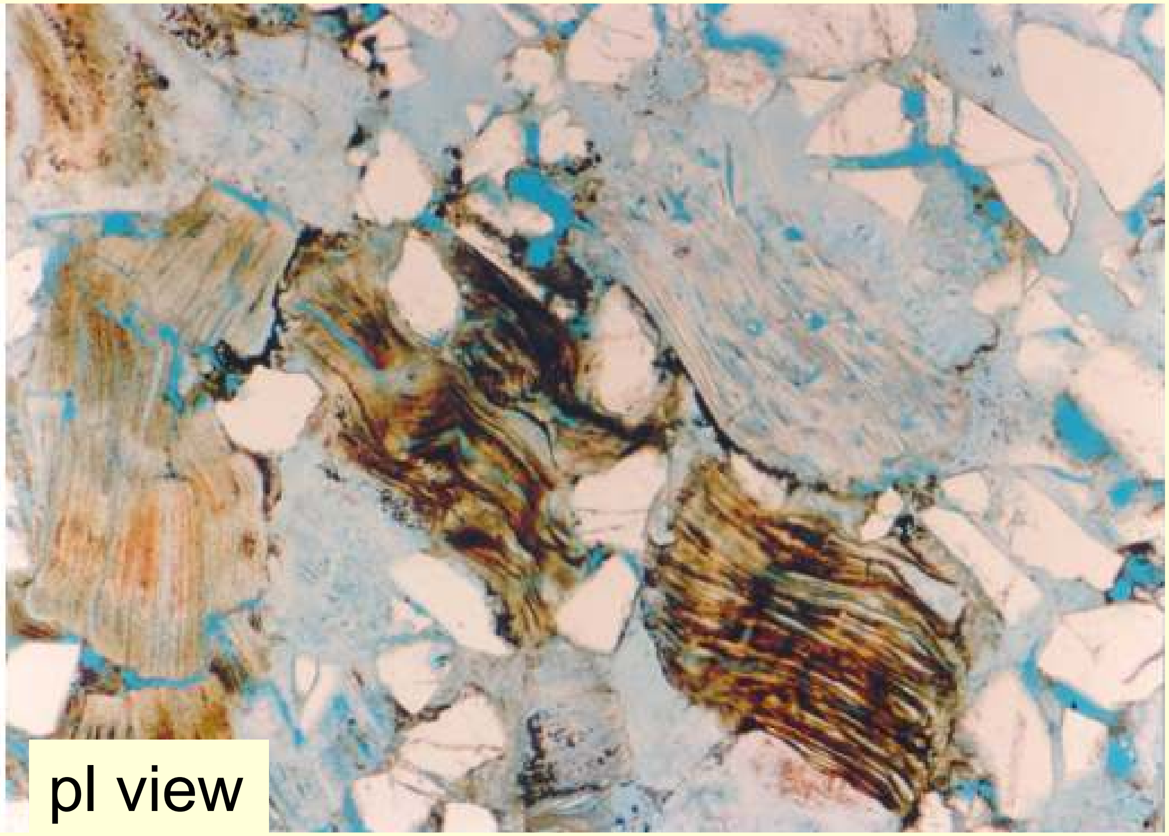
Microprobe back-scattered electron image

Wood, 1994

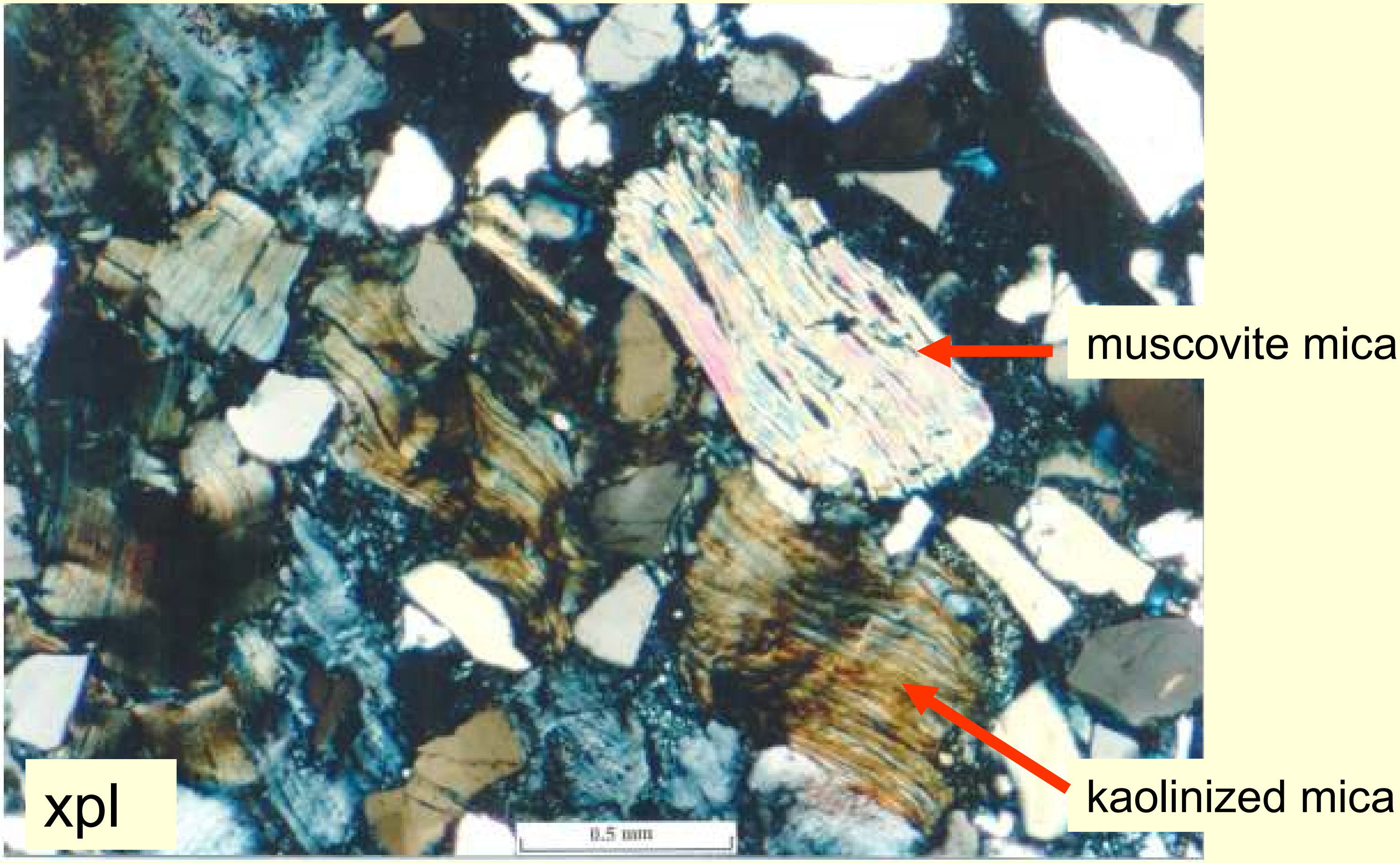
Hydrodynamically equivalent quartz and clay clasts have different average grain size due to different bulk density



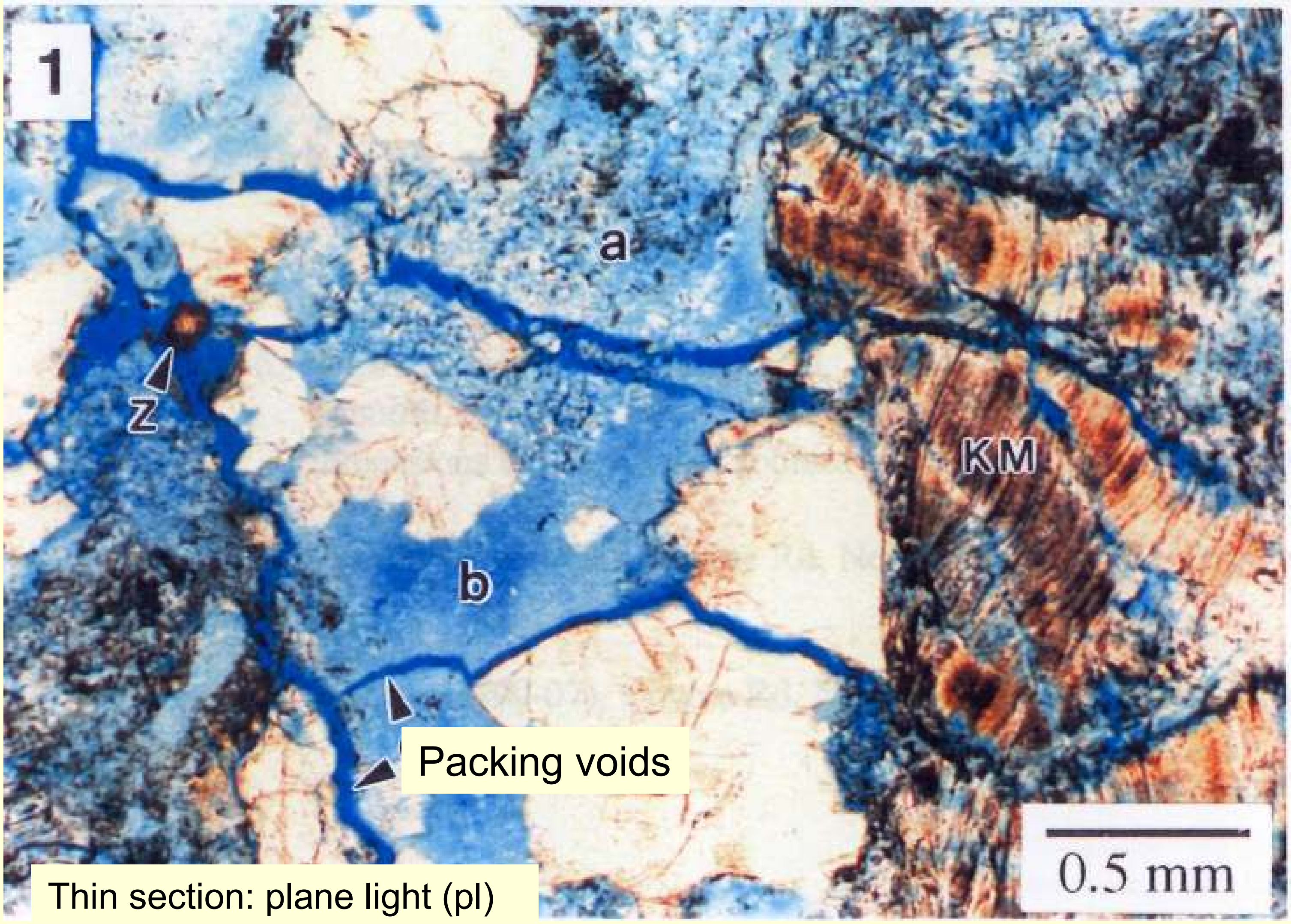
Ione Sandstone – Apricum Hill



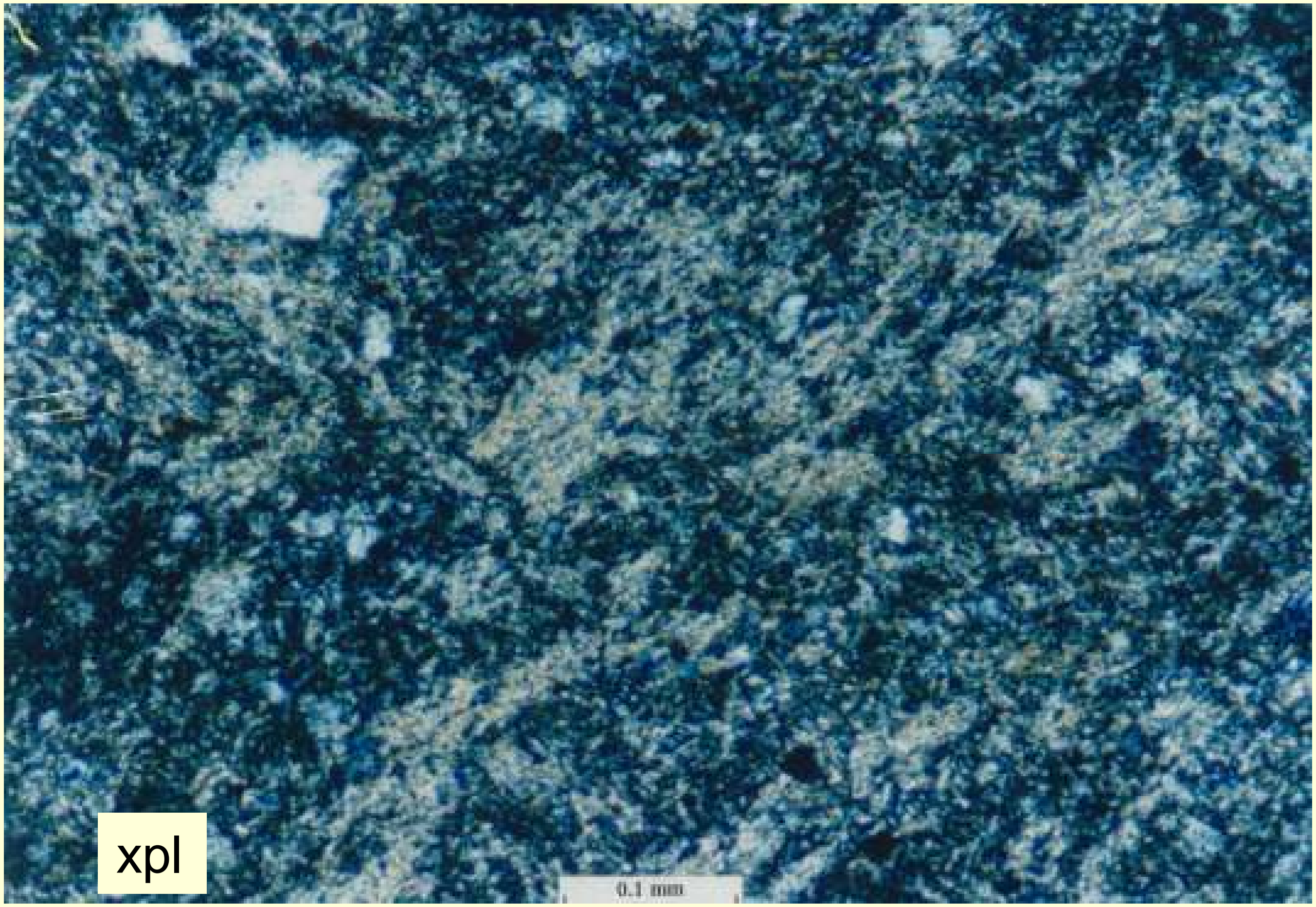
Abundant mica and kaolinized mica


muscovite mica
kaolinized mica
xpl
0.5 mm

Oxisol — Saprolite

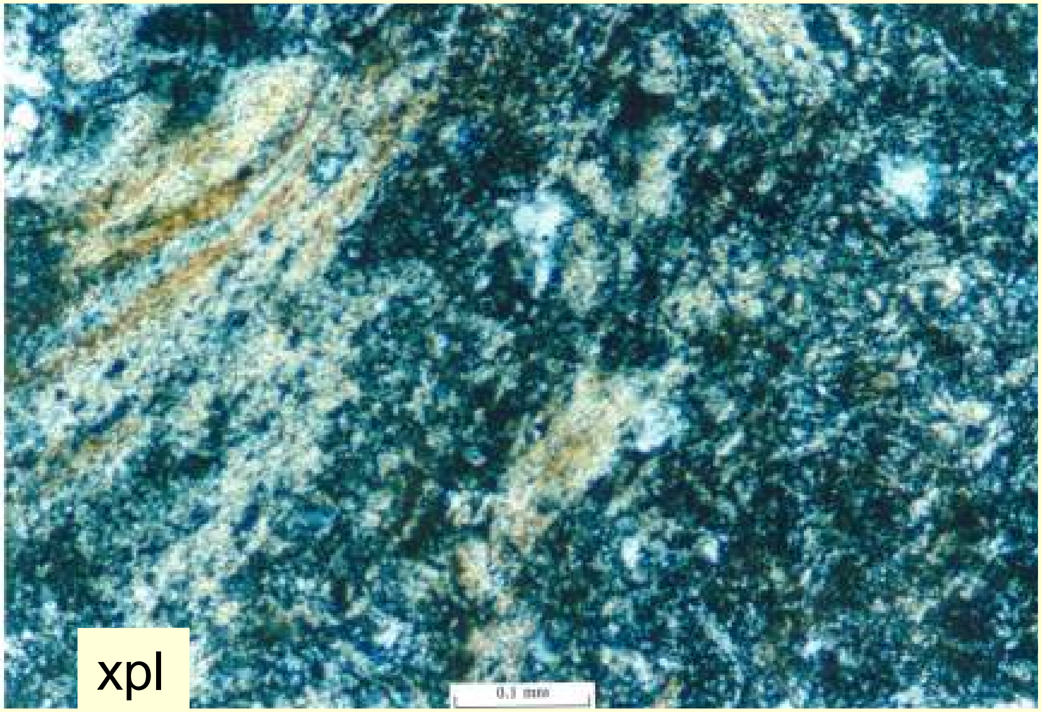


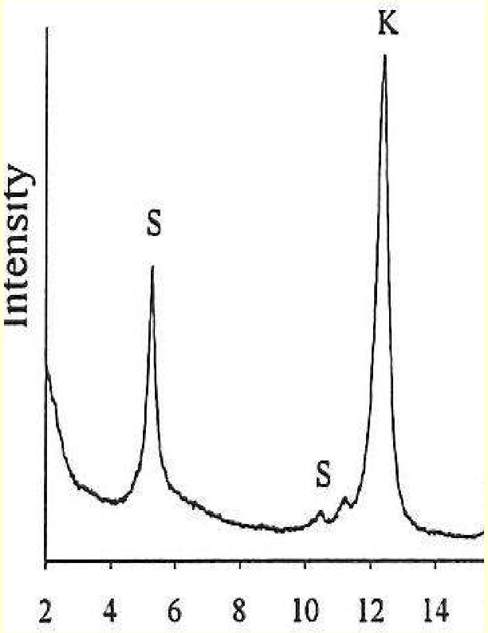
Ione claystones



Clay and silt sized kaolinite clay particles

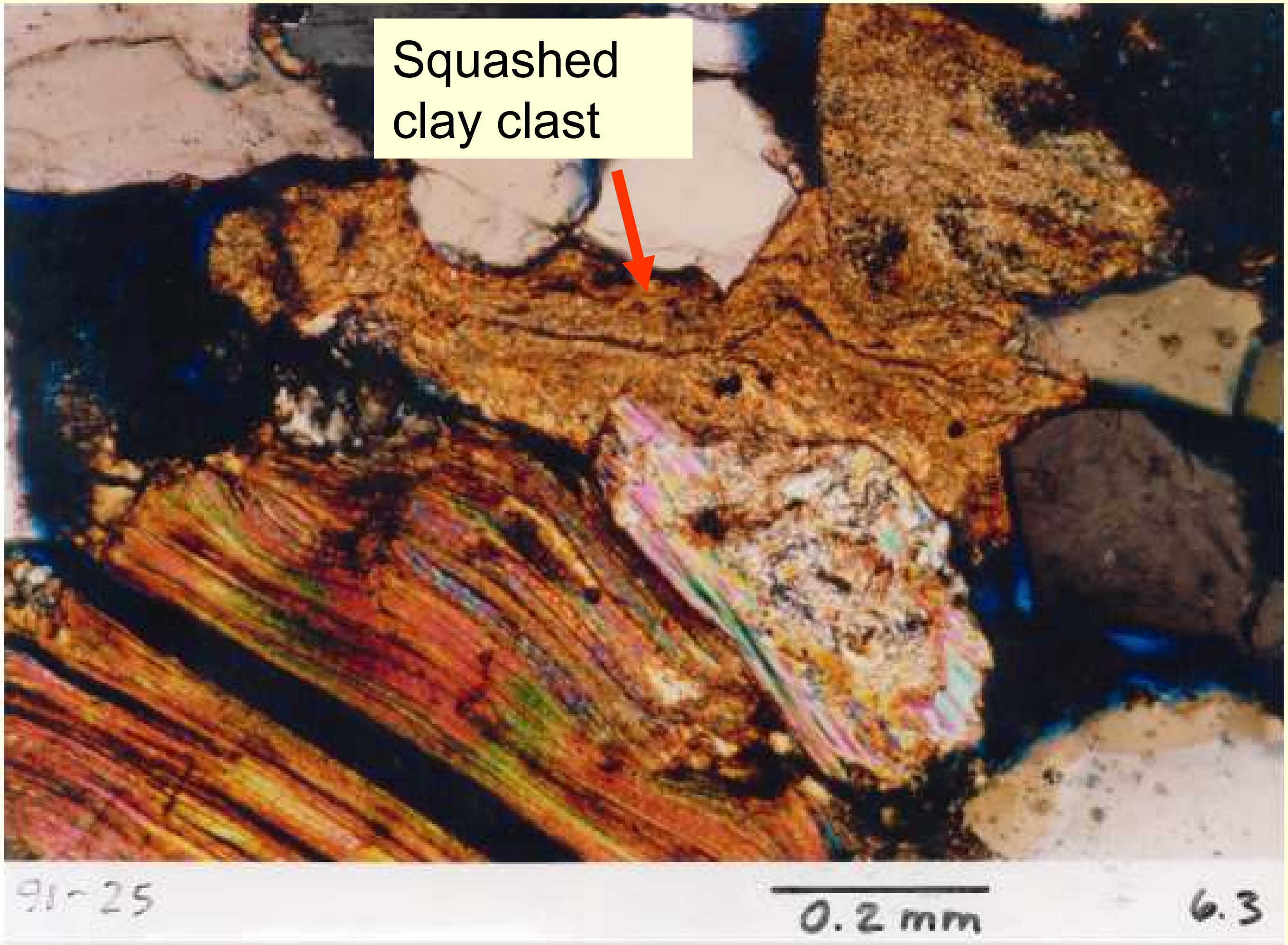
Top of Ione claystone section



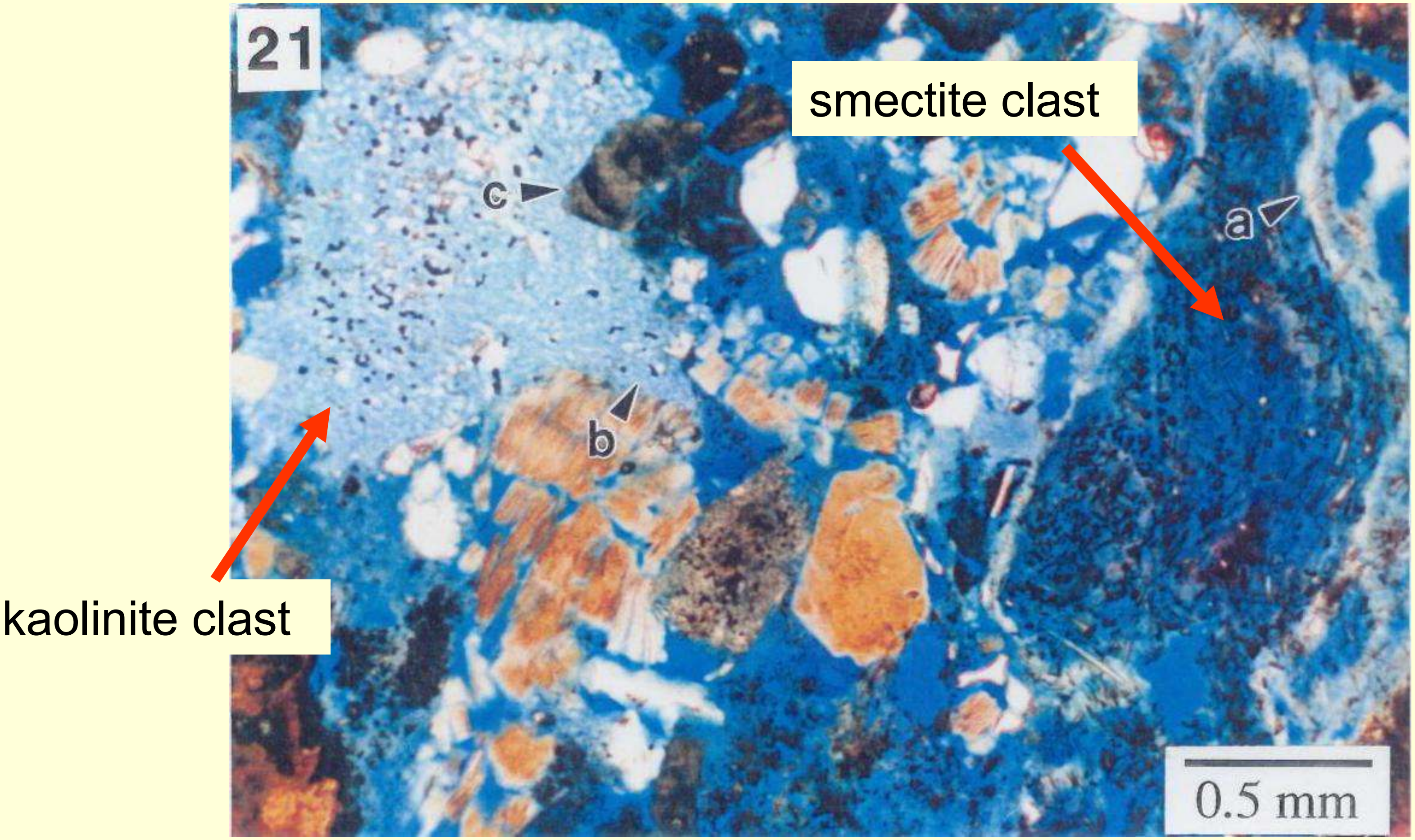


Top of section — silt and sand sized smectitized mica particles

Chalk Bluff unit smectitic sandstones

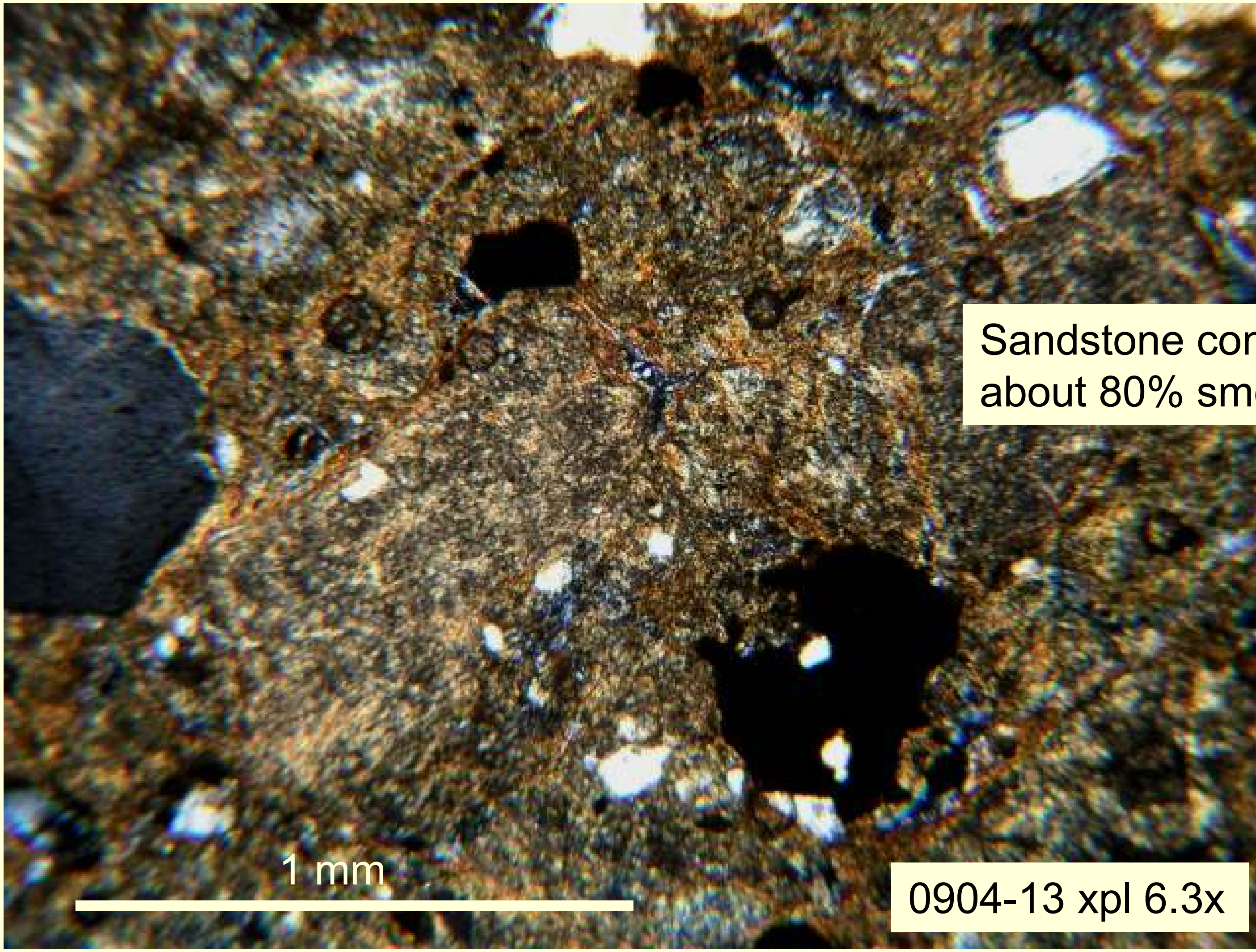


Chalk Bluff unit
smectitic sandstones at Baxter

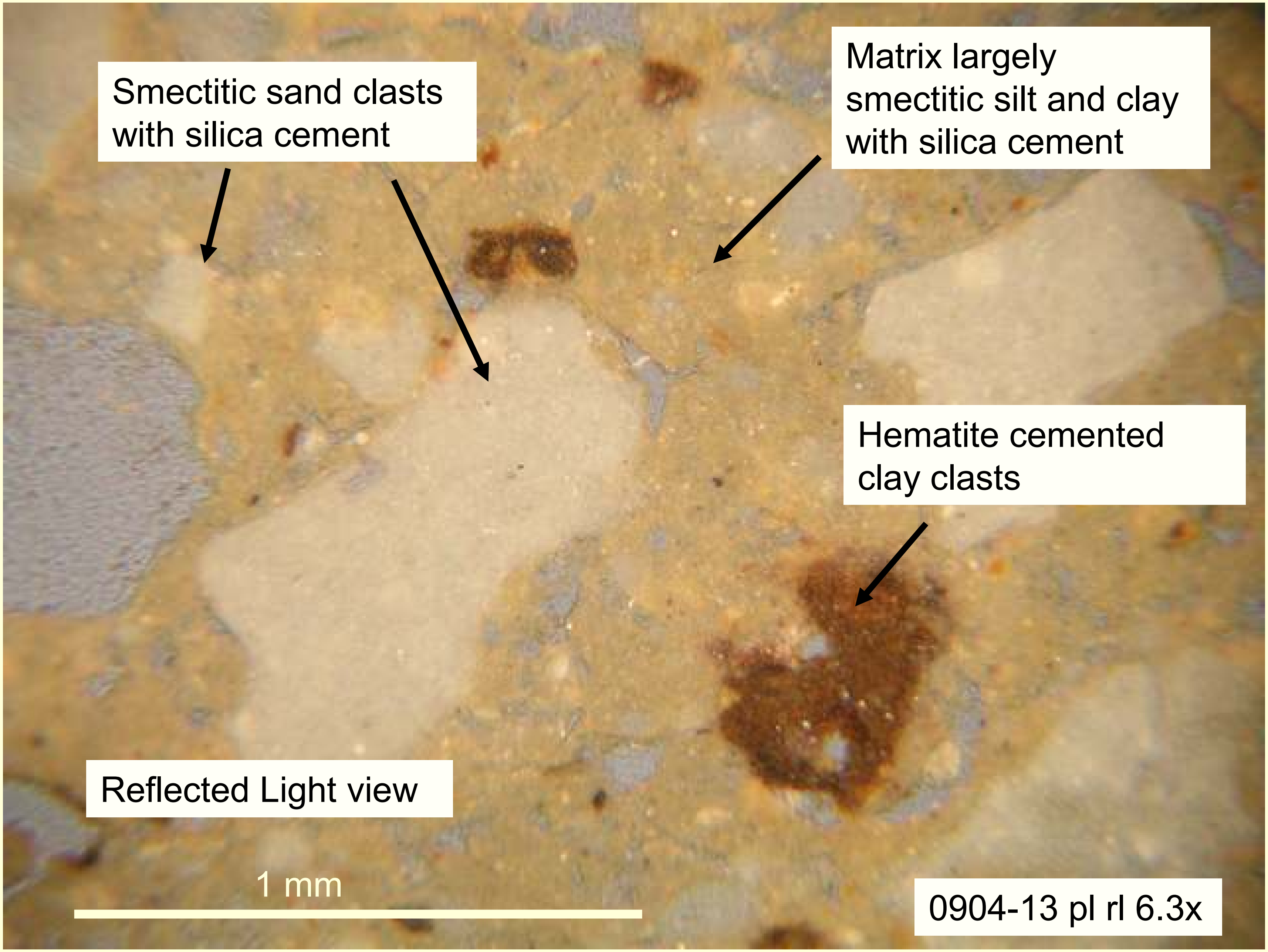


Wood 1994

Smectitic Sandstone – Rancho Murieta

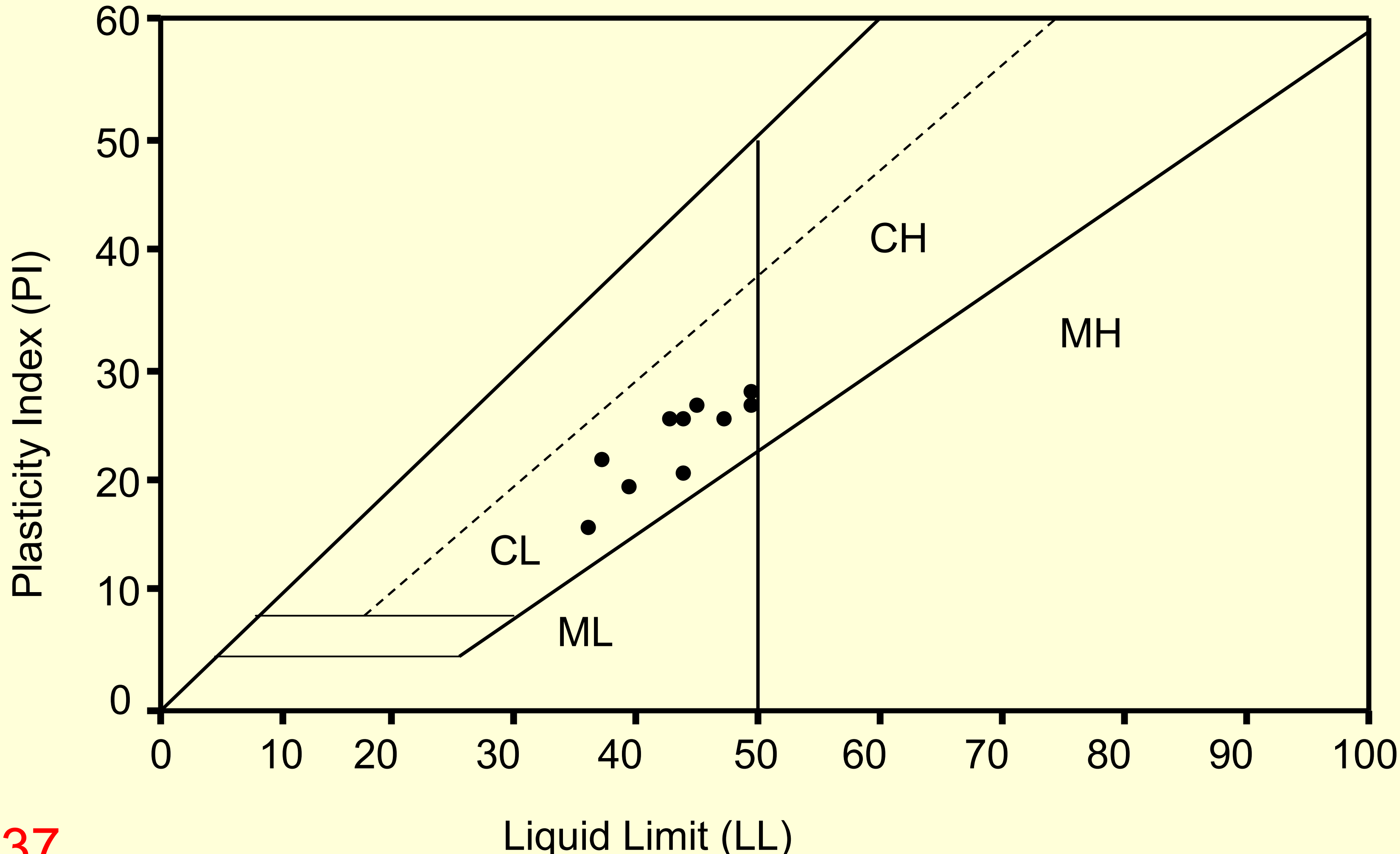


Sandstone composition about 80% smectite


Smectitic sand clasts
with silica cement
Matrix largely
smectitic silt and clay
with silica cement
Hematite cemented
clay clasts
Reflected Light view
1 mm
0904-13 pl rl 6.3x

Rancho Murieta ASTM test results

(ASTM D4318)

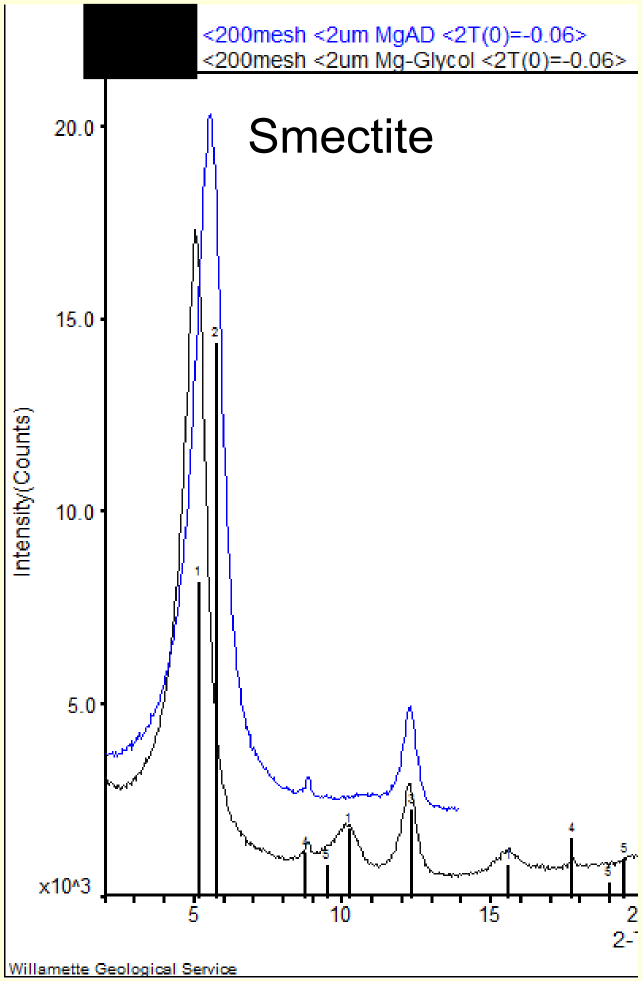


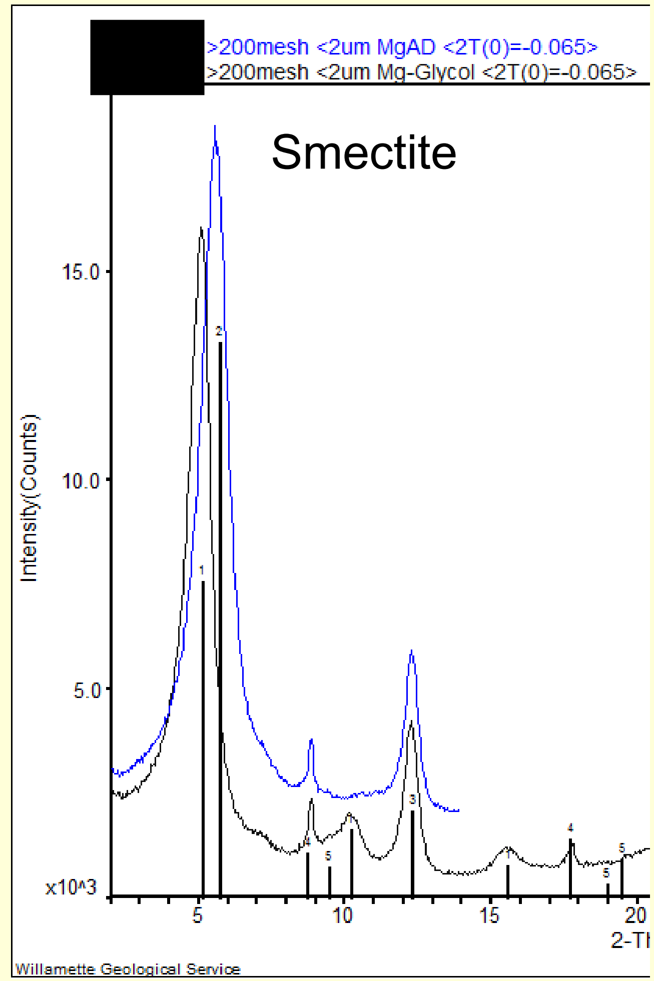
Smectitic sediments

Geologic Hazard Notice | California Geological Survey | December 2009

Typical fine-grained sand of the subject smectite-bearing geologic unit. Sample collected from northeas Sacramento County. Microscope photo by James L. Wood.

XRD Results





<200 mesh fraction (silt and clay)

Sand fraction (>200 mesh)

Summary

- Clay in Early Tertiary sandstones occurs largely as silica cemented sand sized clasts that were transported as bedload constituents
- The clay in claystones/mudstones was derived from clay and silt in suspension
- Weatherable minerals occur in trace amounts in the kaolinitic Ione sandstones but show little, if any signs of post-depositional leaching or alteration
- The fabric of sandstones and claystones do not possess pedogenic morphologies such as packing voids indicative of significant post-depositional weathering activity
- The cemented sandy form of smectite in sediments of Chalk Bluff lithology defies the ASTM test methods and leads to latent expansion problems for soil engineering in the region