Core Description, Lithofacies Interpretation and Sedimentological Characterization of a Mixed Provenance Alluvial Fan: the Pleistocene Tulare Formation, Midway Sunset Field, Kern County, California*

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Abstract

The Pleistocene Tulare Formation in the Midway Sunset Field (MWSS), San Joaquin Basin, records a unique and complex mixed facies of alluvial, braided fluvial and lacustrine environments. Due to continuous tectonic activity, changes in depositional environment were rapid both laterally and temporally. This study describes a shallow, undocumented section of the Tulare Formation found in western MWSS, called the Upper Tulare.

Two hundred feet of continuous core was obtained in the Upper Tulare section MWSS. The core was described and categorized into seven lithofacies: (1) orange-brown massive matrix-supported conglomerate with silt and fine-grained sand and clay framework grains. (2) light brown massive matrix-supported conglomerate with siltstone matrix and angular to subrounded granules and pebbles. (3) massive coarse-grained conglomerate with framework grains of sand and high volumes of rounded diatomite clasts. (4) alternating wavy beds and lamina 0.5-2 cm thick of interbedded clays and fine-grained sand and occasional pebble beds, characterized by diffuse contacts and soft-sediment deformation. (5) normally graded, fine- to coarse- grained sandstones 30 cm thick punctuated by beds of granule to pebbles and 2-mm mud drapes and clay beds. (6) massive, coarse-grained, well-rounded unconsolidated quartz sand. (7) laminated blue-gray and white claystone with wavy deformation.

Core plugs were sampled every foot, while ultraviolet light photography were taken and the samples analyzed for porosity, permeability and saturation measurements. Two samples were identified for further analysis by thin-section petrography, Scanning Electron Microscopy (SEM), and X-ray diffraction (XRD). Five samples were selected for viscosity, API gravity, Saturate-Aromatic-Resin-Asphaltene geochemical assessment and pyrochromotography.

Seventy percent bulk volume of the cored interval is matrix-supported conglomerates. In each conglomerate facies, the clasts are primarily tan and white subangular to subrounded, Opal-A and Opal-CT diatomite, .2-1.5 cm in diameter. Rounded plutonic, metamorphic, volcanic and limestone clasts are also present. Thin section and SEM of the framework grains in these conglomerates display heterogeneity at 1mm scale;

accessory grains include glauconite, phosphatic fragments, muscovite, amphibole, biotie, and organic particles. Quartz, feldspars, and clay detected by X-ray diffraction occur principally in the mudstone matrix, whereas the two forms of opal are found in the porcelanite clasts. The porcelanite clasts exhibit moldic pores and matrix micropores. The clasts are composed of siliceous microfossils, primarily opal-A, with some areas illustrating partial conversion to opal-CT lepispheres. The presence of both opal-A and opal-CT diatomite silica phases is confirmed by XRD and SEM.

In the Upper Tulare, the low density and clay-rich sediment sources erode and deposit unusually fine-grained alluvial fan sequence while sedimentary structures reflect a high-energy environment. Structures include dish and flame structures, wavy lamina, and convoluted bedding. Within the sandstone facies, pore spaces between silica and plagioclase grains contain an average of 15% intergranular clays. The sandstones are microporous due to the presence of detrital smecitite, illite and mica in some primary pores.

The Upper Tulare is of an alluvial-fan depositional environment, where clasts were sourced from both Miocene diatomaceous Monterey and Miocene-Oligocene siliciclastic Temblor formations. The Temblor formation is a marine clastic reservoir composed of arkosic sandstone and micaceous claystone. The Monterey is composed of deep-marine diatomite and siliceous shale. The two formations were synchronously uplifted and eroded due to transpression along the San Andreas Fault. Sediments were deposited northeastward into the San Joaquin Valley basin.

The heterogeneous sediment and the poor sorting result in a high-porosity (35%), low-permeability (3-100 md) reservoir which contains 30-60% oil saturation of heavy (12 API gravity) biodegraded oil. Good reservoir quality is isolated in the sandstones and diatomite clasts by the pervasive pore-filling clays. With heavy oil, a greater permeability would be required to properly steam flood this alluvial fan facies.

Reference Cited

Dibblee, T.W., 2005, Geologic map of the Fellows quadrangle: Dibblee Geological Foundation, Dibblee Foundation Map DF-96, scale 1:24,000 (edited by and J.W.Minch).

Core Description, Lithofacies Interpretation and Sedimentological Characterization a Mixed Provenance Alluvial Fan Pleistocene Tulare Formation Midway-Sunset Field, Kern County, California

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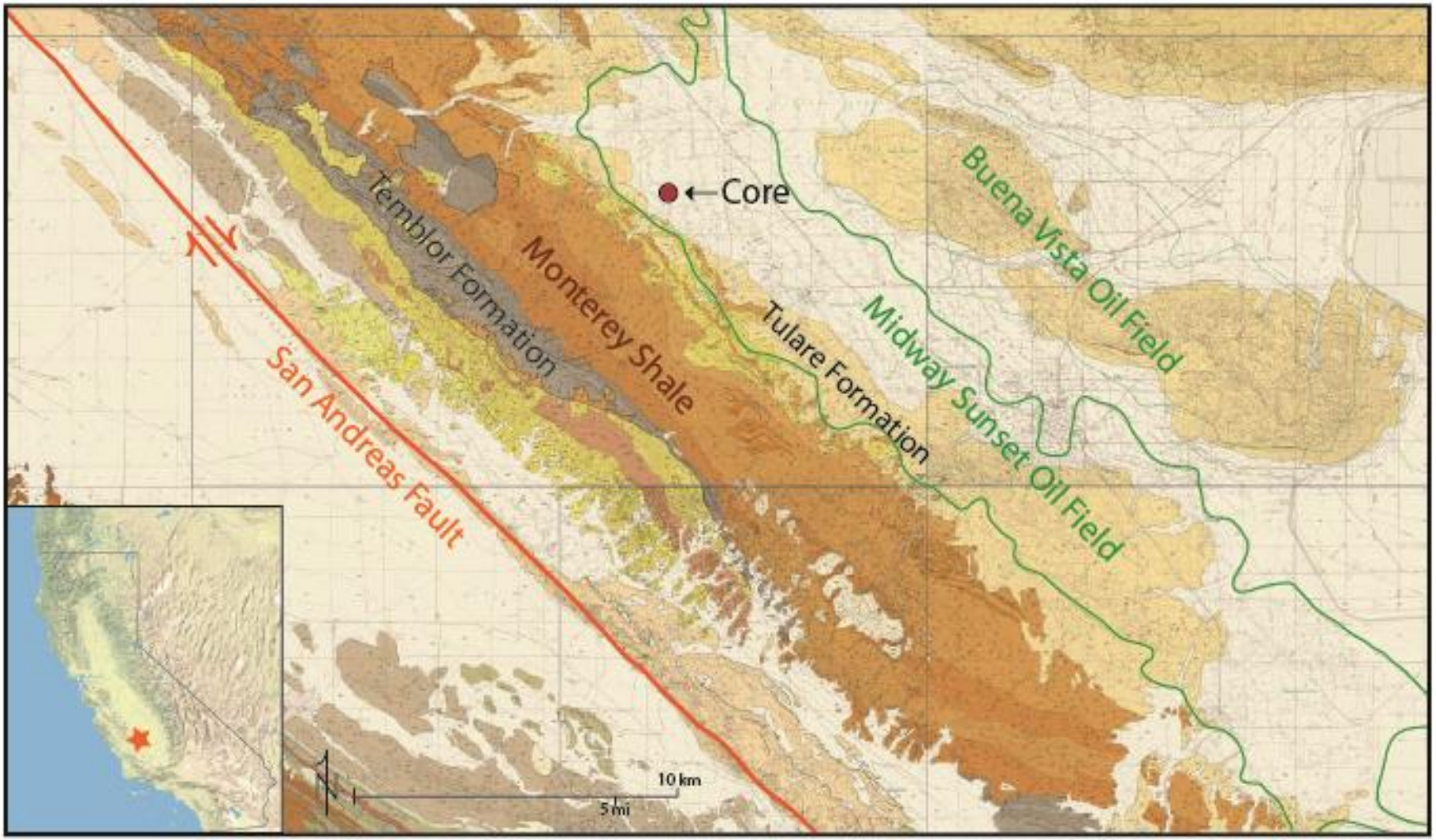
4/24/2013

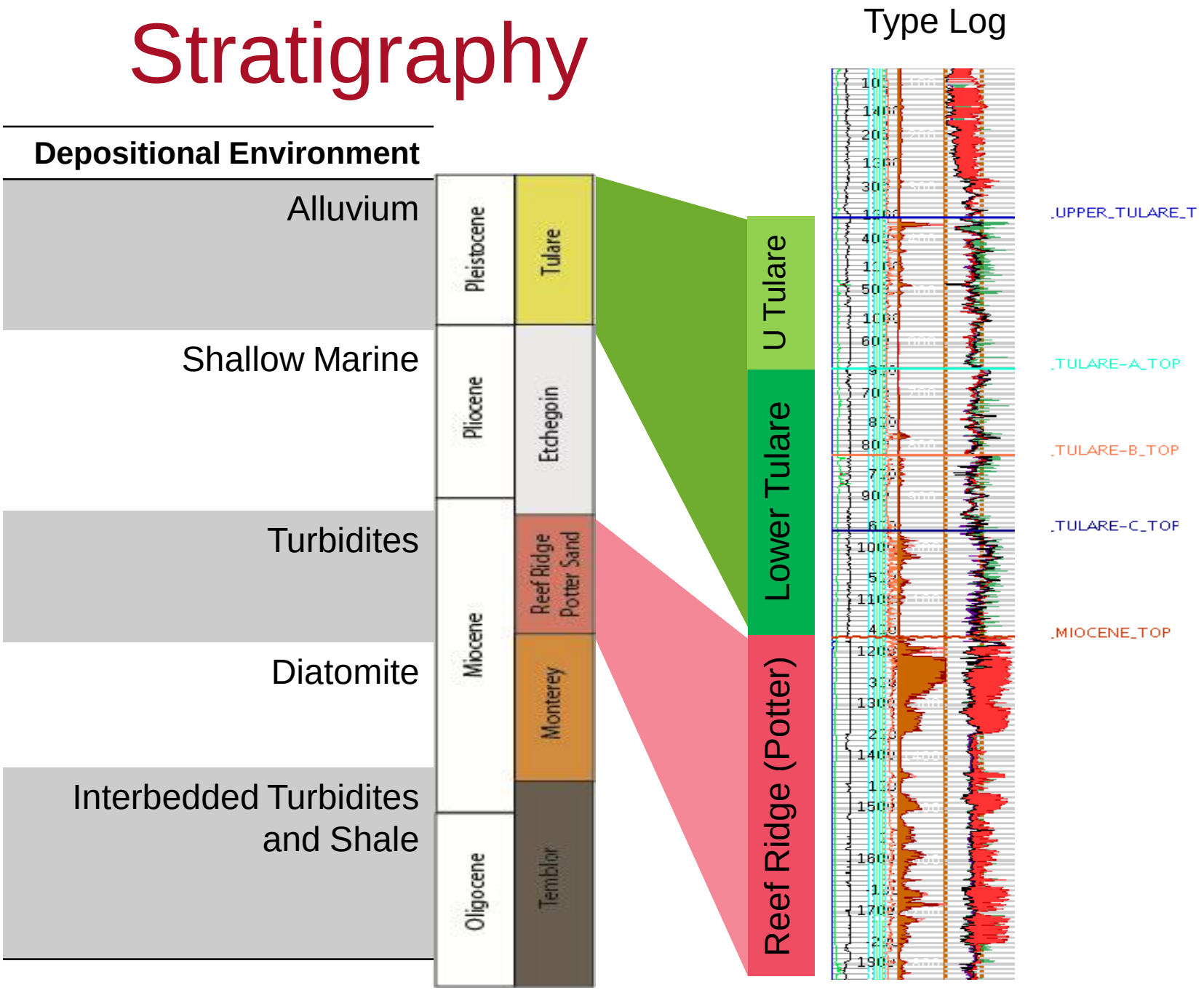
Aera Energy LLC

Midway-Sunset Oil Field



Formation Outcrop Map
Images modified from USGS National Geologic Maps Database

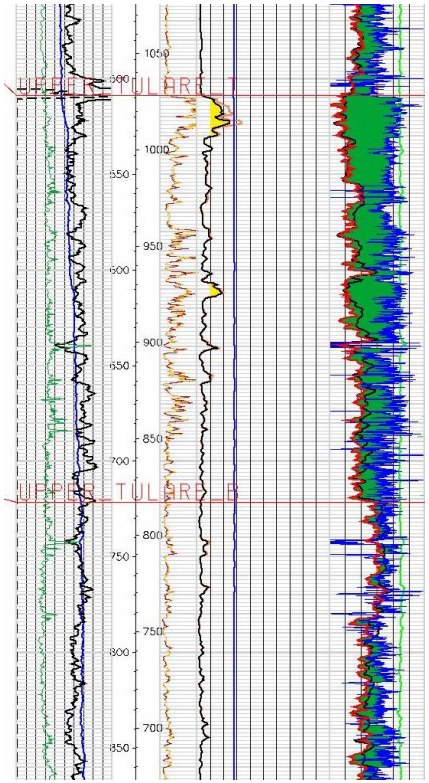
Stratigraphy



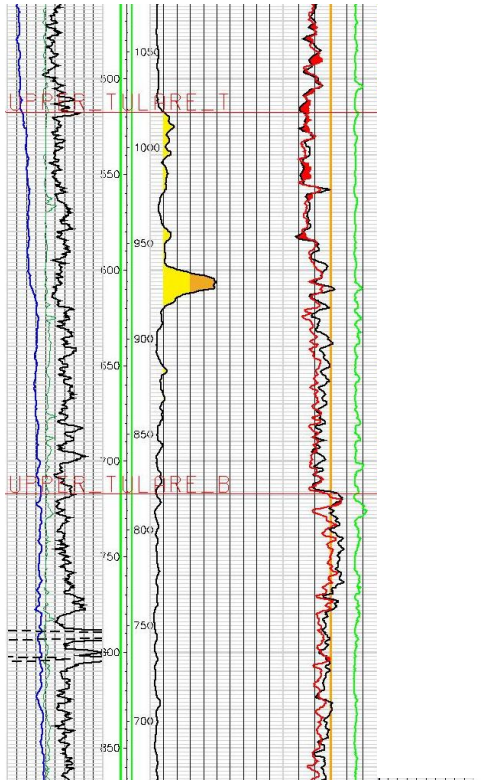
Log Identification of Upper Tulare

- Upper Tulare has low resistivity and significant So was not previously calculated from vintage logs
- The Upper Tulare is primarily identified from the dielectric tool (EPT/ADT)
- Reservoir quality (identified by EPT/ADT) is best at the top and decreases gradually with depth
- Not previously produced
- Core was required to determine if the Upper Tulare is thinly bedded sand and shale or homogeneously low perm

Triple Combo/Dielectric (EPT)
Drilled 2005



Triple Combo
Drilled1994



200’ of Continuous Conventional Core

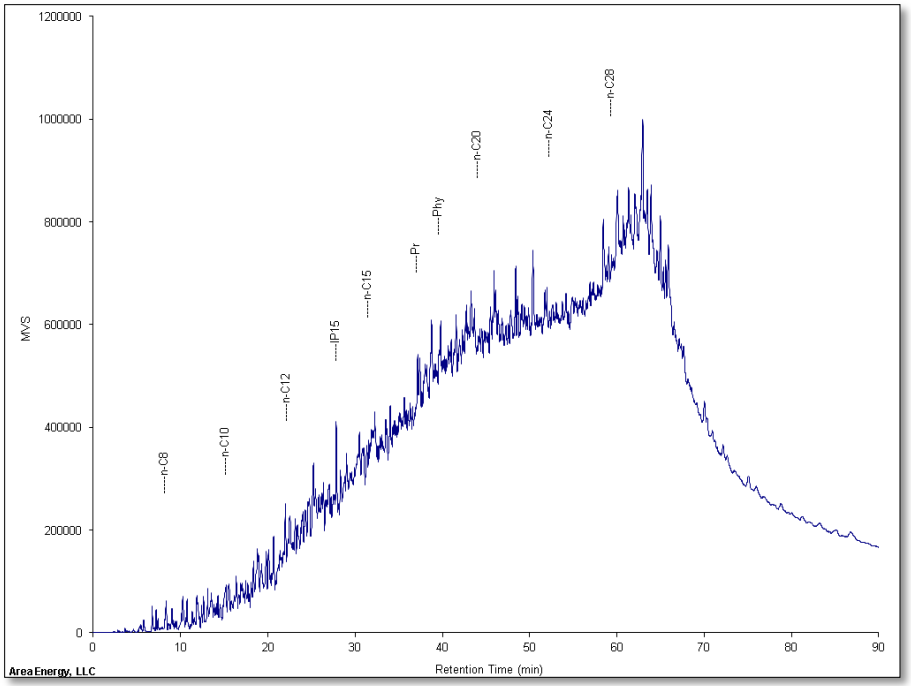
Reservoir Parameters & Oil Geochemistry

Reservoir Parameters

- Porosity 35%
- Permeability 3-100md
- S_o 30-60%
- Grain Density 2.56

Oil Geochemistry

- 12 API° Gravity
- Viscosity 1417 centipoise at 122^{0}F



Lab Sample No.	Depth (ft)	SARA Data				
		%Saturates	%Aromatics	%Resins	%Asphaltenes	Sat/Aro
512057-1	417.4	27.49	30.33	26.18	16.00	0.91
512057-2	432.5	25.77	30.19	27.79	16.25	0.85
512057-3	520.0	26.30	32.23	27.06	14.38	0.82
512057-4	595.6	29.88	33.90	26.33	9.88	0.88

Seven Lithofacies Classified

P	Paleosol Overlying Unit
C_S	Conglomeratic Sandstone
F_M	Pebbly Siltstone
Sw	Interbedded Sandstone and Claystone
Sp	Interbedded Sandstone and Conglomerate
S_C	Conglomeratic Sandstone
S_{BG}	Oil Sand
M_L	Claystone

Facies Association

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C_S	Conglomeratic Sandstone
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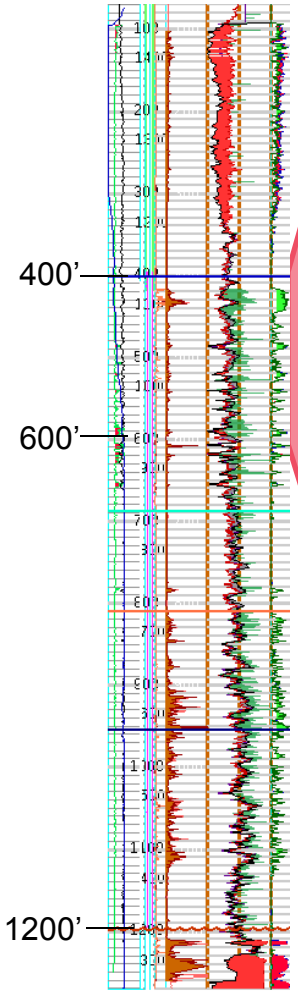
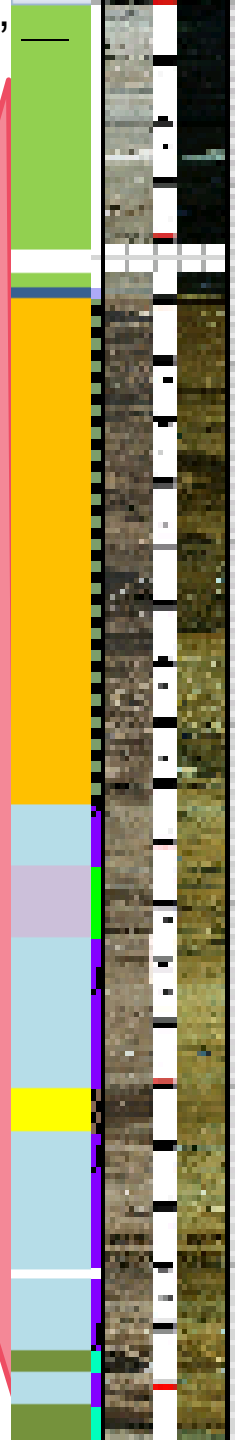
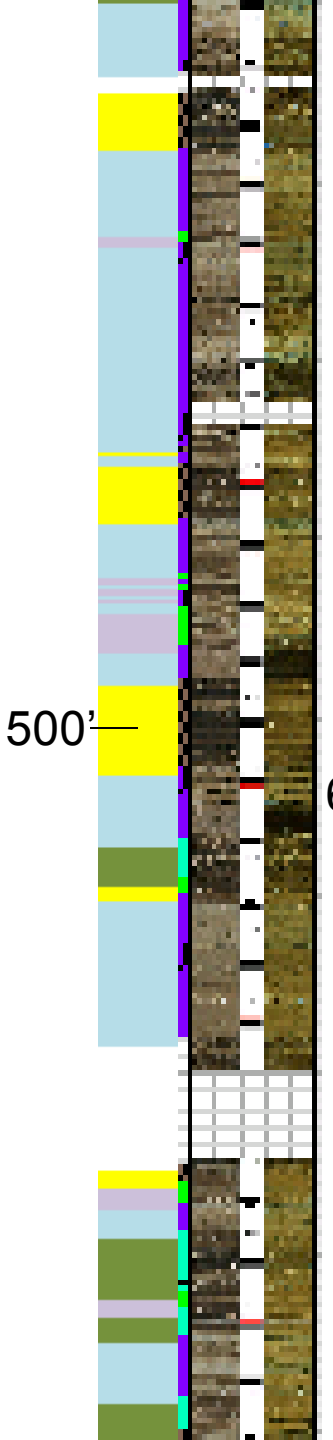
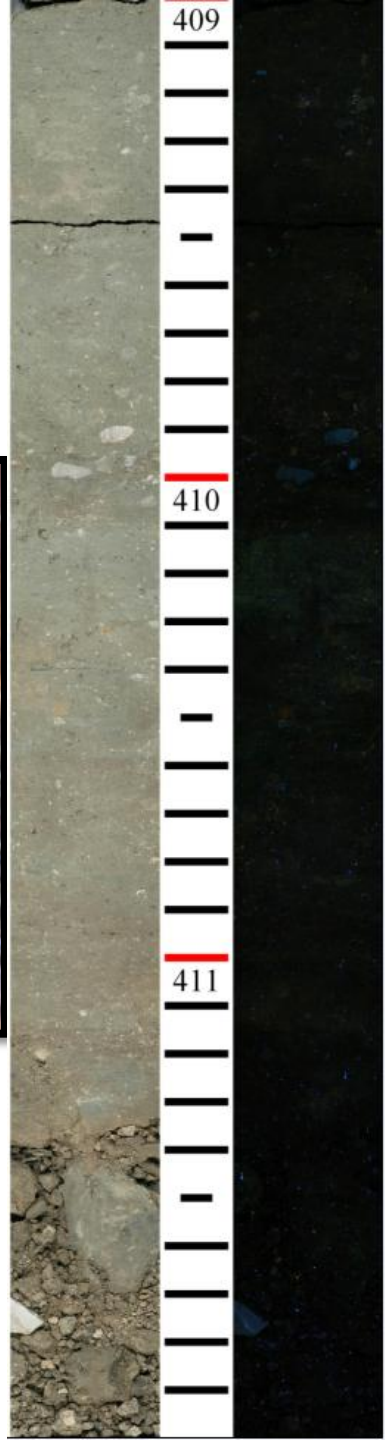






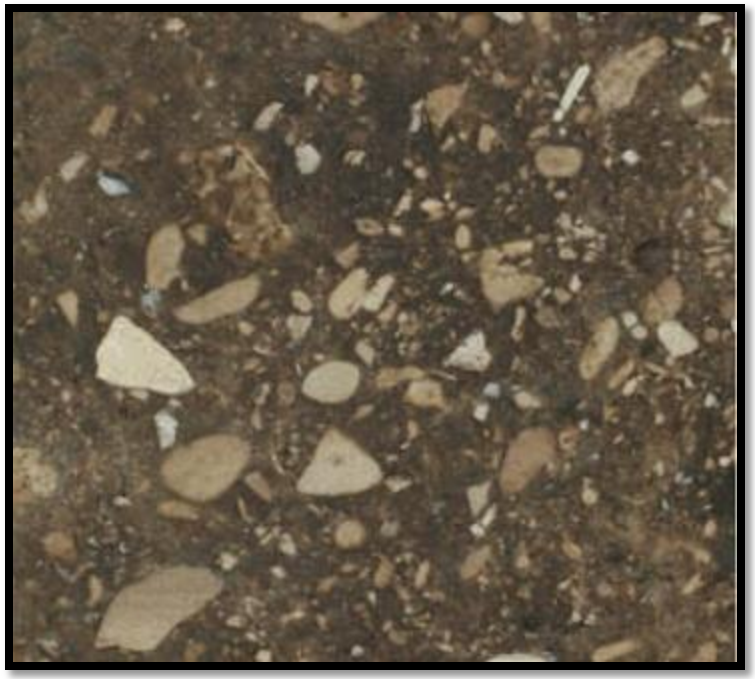
Paleosol- Overlying Unit

- Description: Green-gray massive silty claystone; matrix-supported subangular to well rounded clasts, calcite cement and vesicles
- Textures: massive
- Framework grains: clay to silt
- Clasts: matrix-supported angular to rounded pebbles, mostly diatomite; rare black chert; one >6” diameter limestone clast with vugs
- Other: calcite fibers (root casts); streaks of pure clay
- Cement: calcite cement
- Structures: structureless, no sorting, no grading
- Thickness Range: 15’



C_S-Conglomeratic Sandstone

- Description: Orange-brown massive matrix-supported conglomerate. Clasts are subangular to subrounded; mostly tan diatomite
- Textures: massive; some rare horizontal zones, generally 2-4” thick, of more conglomeratic, more silty, or more sandy rock; contacts to these zones are conformable and diffuse
- Framework grains: silt and very fine-grained sand, possible low-volume clay
- Clasts: high volume of matrix-supported subangular to subrounded clasts; mostly tan diatomite, but also contains granitic clasts
- Other: a clast with straight edges and rounded corners of well sorted subrounded fine-grained sandstone; resembles toast
- Cement: well cemented, non-calcite
- Structures: structureless; no apparent grading
- Bed Thickness: N/A
- Thickness Range: 30’



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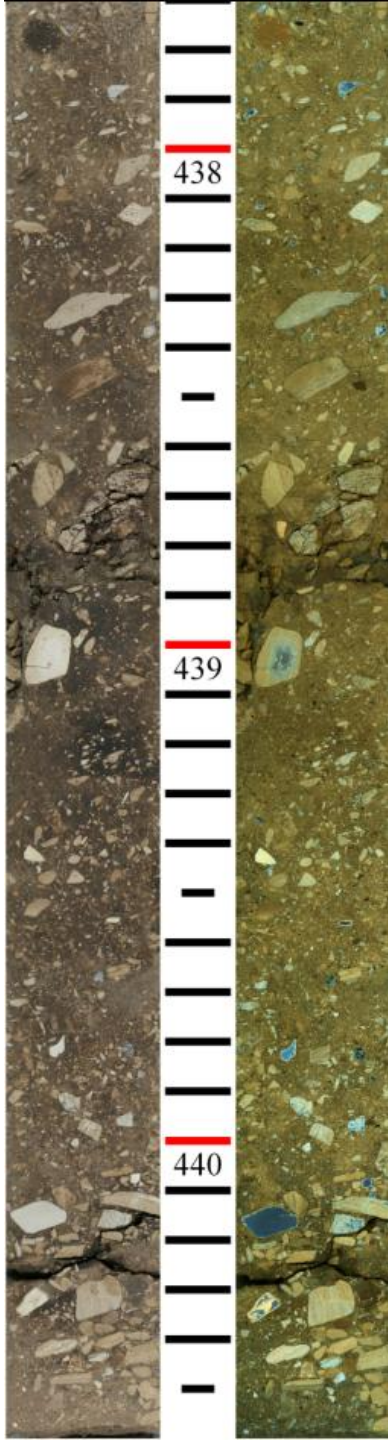
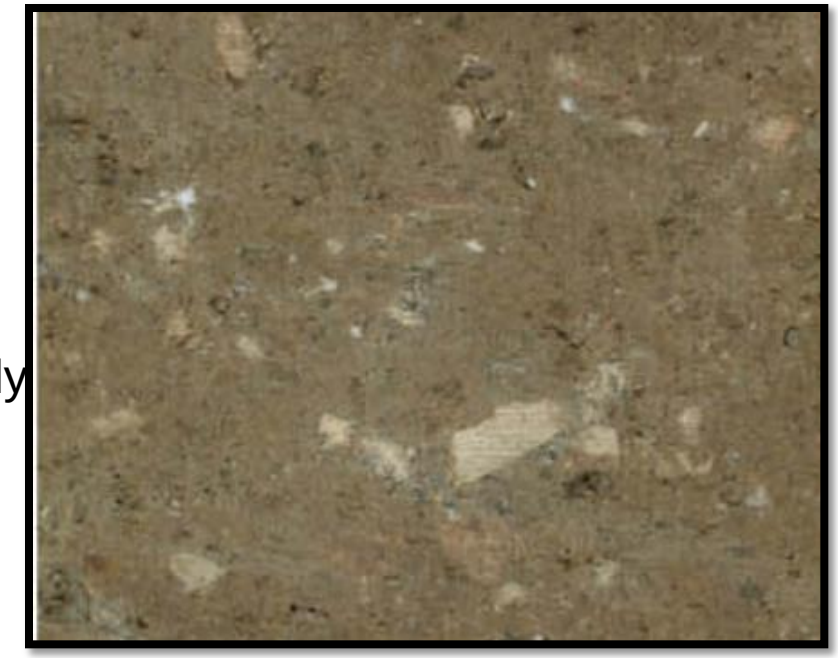


F_M-Pebbly Siltstone

- Description: Light-brown siltstone with matrix-supported angular to subrounded granules and pebbles (mostly tan and white diatomite)
- Textures: massive
- Framework grains: silt
- Clasts: matrix supported angular to subrounded pebbles and granules, mostly tan and white diatomite
- Cement: very well cemented, non-calcite
- Structures: structureless; no apparent grading
- Bed Thickness: N/A
- Thickness Range: 2”-15’



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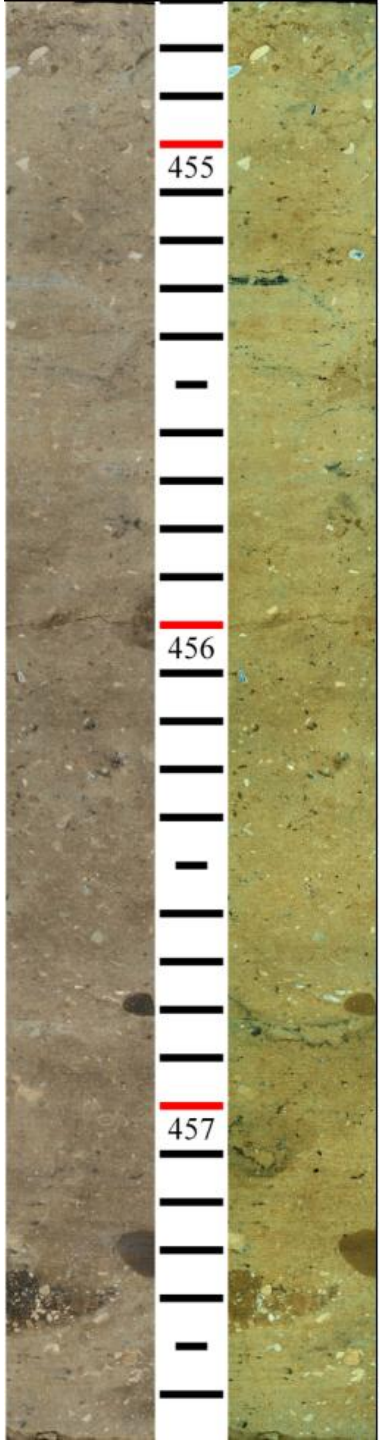
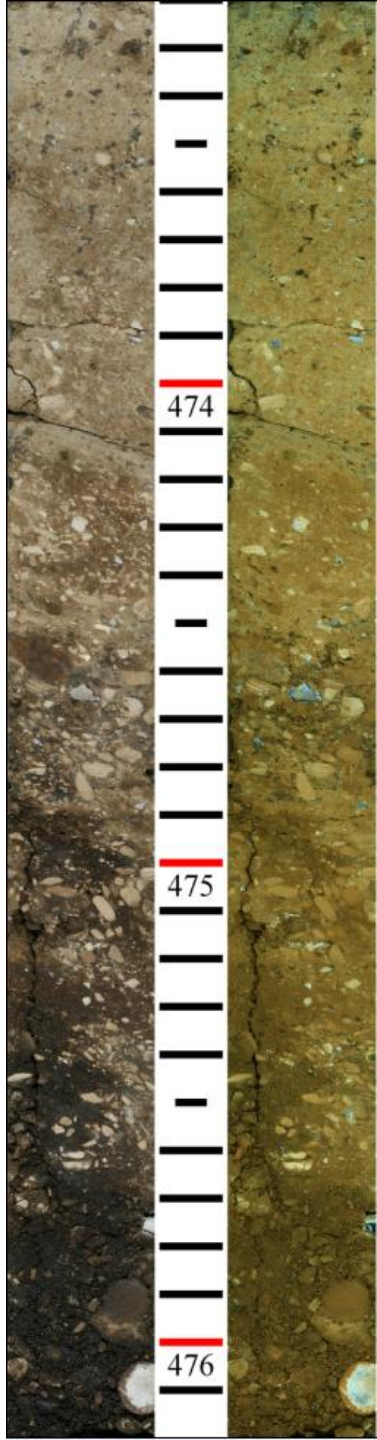


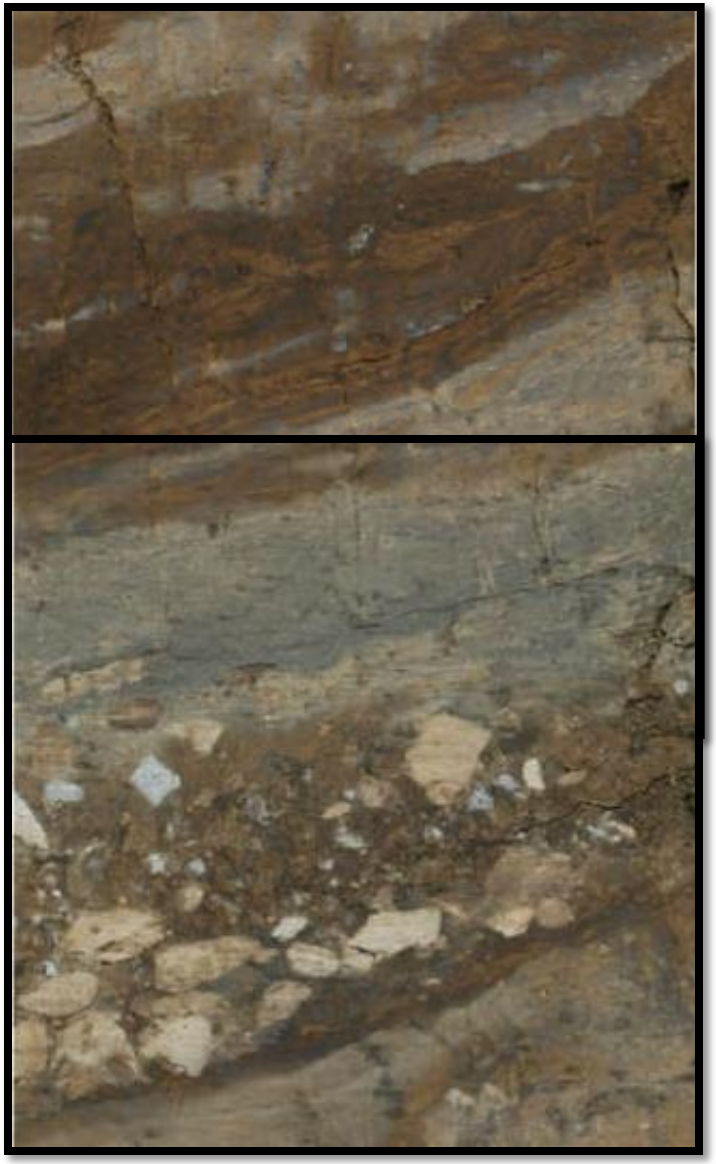
S_C- Sandy Conglomerate

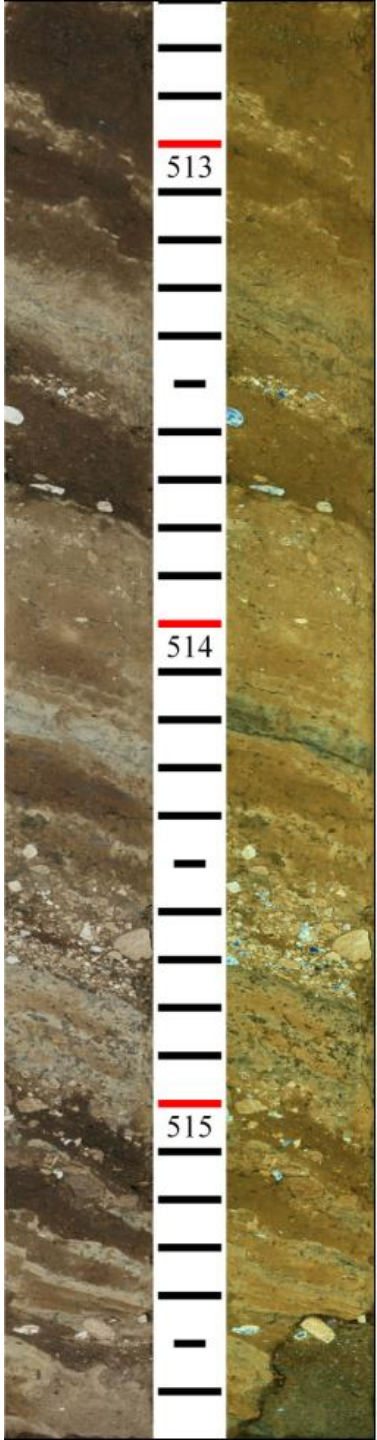
- Description: Massive coarse-grained sand with high volumes of rounded diatomite clasts
- Textures: massive, with some beds of more pebbly material; poorly sorted
- Framework grains: coarse-grained sandstone, primarily quartz
- Clasts: rounded, with some subangular, tan and white diatomite.
- Cement: poorly consolidated
- Structures: structureless; no apparent grading
- Bed Thickness: N/A
- Thickness Range: 2’-8’



S_W-Interbedded Sandstone & Claystone

- Description: Alternating wavy beds of clay and fine-grained sand, characterized by gradational contacts and soft- sediment deformation
- Textures: wavy; some laminations present in clays and sand; occasional pebble-rich beds (up to 1” thick)
- Framework grains: clay to very fine-grained sand
- Clasts: rounded to subangular pebbles; pebbles occur predominantly in pebble beds
- Other: apparent bedding dip of 30^0
- Cement: well cemented; non-carbonate
- Structures: soft sediment deformation including flame structures, dish structures, small-scale faults. Intercalation of sand into clay
- Bed Thickness: 1in
- Thickness Range: 2”-5’

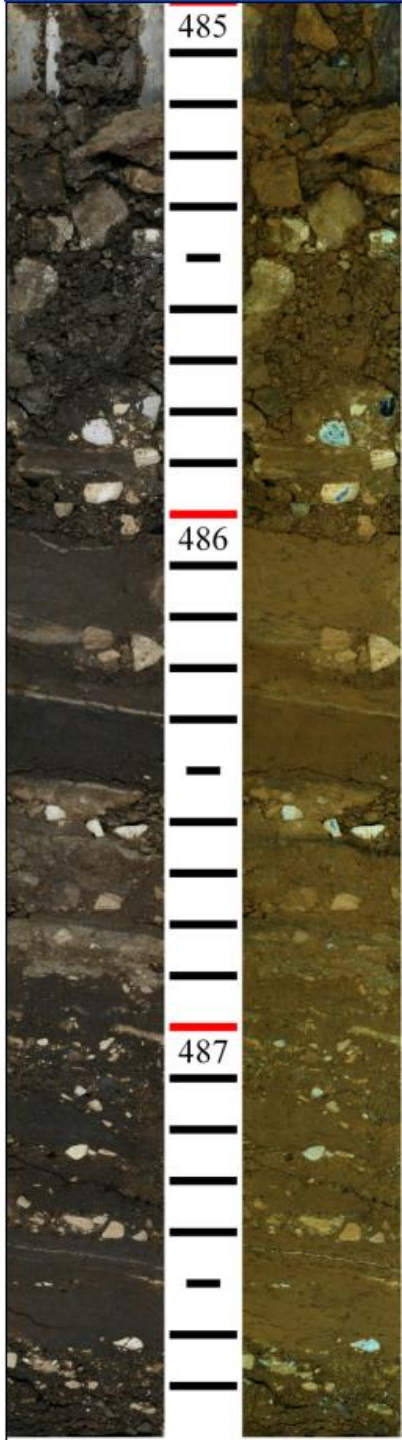




S_P-Interbedded Sandstone and Conglomerate

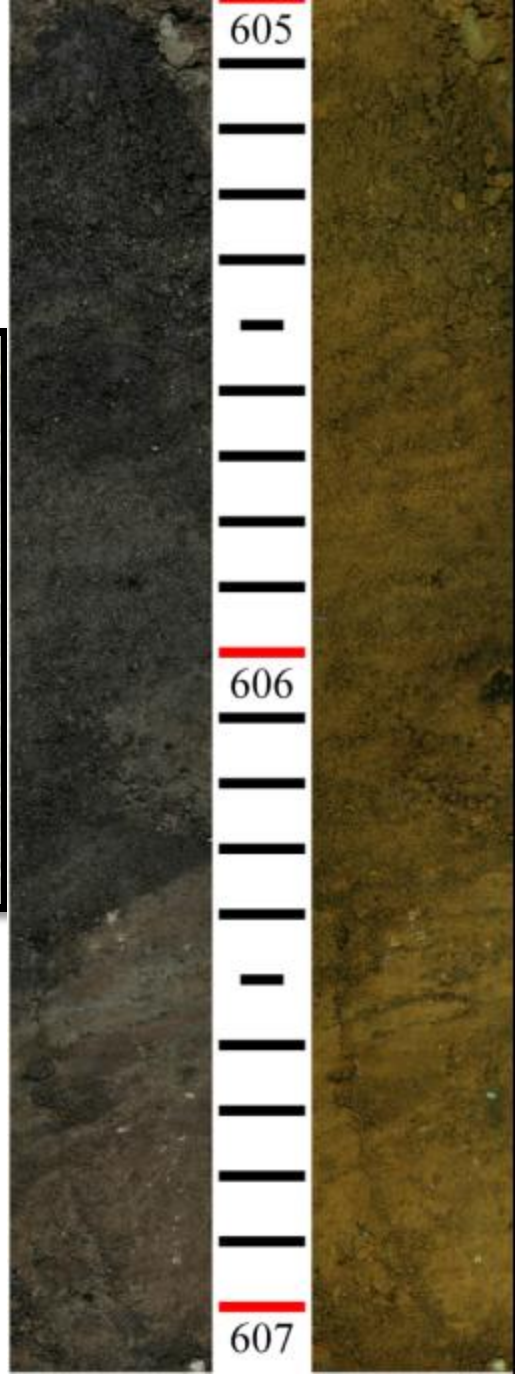
- Description: Graded fine- to coarse-grained sandstone punctuated by beds of granules and beds of pebbles
- Textures: local sand-rich laminations, some wavy texture within fine-grained sands
- Framework grains: sub-to well rounded fine- to coarse-grained sands
- Clasts: subrounded to subangular white diatomite clasts; generally restricted to pebble beds
- Other: mud drapes and very thin (2mm) clay beds
- Cement: consolidated but no cementation
- Structures: low- to high-angle cross-stratification and cross-bedding; normal grading. Dip is horizontal to 20^0
- Bed Thickness: 1”- 1’
- Thickness Range: 1-12’

1in



S_{BG}- Oil Sand

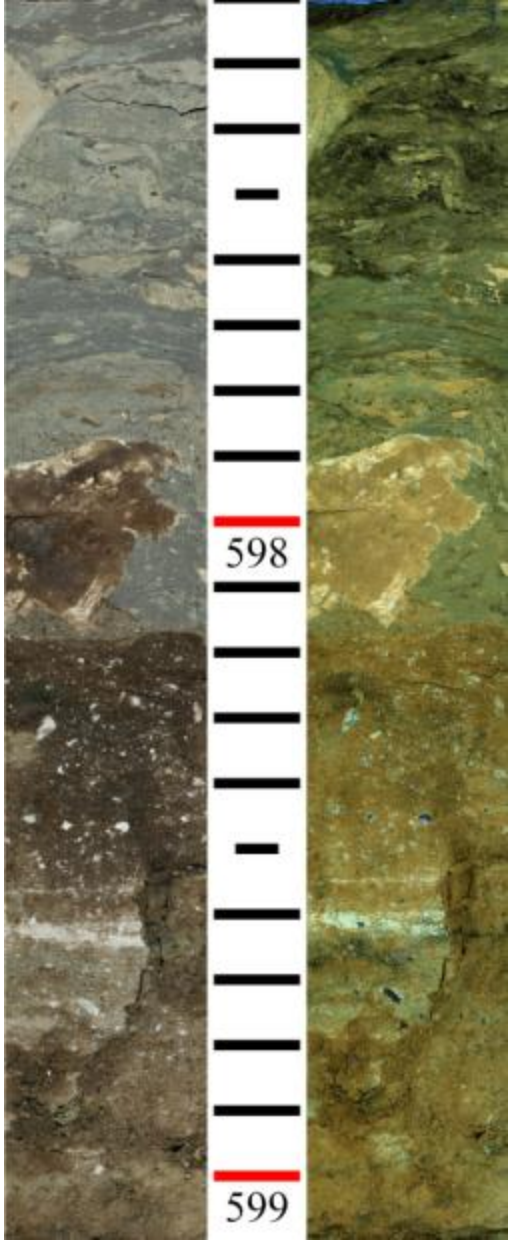
- Description: Massive, coarse-grained, well rounded, oil-stained sand
- Textures: massive, well sorted
- Framework grains: coarse-grained sandstone, primarily quartz
- Clasts: no clasts present
- Cement: unconsolidated
- Structures: no apparent grading
- Bed Thickness: N/A
- Thickness Range: 2’



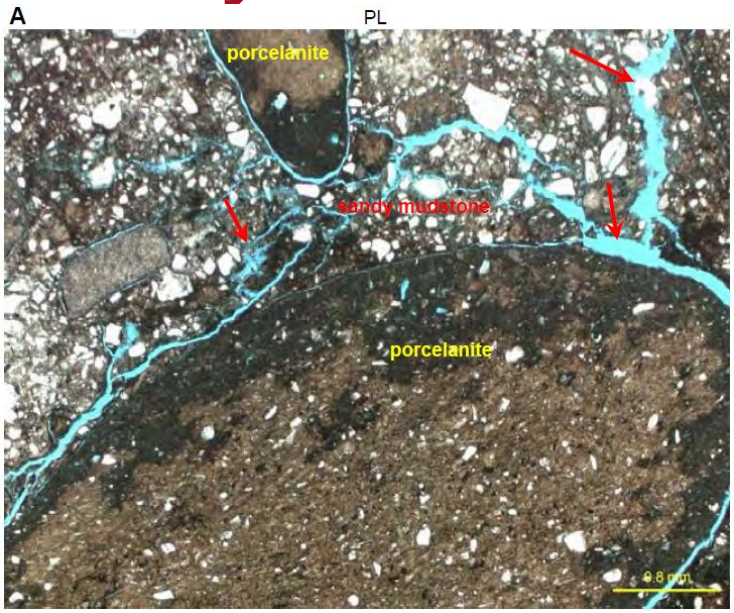
M_L-Claystone

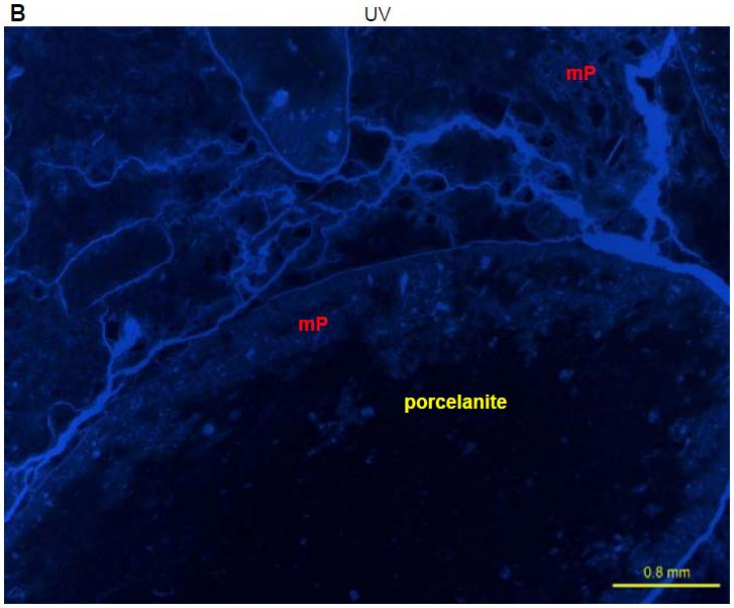
- Description: Laminated blue-gray and white claystone
- Textures: wavy laminations; distorted due to soft sediment deformation
- Framework grains: clay
- Clasts: no conglomeratic clasts present
- Other: at 598’ a calcite-cemented chunk of fine-grained sandstone is suspended at the base of the claystone
- Cement: consolidated clay, no calcite
- Structures: soft-sediment deformation structures (i.e., escape structures, slump structures)
- Bed Thickness: laminated
- Thickness Range: 8”-1’

1in

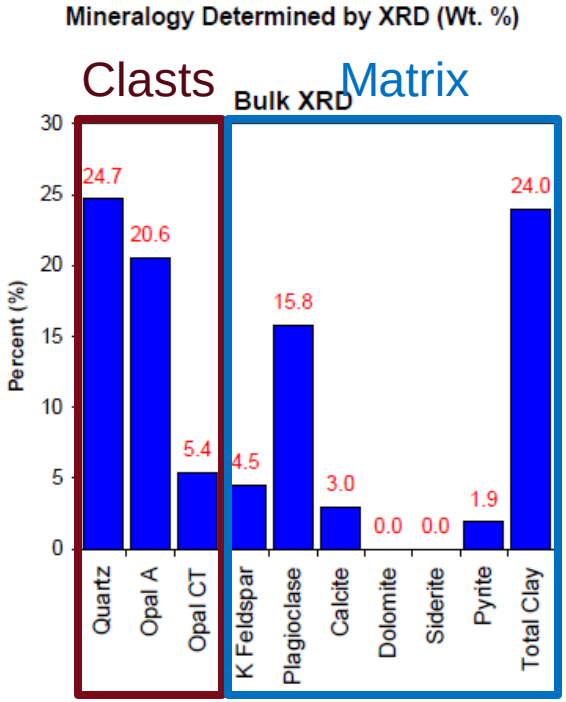


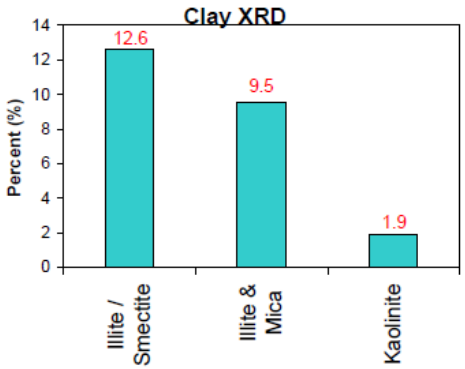
Pebbly Siltstone – Thin Section/SEM/XRD



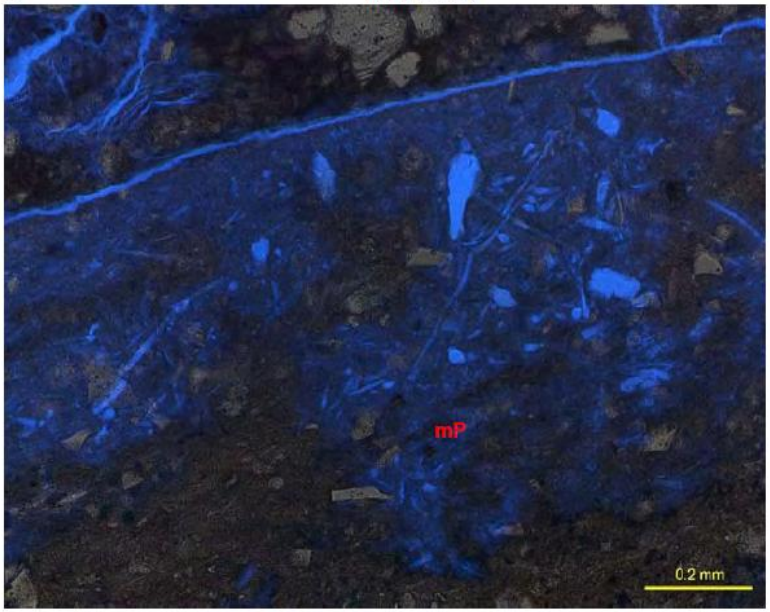


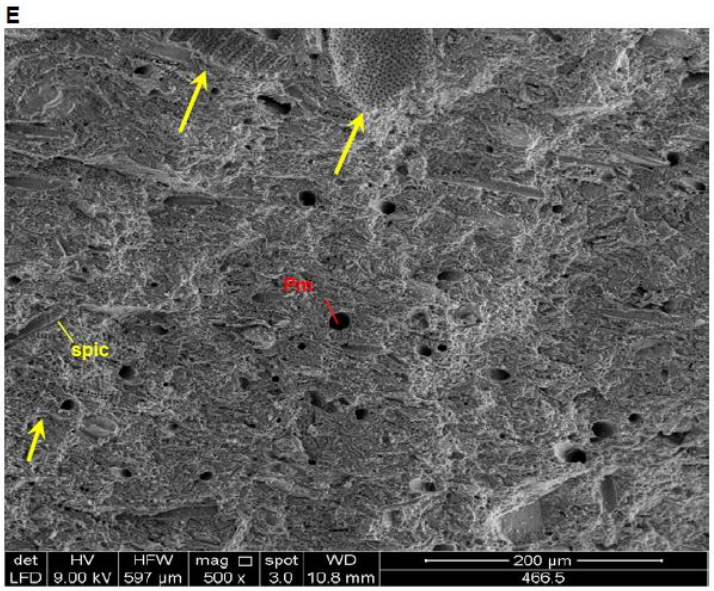
- Matrix-supported conglomerates (C_s F_S M_C) are the most abundant facies, accounting for 70% bulk rock volume of recovered core

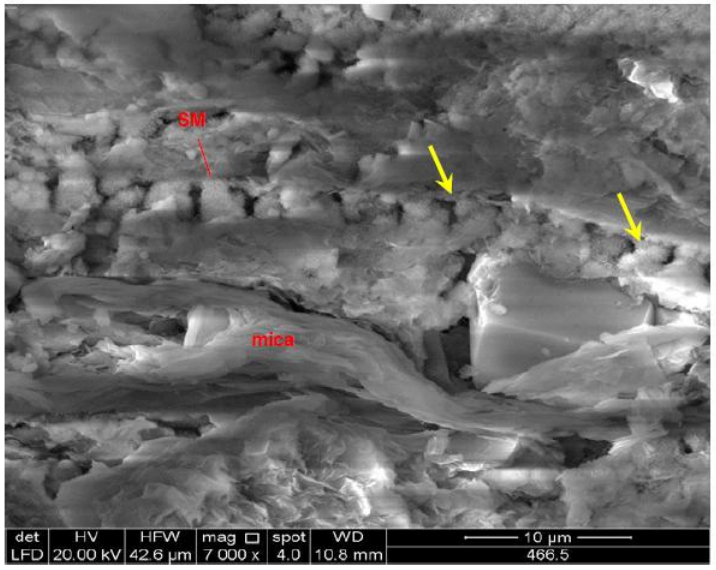




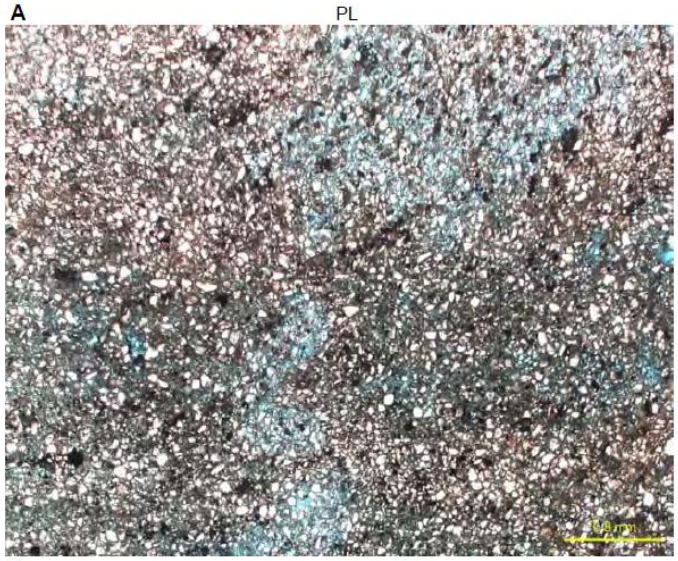
Pebbly Siltstone - Thin Section/SEM/XRD



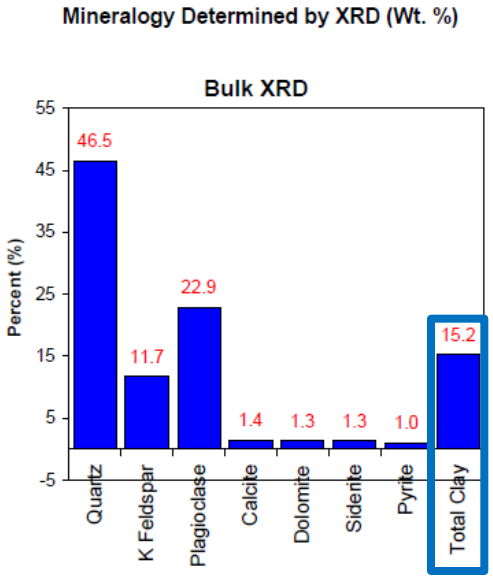


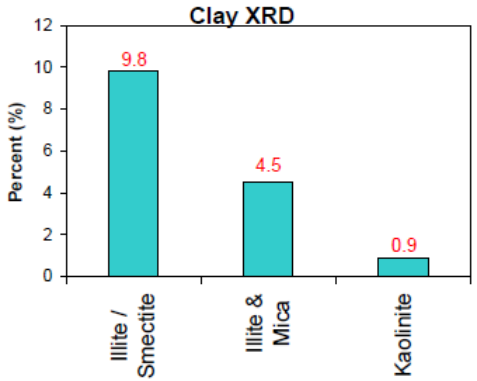


Interbedded Sandstone & Conglomerate- Thin Section/SEM/XRD

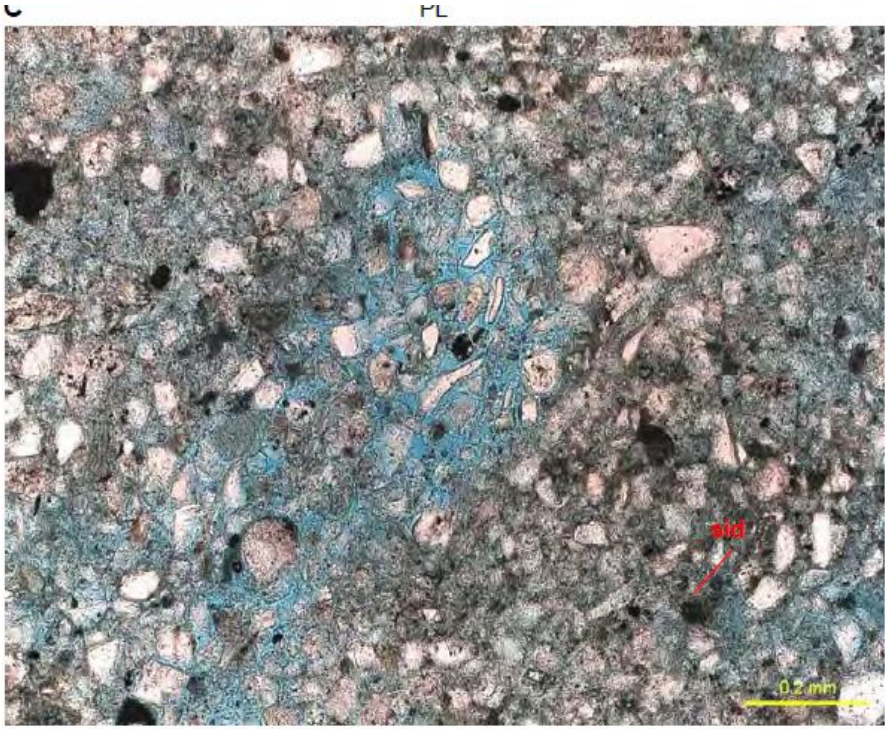


- Interbedded sandstone and conglomerate, 17% bulk rock volume of recovered core
- Sandstone contains 15% clay

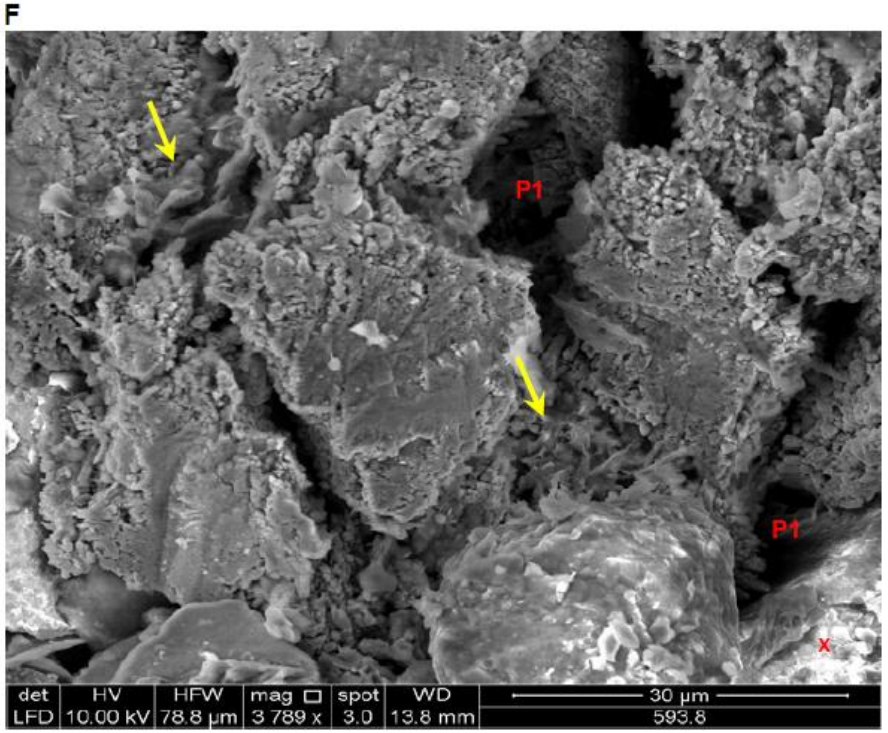




Interbedded Sandstone & Conglomerate- Thin Section/SEM/XRD



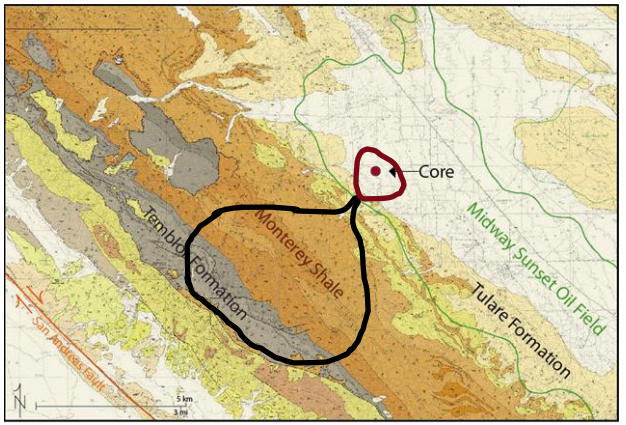
High-Porosity sandstone

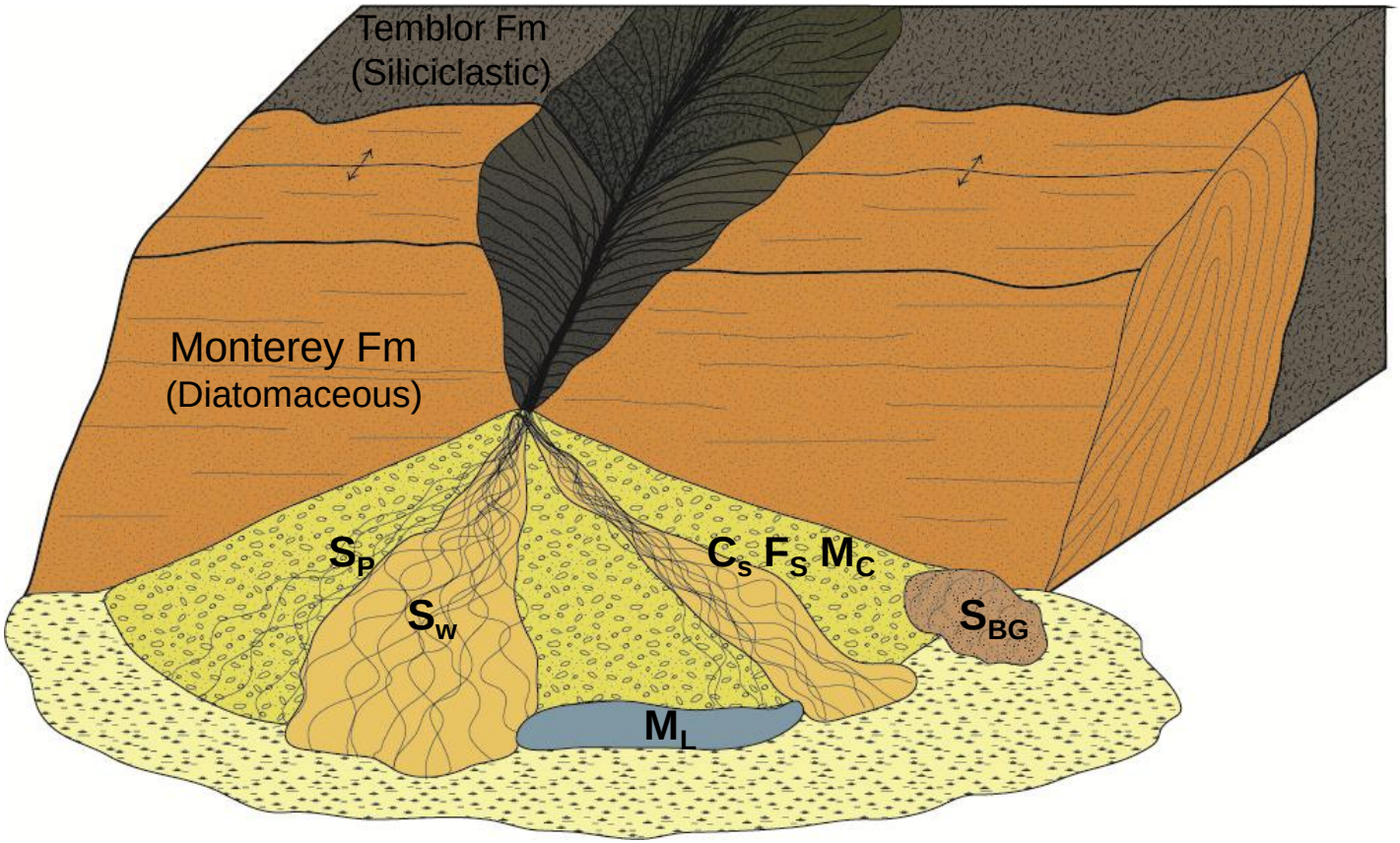


Intergranular pore spaces are filled with detrital clays

Depositional Environment Interpretation

- Depositional environment - clay-rich alluvial fan
- Siltstone conglomerates - debris flows
- Sand facies - fluvial channels
- Mudstones - ephemeral lakes or overbank fines
- Oil Sand – eolian dune
- The sediment sources for this alluvial fan are both fine-grained





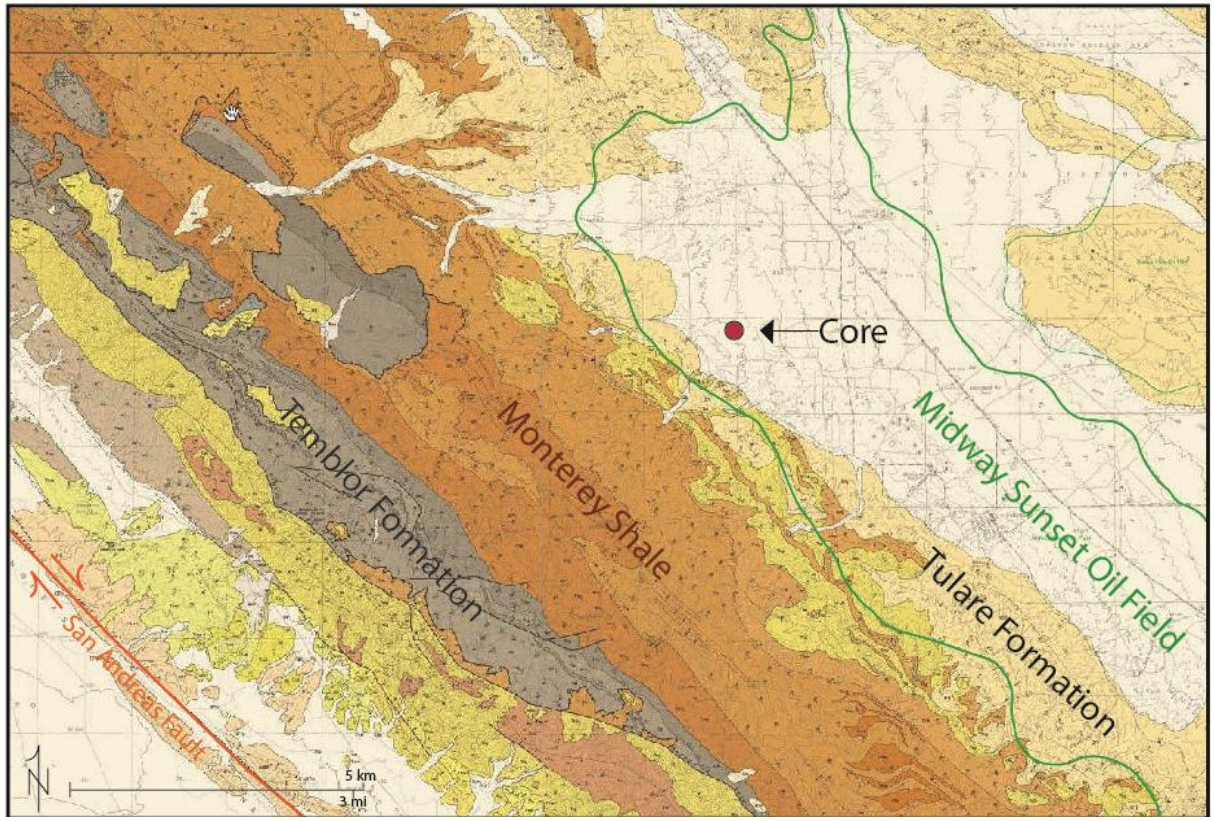
Dual Sediment Provenance

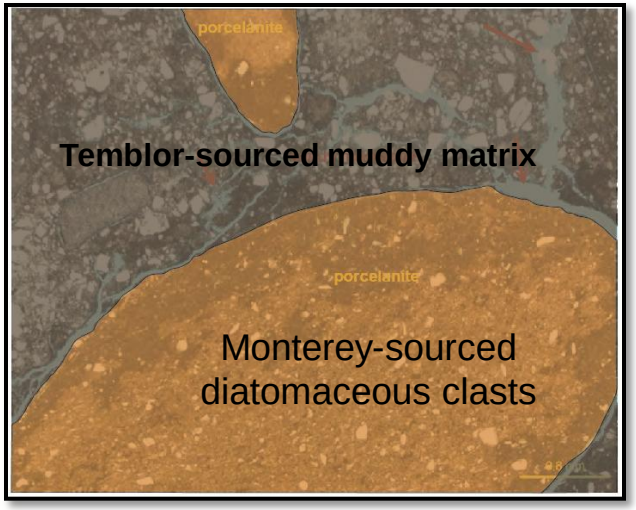
Formation	Temblor Formation	Monterey Formation
	Siliciclastic	Diatomaceous
Depositional Environment	Deep Marine Turbidities	Deep Marine
Age	Lower Miocene-Oligocene	Middle Miocene
Rock Types	Sandstone, light gray, coherent, bedded to massive, arkosic, with local calcareous concretions	Belridge Diatomite, white, soft, punky, faintly laminated.
	Clay shale or claystone, gray, crumbly with ellipsoidal fracture parallel to bedding, micaceous.	McLure Shale Member, siliceous shale, thin bedded, platy, hard, porcelaneous, brittle.

Descriptions from T.W. Dibblee 2005 “Geologic Map of the Fellows Quadrangle”

Conclusions

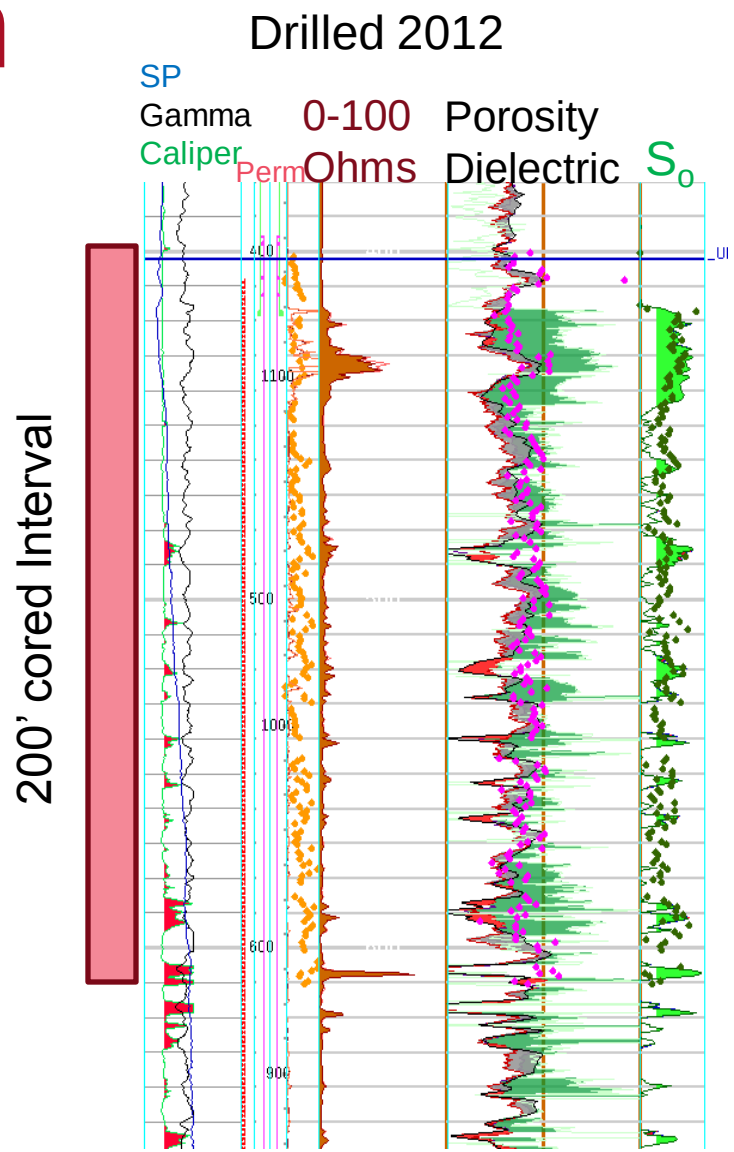
- Dual provenance from Temblor Formation and Monterey Formations results in siliciclastic reservoir with diatomaceous clasts.





Log Interpretation

- Diatomaceous clasts cause low resistivity high porosity log signature
- Typical siliciclastic log signature is masked by clasts



Implications

- Siliciclastic reservoirs disguised by diatomite clasts could occur anywhere you have Monterey Formation as one of multiple sediment provenances
- Potential for unrealized reserves is ubiquitous over Southern California

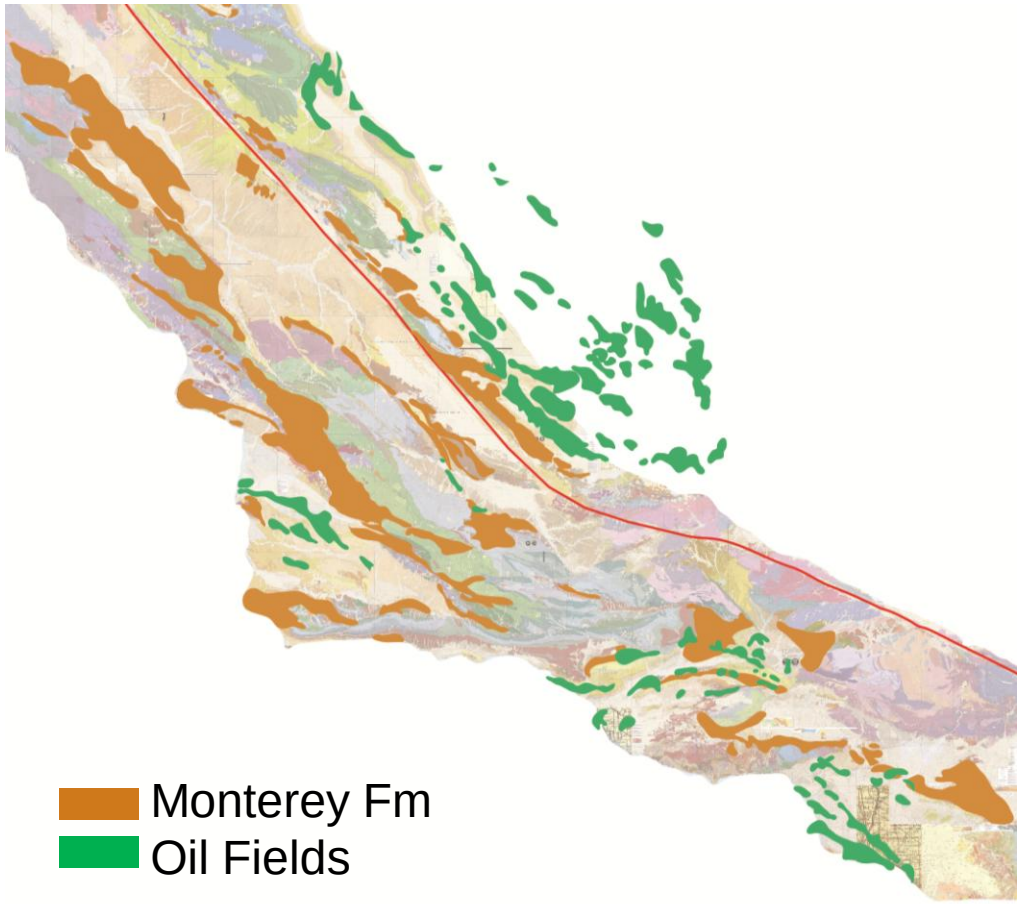


Image modified from USGS National Geologic Maps Database

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