

Permeability Anisotropy Related to Braided Fluvial Facies Architectural Elements in Middle Boggy Formation, Middle Pennsylvanian, McIntosh County, Oklahoma*

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Abstract

Permeability of sedimentary deposits varies with different facies and subfacies and is significantly affected by variations of sediment texture and fabric. This research is to evaluate the relationship between permeability anisotropy and facies architectural elements of braided fluvial facies in the middle Boggy Formation (Middle Pennsylvanian, Desmoinesian Series) in the Lake Eufaula area (McIntosh County). Three fluvial storeys are recognized in the study outcrop. Six lithofacies and up to sixth order of bounding surfaces are identified based on Miall's (1996) facies architecture scheme. Porosity of core plug samples with different lithofacies is relatively uniform (14–19%). Core plug results show relatively higher permeability values in the parallel to cross strata strike orientation than parallel to dip and perpendicular to dip orientations. Low probe permeability results suggest the unreliability for permeability anisotropy characterization. Diagenetic overprint on grain fabric and the dual pore system brings more complexity in affecting the preferred fluid flow direction in thin section examination. Micro-CT imaging provides 3-D visualization of pore networks and aids in understanding pore conductivity at the scale of core plugs. Middle Boggy braided fluvial facies architecture example demonstrates the control particular architectural elements play in permeability anisotropy and provides insights to understanding reservoir scale heterogeneity issues.

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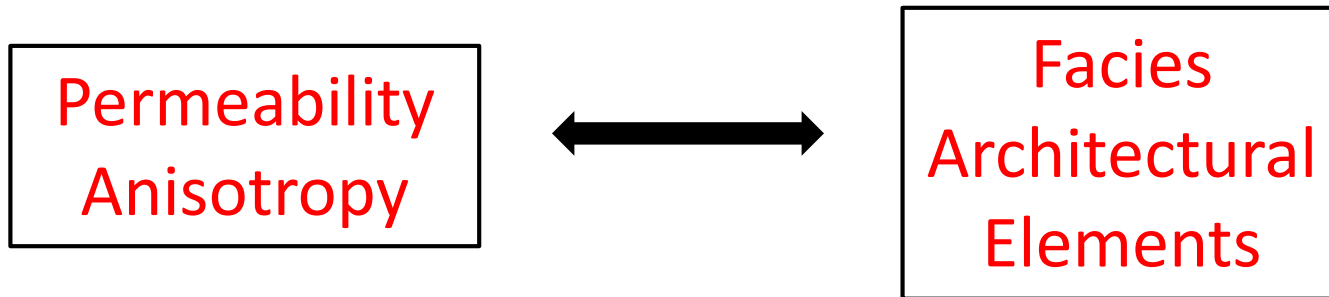
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University of Tulsa

OUTLINE

- Introduction
- Facies Architecture
- Porosity and Permeability Analysis
- Pore Network Characterization
- Conclusions

>> Goal and Motivation

Braided fluvial facies in the middle Boggy Formation –



The significance of the research is to better understand the development of permeability variation in complex reservoirs.

>> Goal and Motivation

Definition of Permeability (K) Anisotropy: The magnitude of permeability at a given point changes with the direction of fluid flow through the rock.

(Meyer, 2002)

- The variations of sediment texture and fabric influence the spatial variation of permeability
- K is typically measured vertical and horizontal to horizontal strata boundaries for modeling purposes.

For the case of inclined strata, such as cross-bedded strata:

- May not fully capture the nature of K anisotropy
- Should be studied directly related to orientations of facies architectural elements

>> Study Area

Onapa quarry, McIntosh County,
east-central OK

5 miles south of Checotah, OK

Quarry operations cover about 71
acres: ~ 3 units of a 9-spot drilling
pattern.



System	Series	Group		Formation	Member	
					Subsurface	Surface
Pennsylvanian	Desmoinesian	Krebs	Cherokee	Boggy	Red Fork sandstone	Taft Sandstone
					Inola Limestone	Inola Limestone
					Bartlesville sandstone	Bluejacket Sandstone
				Savanna	Brown Lime	

Study stratigraphic interval is a 35 ft thick interbedded medium sandstone and silty shale within the basal middle Boggy (Red Fork and Taft Sandstones)

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>> Facies Architecture

Facies architecture is a hierarchy of architectural elements and each element is comprised of genetically related rock strata.

(Allen, 1983; Miall, 1996)

Facies architecture hierarchy used in this study arranged from smallest to largest spatial dimensions:

- lamination set (1st order)
- simple lamination coset (2nd order)
- accretionary phases (3rd order)
- geometry of macroforms (4th order)
- major sand sheets (5th order)
- member or submember level (6th order)

>> Facies Architecture

2nd-order lithofacies elements:

- Sr (ripple cross laminated sandstone)
- Sp (planar cross-bedded sandstone)
- Sh (horizontal lamination sandstone)
- St (small-scale trough cross-bedded sandstone)
- St (dune-scale trough cross-bedded sandstone)
- Sl (low angle stratified sandstone)
- Sm (structureless sandstone)

Sample Locations ① through ⑦



>> Facies Architecture

Fluvial storey: consists of channel belts deposited at an equivalent stratigraphic height.

Architectural elements bound by 4th- and 5th-order surfaces:

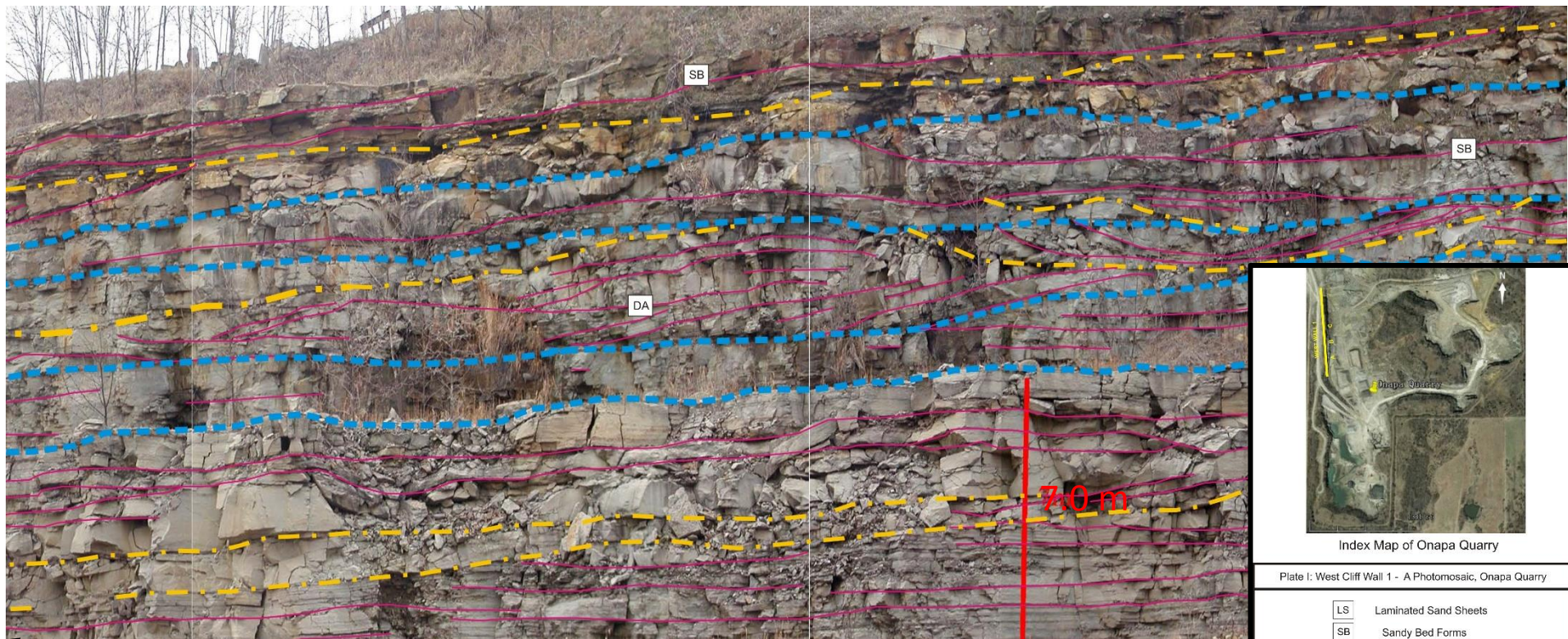
Channel Belts (CH)

Sandy Bed Forms (SB)

Downstream Accreting Macroforms (DA)

Lateral Accretion Deposits (LA)

Laminated Sand Sheets (LS)



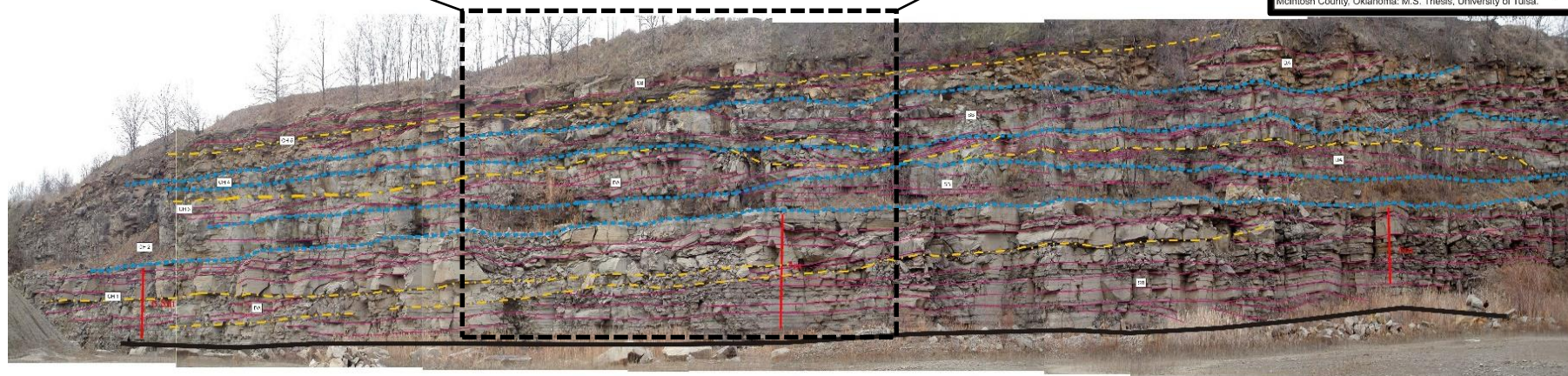
Index Map of Onapa Quarry

Plate I: West Cliff Wall 1 - A Photomosaic, Onapa Quarry

- | | |
|------|---------------------------------|
| LS | Laminated Sand Sheets |
| SB | Sandy Bed Forms |
| DA | Downstream Accreting Macroforms |
| CH 2 | Designated Channel Elements |
| | 3rd-order Surface |
| | 4th-order Surface |
| | 5th-order Surface |
| | 6th-order Surface |

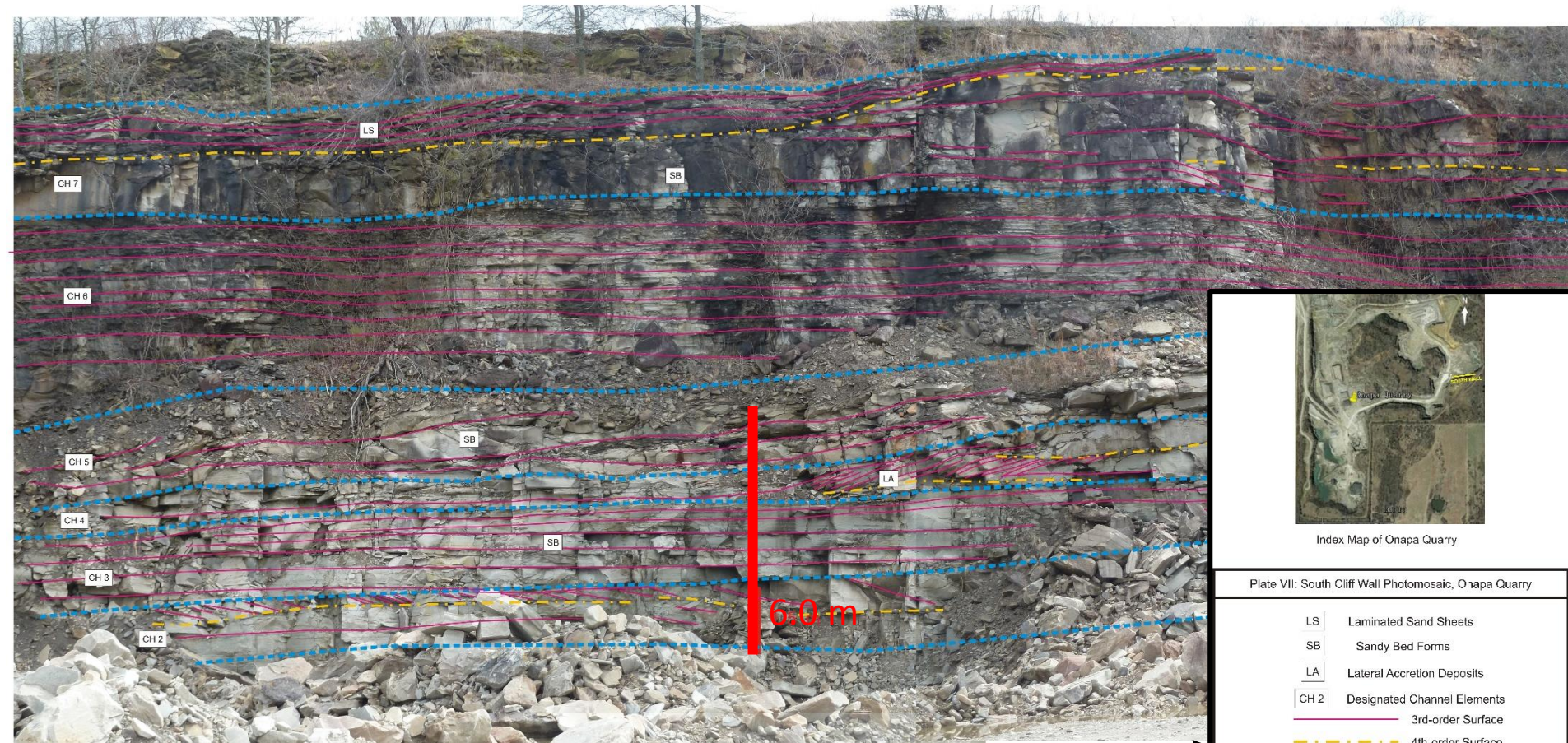
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West Cliff Wall I



2nd Storey

1st Storey



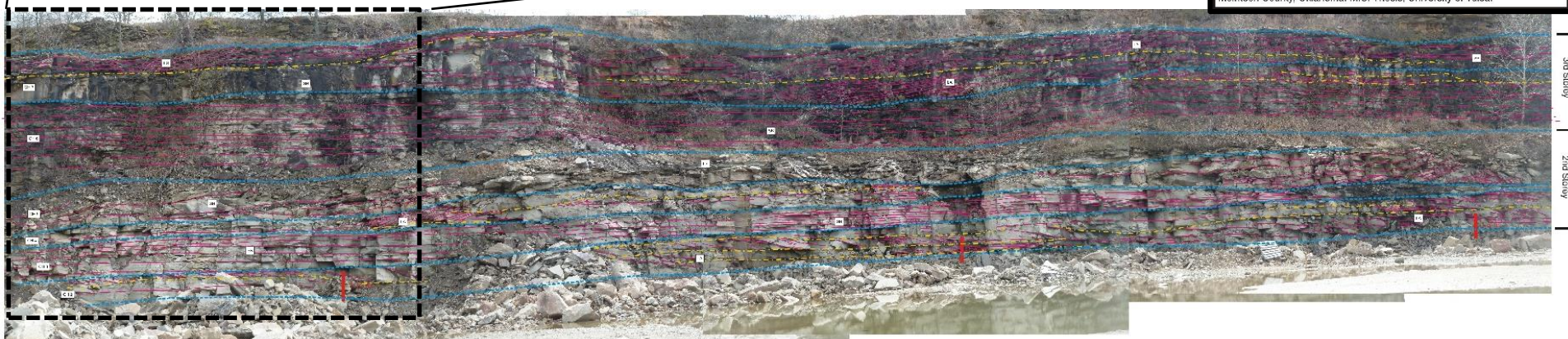
Index Map of Onapa Quarry

Plate VII: South Cliff Wall Photomosaic, Onapa Quarry

LS	Laminated Sand Sheets
SB	Sandy Bed Forms
LA	Lateral Accretion Deposits
CH 2	Designated Channel Elements
	3rd-order Surface
	4th-order Surface
	5th-order Surface

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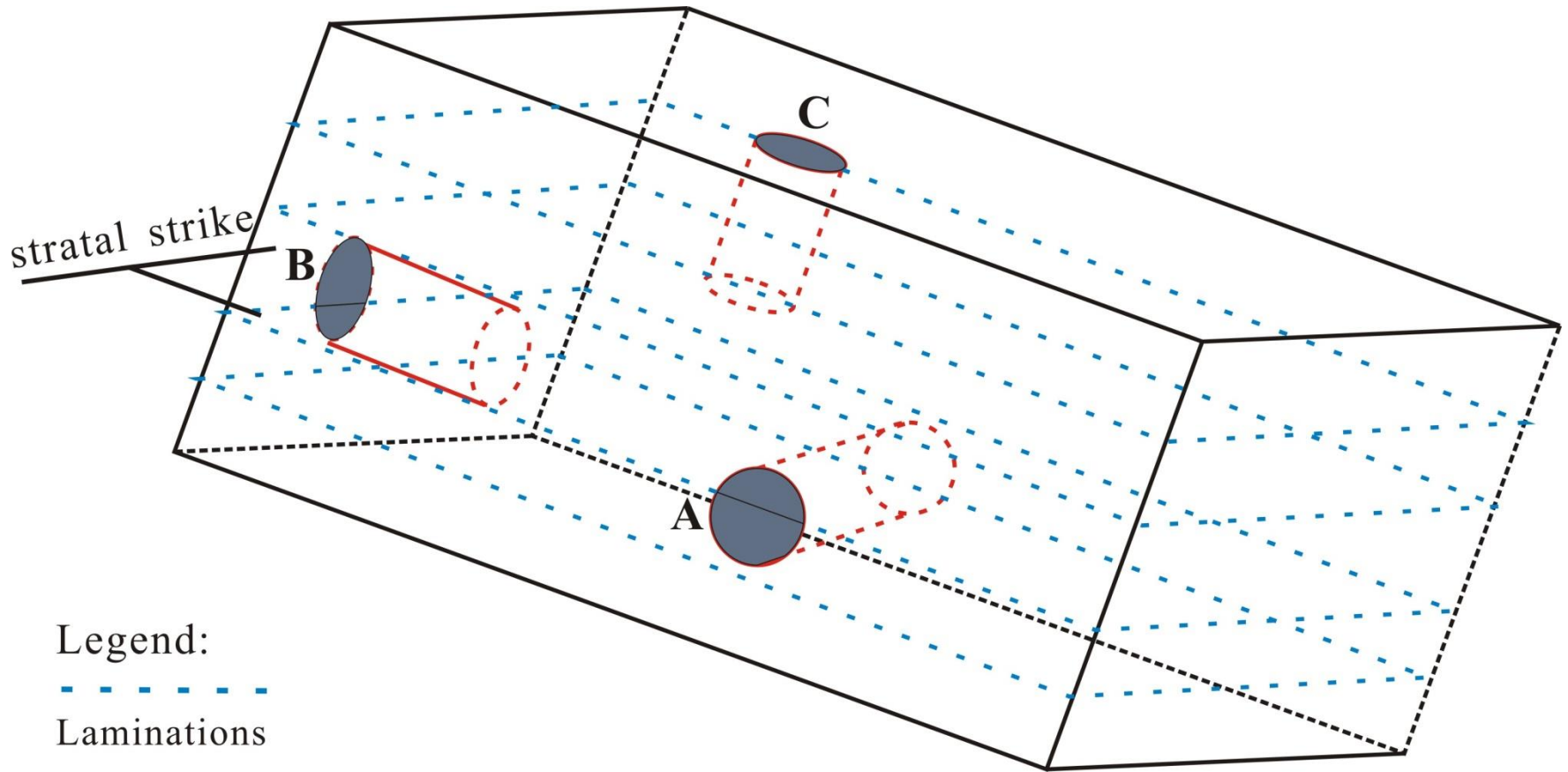
South Cliff Wall



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>> Porosity & Permeability



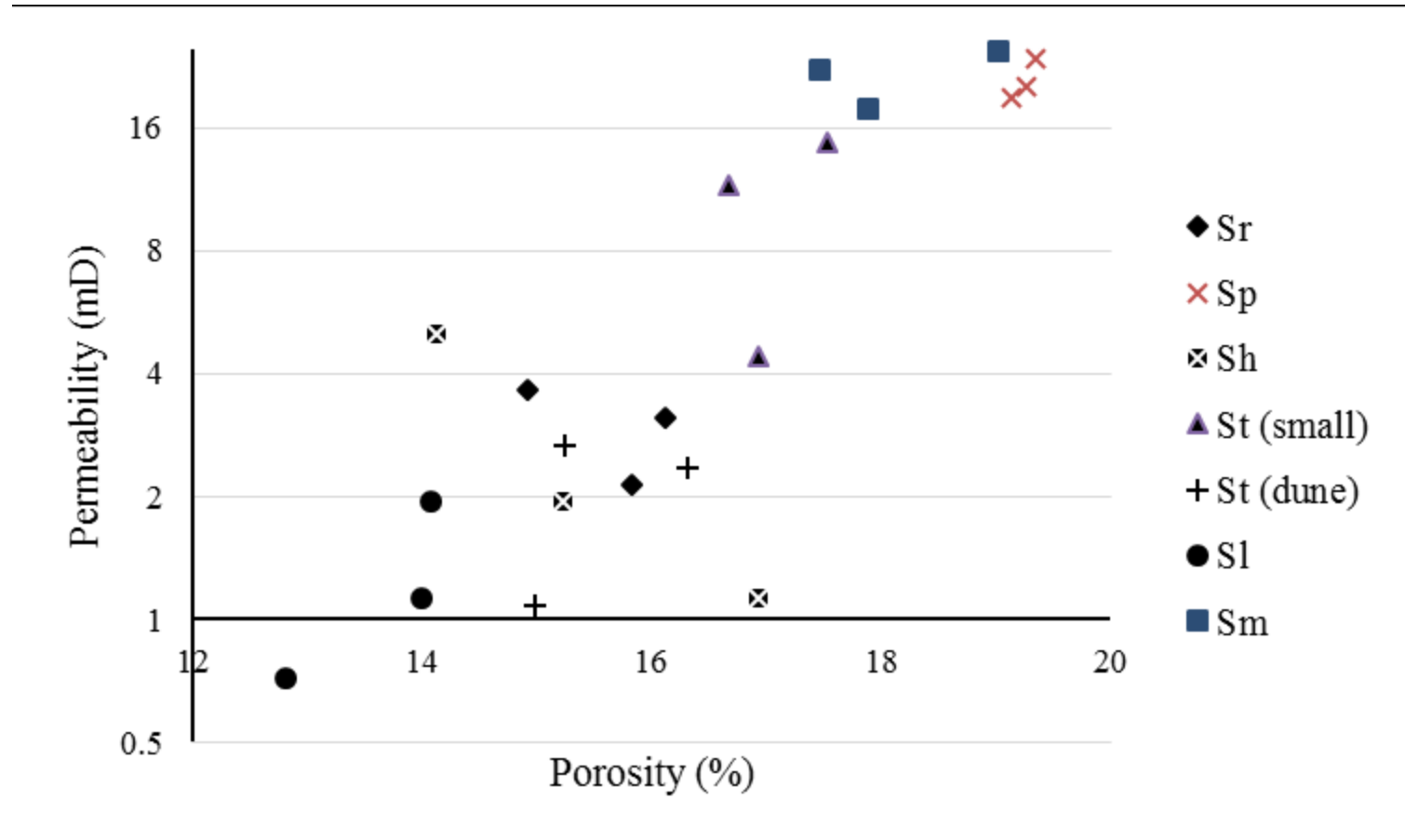
Field sample trimmed to provide architectural oriented surfaces and plugs

>> Porosity & Permeability

Porosity: 14~19%

Lithofacies	Permeability (md)					
	strike/⊥paleocurrent		dip/ paleocurrent		⊥strata	
	PlugK	ProbeK	PlugK	ProbeK	PlugK	ProbeK
Sr	3.65	NA	3.13	NA	2.14	NA
Sp	23.77	5.80	20.22	5.71	18.96	4.99
Sh	4.99	NA	1.94	NA	1.13	NA
St (small)	14.80	2.25	11.62	2.06	4.39	0.51
St (dune)	2.67	NA	2.34	NA	1.08	NA
Sl	1.13	NA	1.94	NA	0.72	NA
Sm	17.75	7.19	24.70	5.72	22.11	9.89

>> Porosity & Permeability



Relatively good porosity vs. low permeability?

>> Porosity & Permeability

Lithofacies	Min K/Max K
Sr	0.68
Sp	0.80
Sh	0.23
St(small)	0.30
St(dune)	0.40
Sl	0.64
Sm	0.72

- Carbonaceous and micaceous debris
- Grain texture and fabric
- Sampling position and scale
- Dual pore system, cementation, replacement, dissolution

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>> Thin Sections

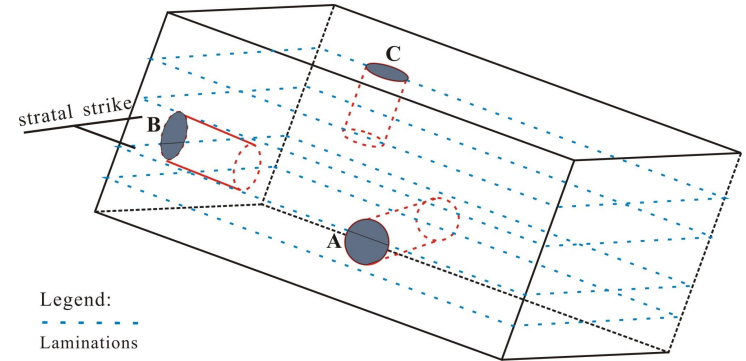
Four lithofacies were selected for thin section and micro-CT analysis.

Sr, Sp, Sh and Sm

Sp and Sm are sublitharenites;

Sr and Sh are litharenites.

(Folk, 1968)



Framework:

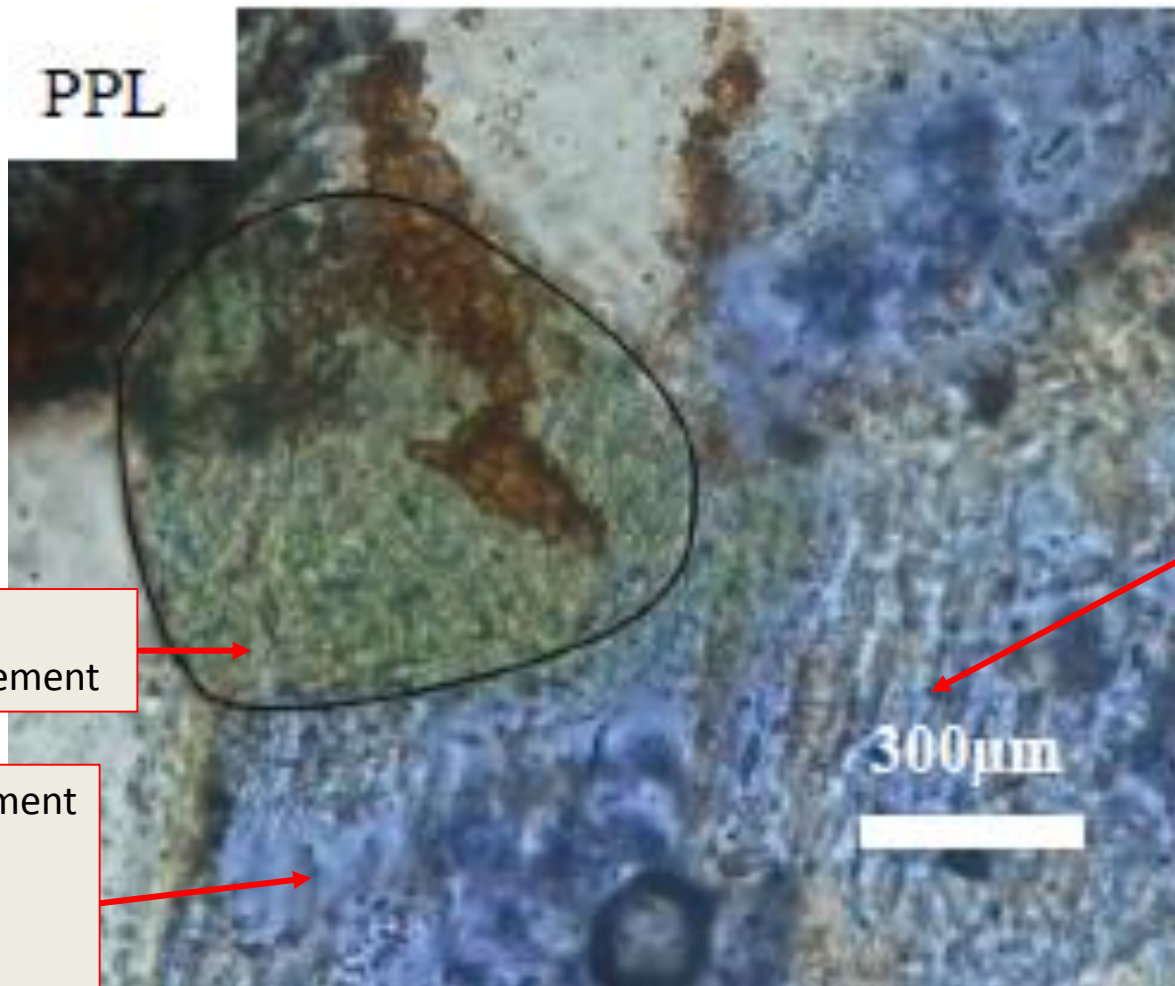
Quartz (Mono- and polycrystalline)

Feldspars (K-feldspar, plagioclase, microcline)

Sedimentary and metamorphic lithic fragments

Other minerals: zircon, tourmaline, muscovite, calcite, clays and opaque minerals, including magnetite, hematite and limonite

>> Thin Sections



Dual pore system in Sh.

>> Thin Sections

Thin section study suggests:

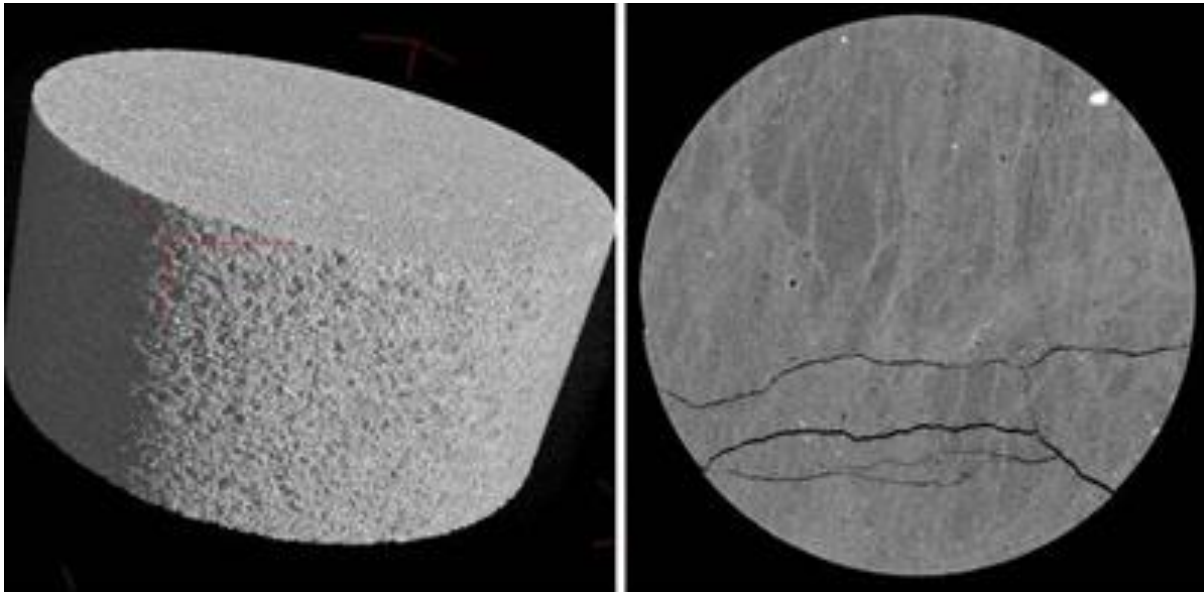
- Carbonaceous laminations in Sr and Sh.
- Framework texture in Sp and Sm.
- Rip-up pseudomatrix sedilithics occupying interparticle pore space.

Dual pore system has an impact on permeability –

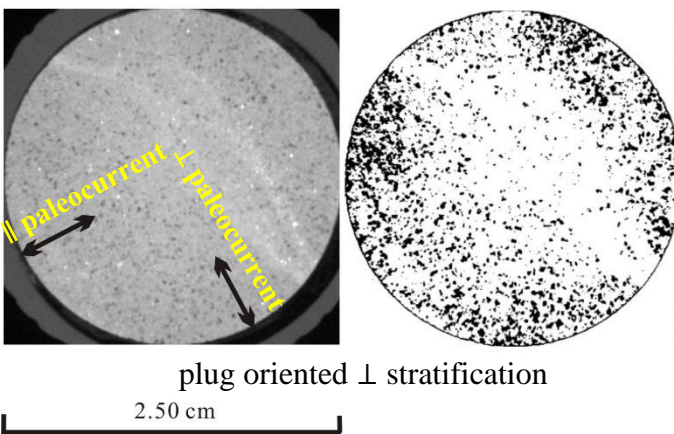
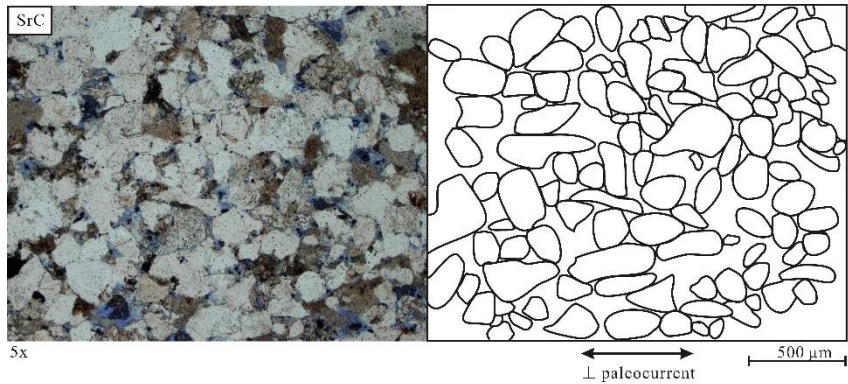
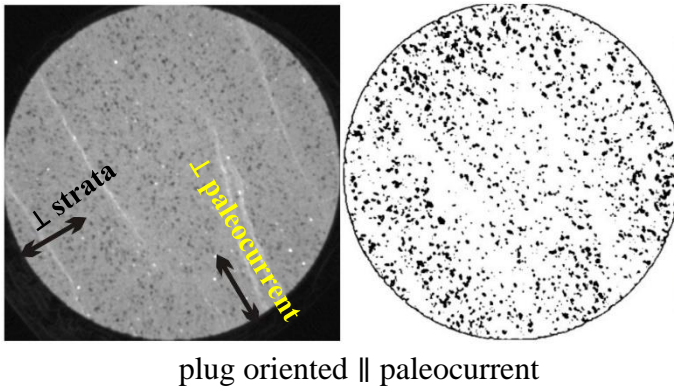
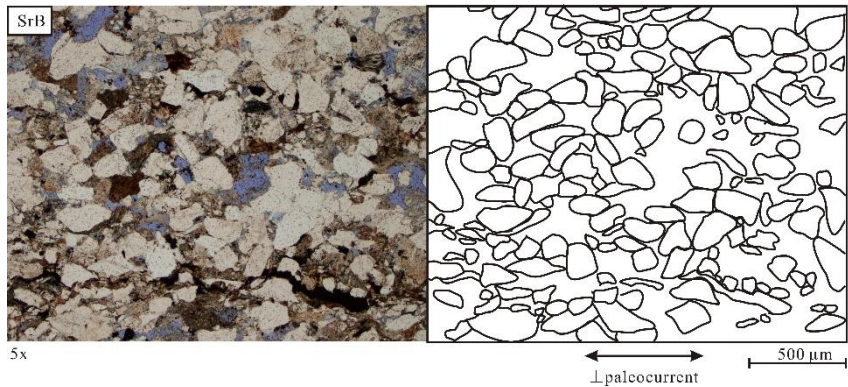
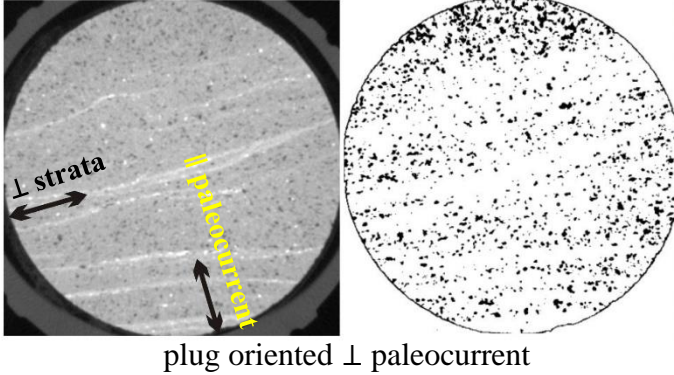
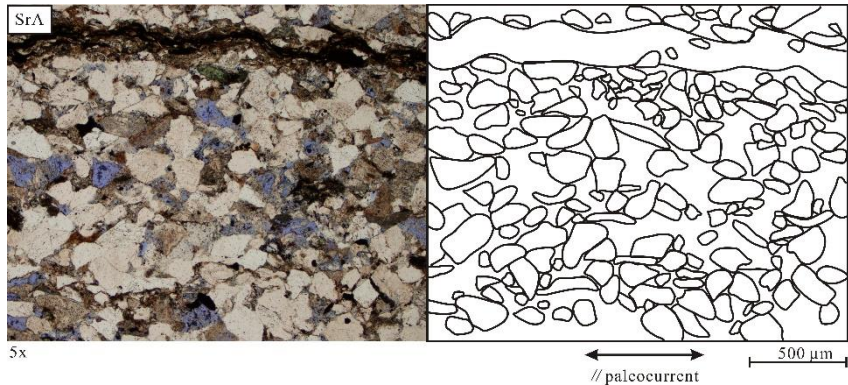
- Interparticle porosity reduced by
Quartz overgrowth, hematite coating, clay and calcite cement
- Intraparticle porosity created by
Feldspars replaced by clay; dissolved with sedimentary lithics

>> Micro-CT Imaging

Micro-computed tomographic (micro-CT) imaging is a useful method to scan a rock sample with focused X-rays of certain frequency.



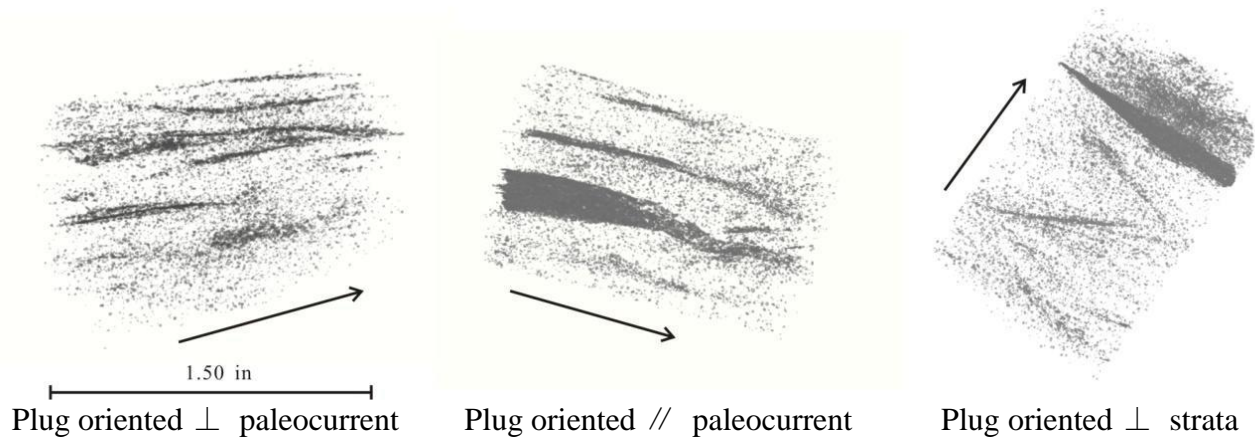
>> Integrated Thin Sections & 2D CT images



>> Micro-CT 3D Imaging

Plugs can be oriented to project cross sections in various directions by changing the threshold in the 3D Viewer window. Hence, higher density compositions, mostly fabric-selective hematite (possibly calcite) cement, were highlighted to show the internal cement distribution within core plugs.

Sr



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>> Conclusions

- Up to sixth order bounding surfaces, three fluvial storeys, Six lithofacies, five architectural elements bound by 4th- or upper order surfaces were recognized in the study area.
- Permeability in most lithofacies samples showed higher value in the orientation parallel to strike and lower in the orientation perpendicular to stratification, however, magnitude of K variation was not observed as expected.
- Thin sections and micro-CT imaging aided in identifying grain packing, diagenetic overprint and dual pore systems, which added complexity to K anisotropy.

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