Correlation of Red Beds and Evaporite Units between Surface and Subsurface: Addressing Challenges for Petroleum Geology*

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Abstract

Rock units consisting of both evaporites and siliciclastics, such as those of the Permian-Triassic of the midcontinental U.S., are of interest to the petroleum industry because they typically serve as seals, act as marker beds as seen in well logs, and pose drilling hazards. However, distinct differences in mixed evaporite-siliciclastic units between surface and subsurface have been overlooked. These differences present challenges in resolving stratigraphic nomenclature, lithologic correlation, and age determinations. Here we use observations of cores and outcrops from the Nippewalla Group of the southern midcontinent and the Opeche/Goose Egg/Spearfish Formations of the northern midcontinent to compare and contrast the sedimentology and stratigraphy at different depths and various spatial scales. We recognize multiple petrographic textures of rocks composed of both evaporites and siliciclastics and, from them, interpret a variety of depositional and diagenetic processes. Supplemental dissolution experiments add a semi-quantitative framework, allowing for estimation of loss of rock thickness and volume to late-stage, shallow diagenesis. Our observations lead to refinements in facies interpretations and diagenetic history as well as relation of seemingly different lithological units present in core and outcrop. This new knowledge yields solutions to the stratigraphic challenges of extrapolating outcrop data to the subsurface, and vice versa.

Reference Cited

Walker, T.R., 1967, Formation of red beds in modern and ancient deserts: GSA Bulletin, v. 78, p. 353-368.

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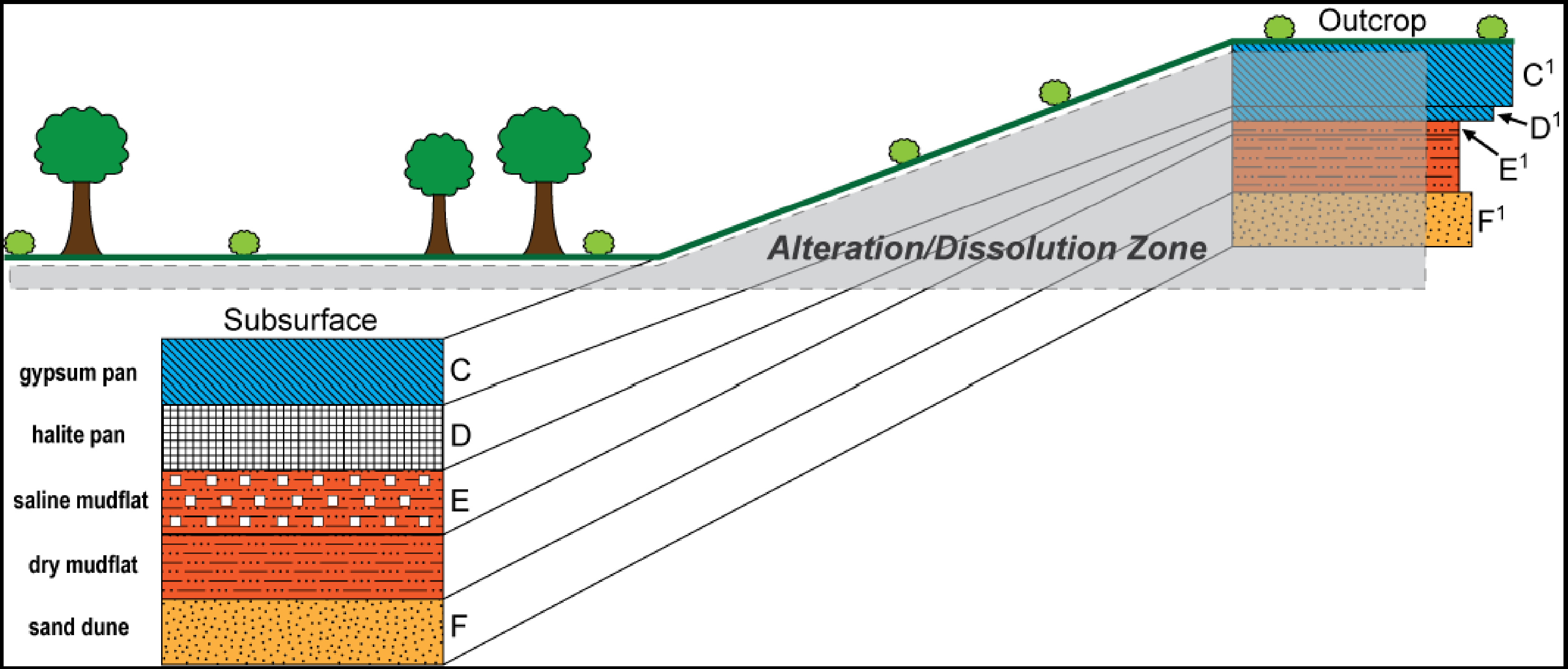

How improved lithological knowledge can help industry

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A new/old horizontal target

Mississippi Lime – A 'Thoughtful' Challenge

By LOUISE S. DURHAM, EXPLORER Correspondent

The advent of the U.S. shale boom placed the spotlight on horizontal drilling and hydraulic fracturing like never before, and with good reason.

These technologies almost always are referred to in a manner indicating they are specifically associated with the still-hot shale plays.

But what's being overlooked for the most part is that these now-common high tech applications are utilized to drill and complete wells in many fields where there is no shale.

Remember the Austin Chalk drilling frenzy in south Texas beginning in the late 1980s? Then-esoteric horizontal drilling was the key ingredient to make it work.

Similarly, the Mississippi Lime play concentrated in northern Oklahoma and southern Kansas is a modern day example of where advanced, improved versions of this technology and others are being used to drill and produce non-shale reservoirs.

This regional carbonate deposit lies beneath the productive Atoka and Morrow sands and above the Devonian-age Woodford and the older Silurian-age Hunton formations.

It might best be called a new/old drilling target, given that vertical wells have been drilled into the Mississippian section in this region for decades, with the Mississippi Lime giving up only marginal production in many instances.

A variety of rocks occur in this relatively new play – including chert, tripolite, speculite and chat, which has yielded minimal hydrocarbon volumes for many years via vertical wells. Some operators equate chat to tripolite or weathered chert.

The Mississippi Chat is a thin, siliceous zone of variable reservoir quality that intermittently develops on top of the Mississippi Lime, according to petroleum geologist and AAPG member Dan Boyd, formerly with the Oklahoma Geological Survey.

There's a steep learning curve to this play, and Boyd cautioned late in 2011 not to expect everything to pan out.

Starting On a Challenge

On the positive side, Boyd was enthusiastic there will be sweet spots.

Spyglass Energy Group in Tulsa is among the operators who are zeroing in on these.

It's challenging.

"The Mississippi Lime is a new play type," said Spyglass geologist and AAPG member Shane Matson during a presentation on the subject that he gave at the recent Playmaker Forum in Houston. "It brings new metrics to evaluate, new skill sets to be utilized and developed and new nomenclature."

MATSON

> "The Mississippi Lime is a new play type … It brings new metrics to evaluate, new skill sets to be utilized and developed and new nomenclature."

Matson might be said to be carrying on family tradition. He's the great grandson of AAPG's fifth president, Charles Matson, and the grandson of retired petroleum geologist Tom Matson.

Tulsa-based Ceja Corporation drilled the first modern horizontal Mississippian well in 2003 to exploit the tripolite, according to Matson. By 2009, 20 wells had been successfully drilled and completed, essentially kicking off the Mississippi Lime play.

"Three years ago, I was on a logging job for my first horizontal Mississippi Lime well, targeting the low porosity section, or the Dense," Matson said. "We interpreted 1,200 feet of open natural fractures in an 800-foot interval.

"Someone on the well from Schlumberger said that the rock was not just fractured, but shattered," he said.

"We recognized we had discovered a new reservoir.

"We were in Osage County, and there was no announcement of the well, which we had permitted through the Bureau of Indian Affairs," Matson continued. "We went from 45,000 acres to a gross 550,000-acre position in six months."

Water: An Important Aspect

Matson emphasized the entire play is huge in aerial extent, encompassing 30 million acres, where more than a thousand wells have been drilled.

In comparison, the famed Elm Coulee Field in the Bakken play in North Dakota is 12 million acres with 5,000 producing wells, while the East Newark Field in the Barnett covers three million acres with more than 15,000 producing wells.

The complex Mississippi Lime is actually comprised of multiple reservoirs having highly varying petrophysical parameters:

- Unconventional (un-altered): 2 percent to 5 percent porosity; requires massive stimulation; has low natural deliverability. Possible to understimulate.
- Semi-conventional (altered): 15 percent to 20 percent porosity; requires stimulation; medium deliverability. Possible to overstimulate and produce abundant water.
- Conventional (highly altered): 35 percent to 48 percent porosity; no stimulation; high natural deliverability near the wellbore, but doesn't drain large area due to low permeability.

The reservoirs often are stacked or laterally adjacent to one another, according to Matson. The sweep efficiency of the hydrological system increases with porosity.

"The variability of the section coupled with the high fluid volume production has led to another paradigm shift in how the industry interprets reservoir objectives in horizontal carbonate plays," Matson noted.

"This variable reservoir requires thoughtful stimulation design," he said. "You must understand the rock you're stimulating."

Matson emphasized the play is about water.

It's crucial not to underestimate how much water a well will make because there must be adequate disposal capacity for produced fluids.

Handling all this water along with other drilling issues can be mighty power intensive. Matson noted it's estimated there will be a need for another 500 megawatts of generation to fully develop the Mississippian play.

Photos courtesy of Chesapeake Energy Corporation

The Mississippi Lime play is found in southern Kansas and, as seen here, northern Oklahoma.

Talks Set for Discovery Thinking Forum

Tulsa geologist and AAPG member Shane Matson will present the paper, "The Mississippi Lime: Outcrop to Subsurface and the Evolution of a Play," as part of this year's Discovery Thinking Forum at the AAPG Annual Convention and Exhibition in Pittsburgh.

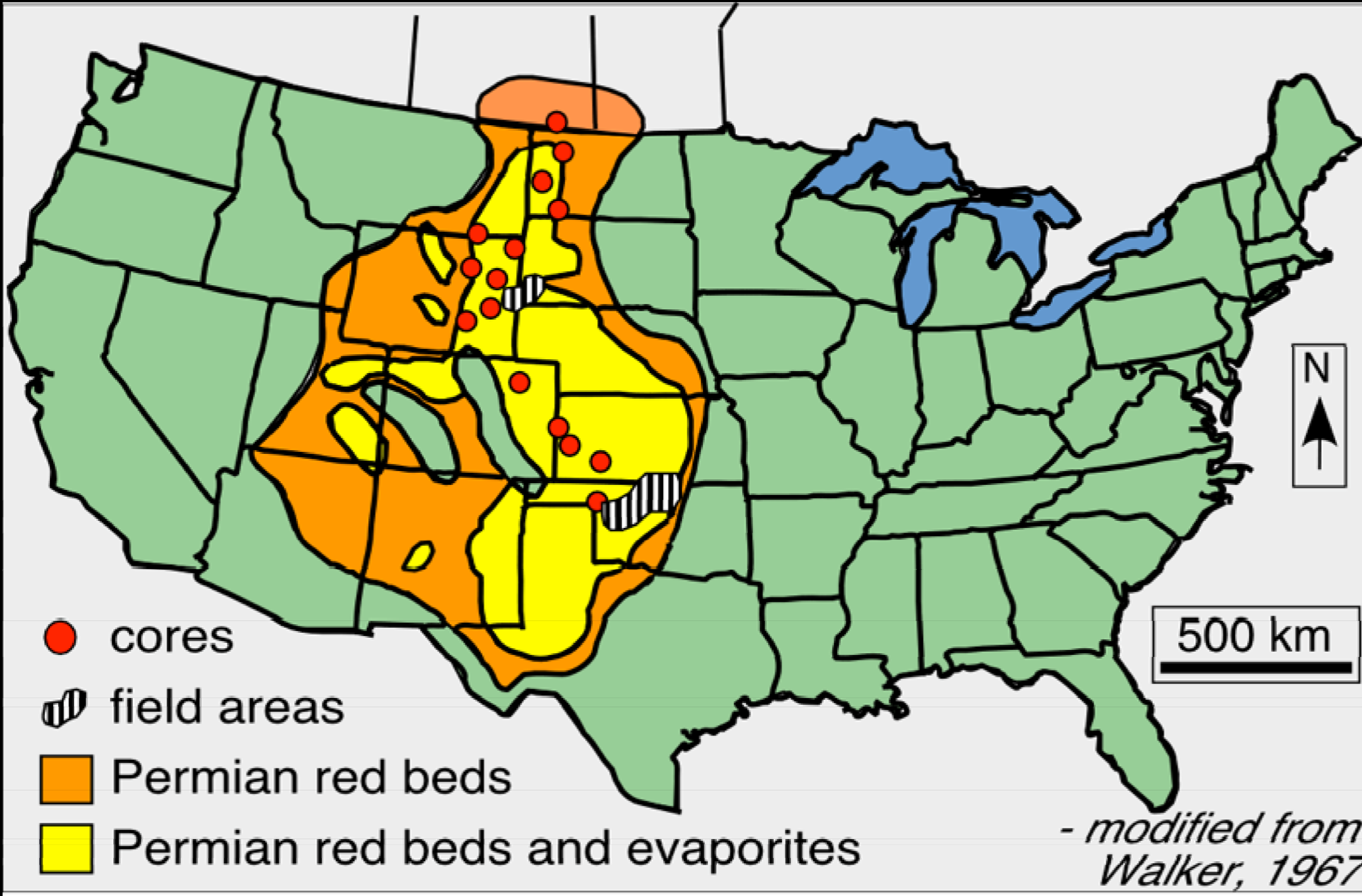
The forum – the seventh presentation of the AAPG 100th Anniversary Committee's program recognizing explorers who have "made a difference" – will be held from 1:15-5 p.m. Monday, May 20, at the David L. Lawrence Convention Center.

Forum co-chairs are AAPG Honorary members Charles Sternbach and Ed Dolly.

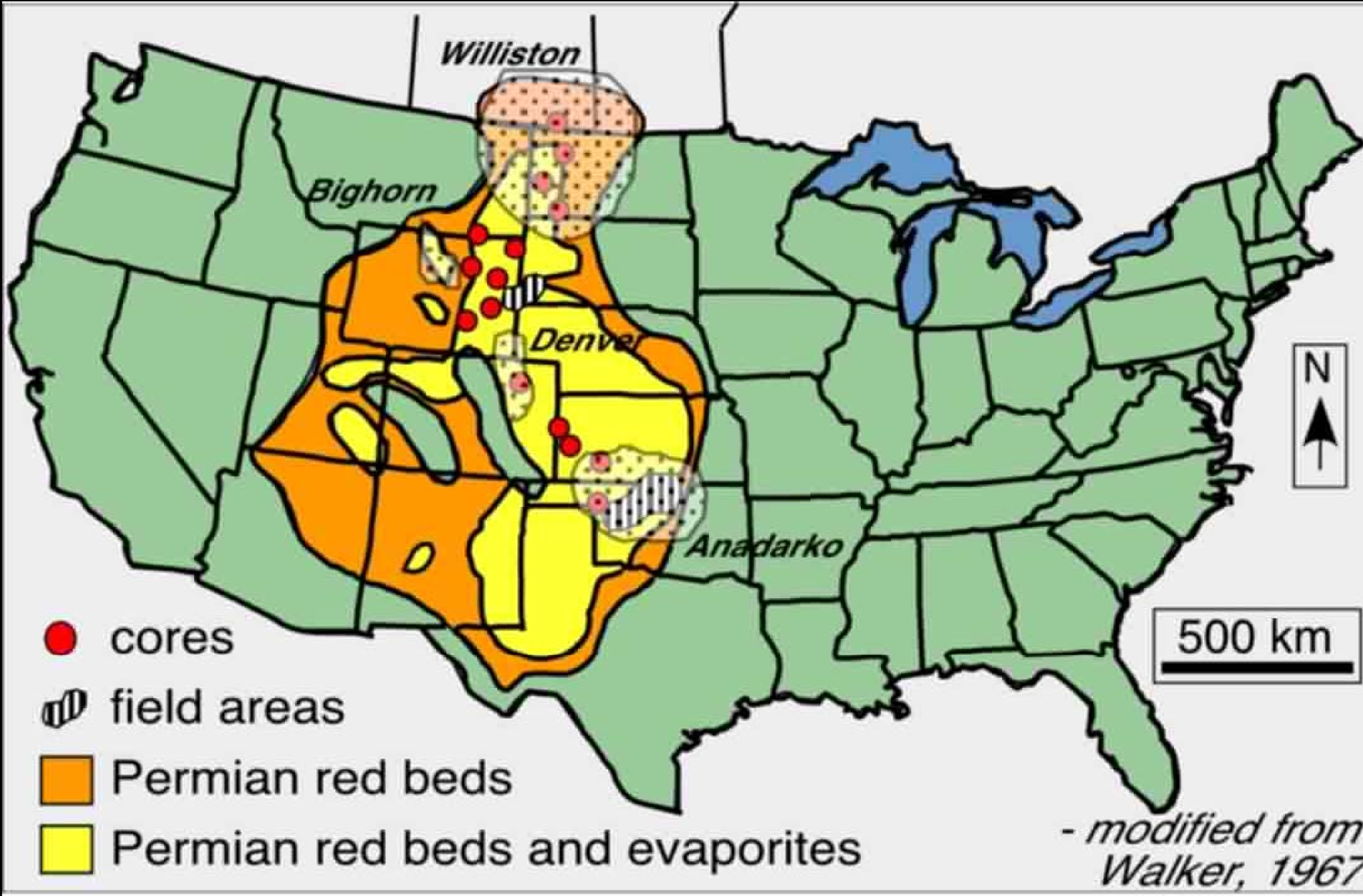
This year's forum will offer five talks from seven explorers who will share how they overcame great challenges in both business and geological aspects to find exploration success. The format calls for philosophies of exploration, stories from remarkable careers, professional insights, colorful anecdotes and lessons learned.

Other speakers at this year's forum are:

- **William Zagorski**, vice president-exploration for Range Resources, who will discuss "The Marcellus Shale – Geologic Considerations for an Evolving North American Liquids-Rich Play." (See related story, page 32.)
- **John Roesink** and **Jason Anderson**, senior research geologists, Bill Barrett Corp., who will discuss "The Wasatch-Green River Resource Play, Utah."
- **Robert Spitzer**, vice president-exploration, Apache Canada, who will discuss "Horn River Devonian Shale Gas Discoveries in Northeast British Columbia."
- **Marshall Deacon**, senior petrophysical adviser, and **Robert Lieber**, geologic adviser, Noble Energy, who will discuss "Integrated Reservoir Evaluation as a Means for Unlocking Maximum Resource Value in an Unconventional Reservoir: Niobrara Formation, DJ Basin, Colorado."



Nippewalla/El Reno Groups (Blaine Fm, Flowerpot Fm, etc), Opeche Shale, Spearfish Fm, Lykins Fm, Dunham & Pine Salts



Nippewalla/El Reno Groups (Blaine Fm, Flowerpot Fm, etc), Opeche Shale, Spearfish Fm, Lykins Fm, Dunham & Pine Salts

red beds and evaporites:

red beds and evaporites are important to the petroleum industry

can be seals
act as marker beds in subsurface
pose drilling hazards

red beds and evaporites present challenges

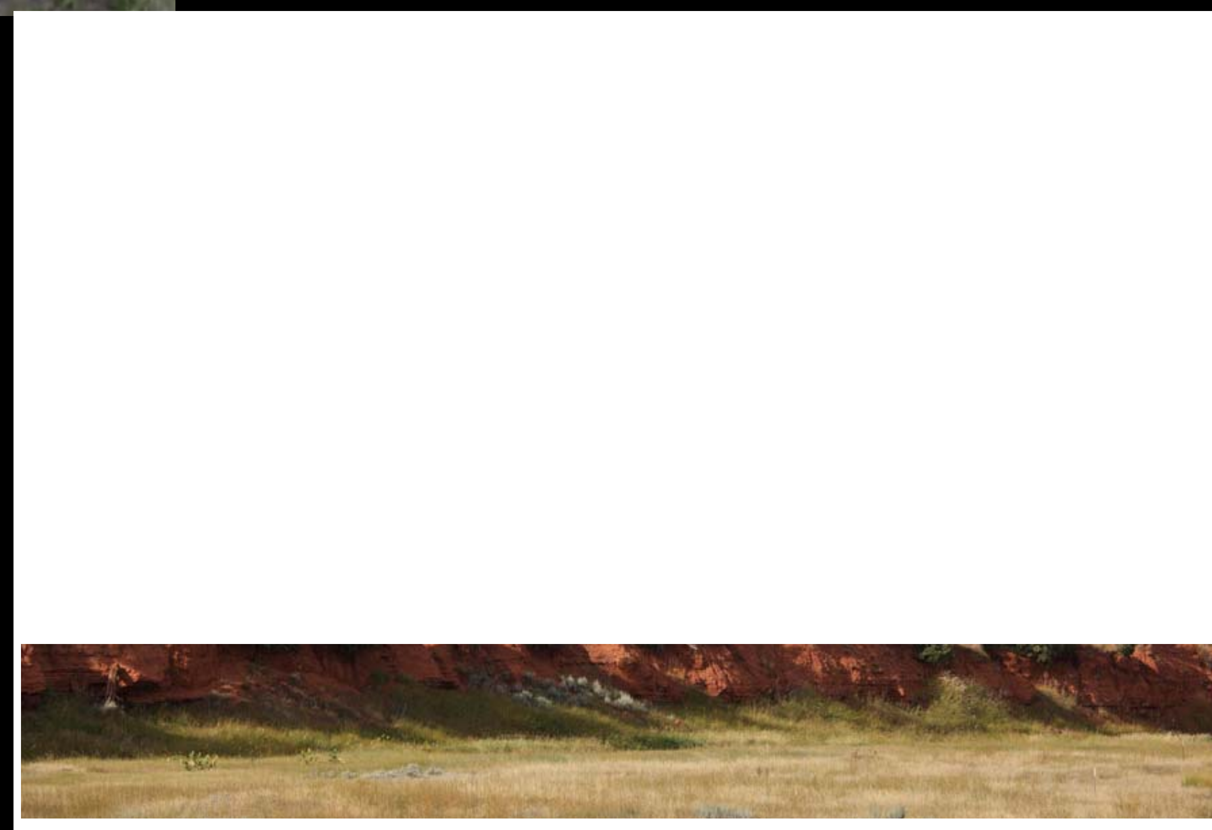
in resolving stratigraphic nomenclature and
age determinations
in recognition of lithologic correlations
in reading detailed lithology in subsurface

Detailed lithologic observations can help industry.

Nippewalla Group
in Gyp Hills of Kansas

Nippewalla Group
in Glass Mountains
of Oklahoma

Opeche Shale
and Spearfish Fm in
South Dakota and Wyoming



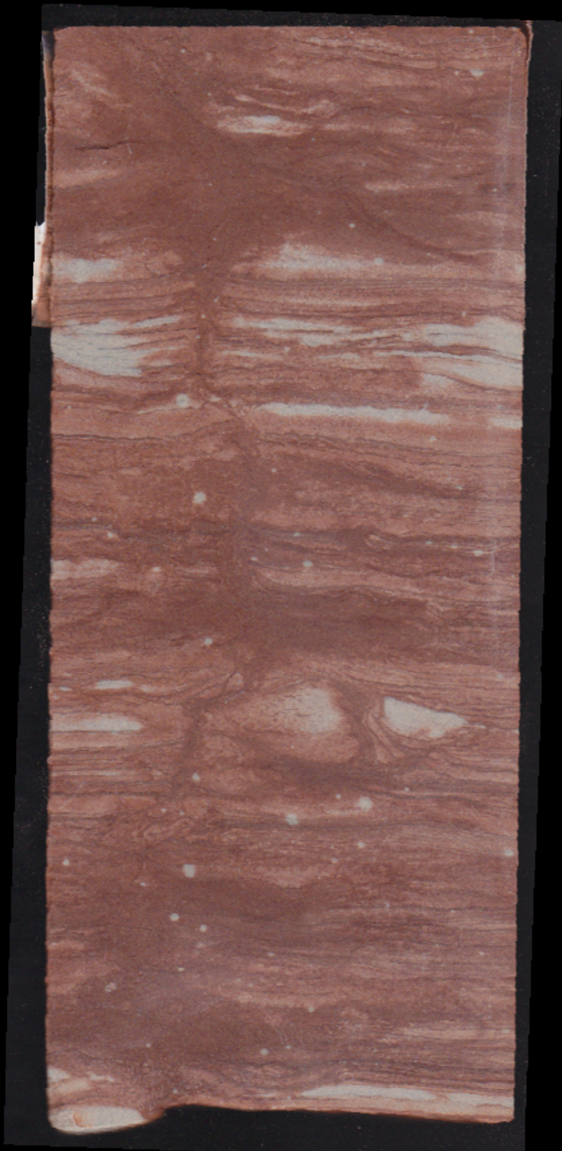
Permian core samples

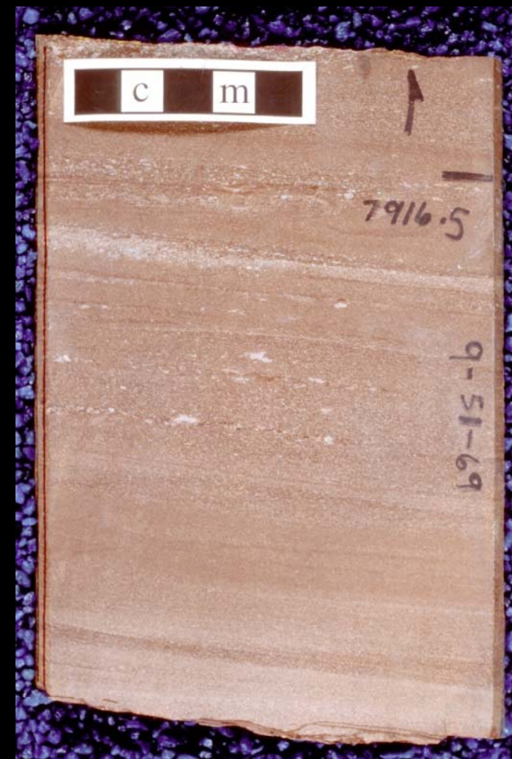
bedded **evaporites** formed in ephemeral acid saline lakes

displacive **evaporites** formed in mudflats and sandflats from acid saline ground waters


bedded halite
formed in acid
saline lakes
displacive halite
formed from
acid saline
groundwaters

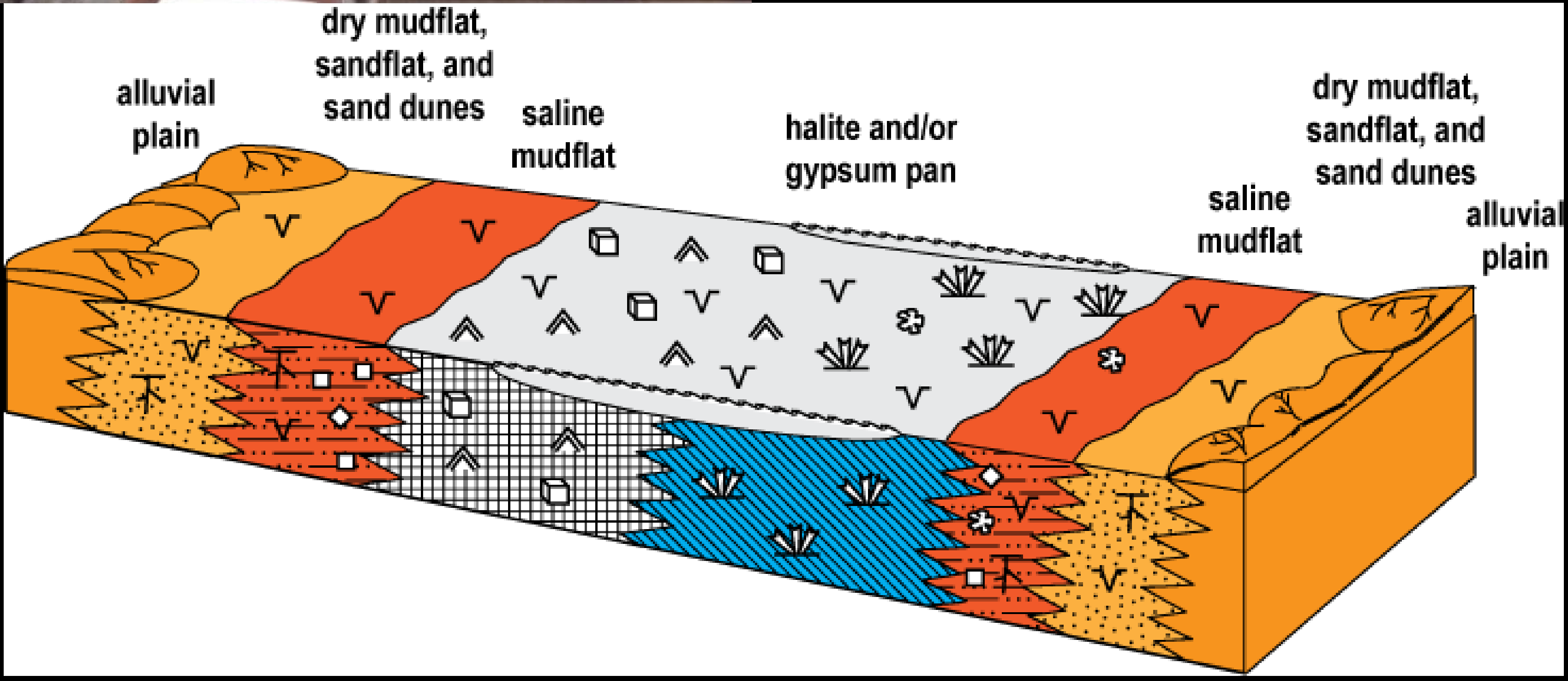
Permian core samples



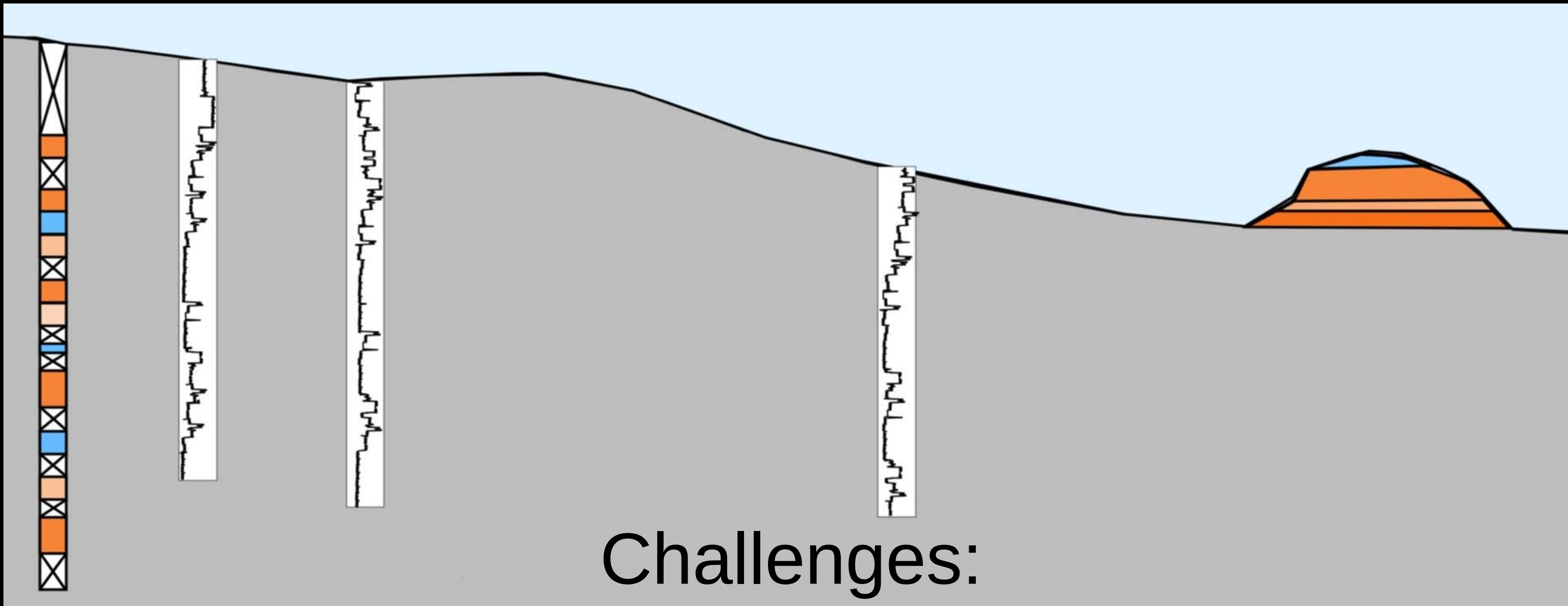


red siliciclastics formed as lake deposits, mudflats, sandflats, dunes, and desert soils

depositional model



Is correlation possible between cores, and between cores and outcrops?



Challenges:

1) few cores, incomplete cores
2) outcrops are incomplete (no halite, poorly-cemented), weather easily
3) geophysical methods cannot easily distinguish mixed halite:redbeds

comparison of lithologies in outcrop and in subsurface

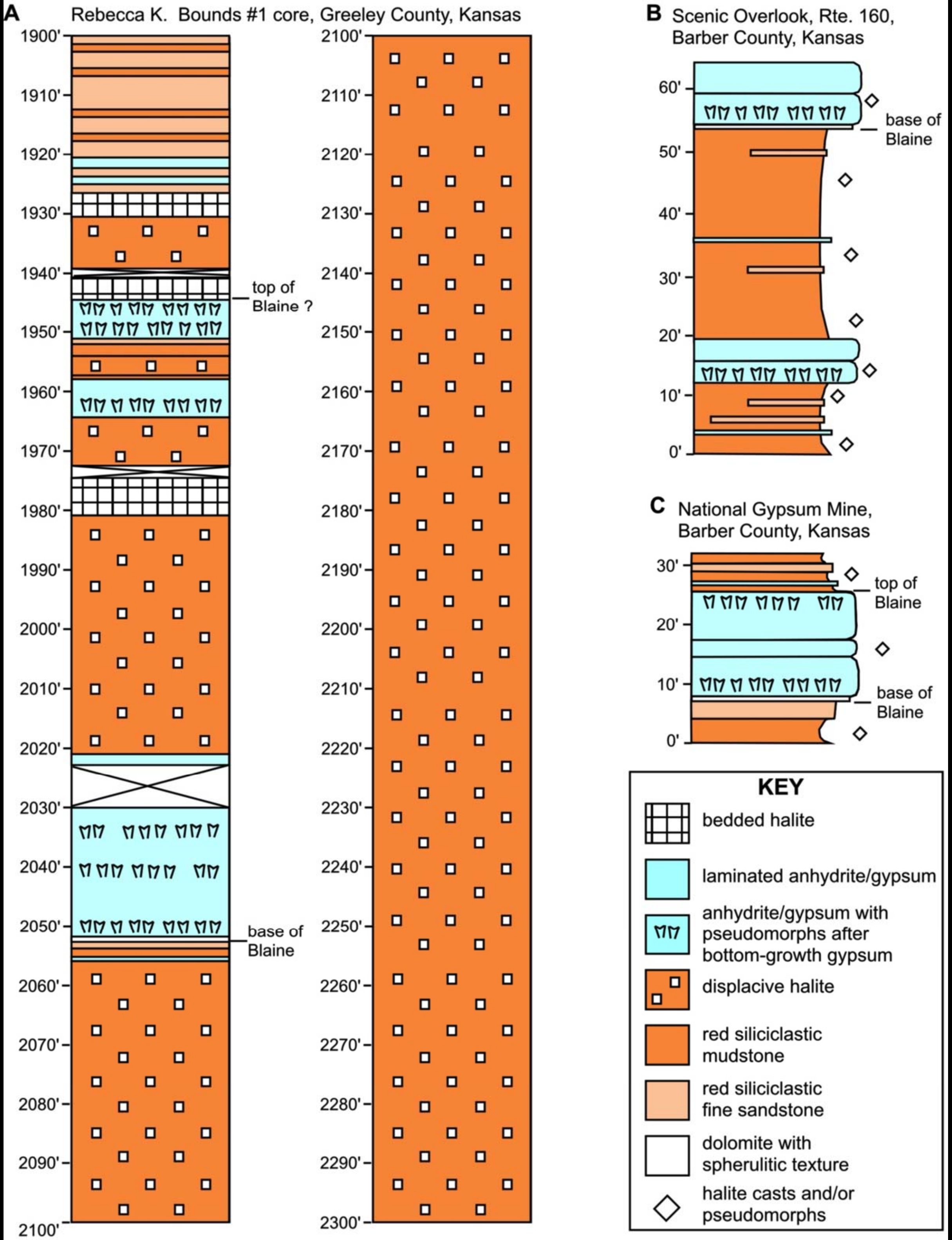
stage	group	formation	lithologies in outcrop	lithologies in core
Leonardian-Guadalupian?	Nippewalla Group	Dog Creek Fm.	red mudstone, red sandstone, minor gypsum/anhydrite	red mudstone, red sandstone, **displacive halite**, minor **bedded halite**, minor gypsum/anhydrite
		Blaine Fm.	gypsum/anhydrite; thin *Microcodium* carbonate	gypsum/anhydrite, **bedded halite**, **displacive halite**, minor red mudstone; minor red sandstonte; thin *Microcodium* carbonate
		Flowerpot Sh.	red mudstone, red sandstone, gypsum/anhydrite	**displacive halite**, **bedded halite**, gypsum/anhydrite, red mudstone, minor red sandstone
		Cedar Hills Ss.	red sandstone, red mudstone	red sandstone, red mudstone, minor **displacive halite**
		Salt Plain Fm.	red mudstone, red sandstone, gypsum/anhydrite	**displacive halite**, **bedded halite**, gypsum/anhydrite, red mudstone, minor red sandstone
		Harper Sandstone	red sandstone, red mudstone	red sandstone, red mudstone, rare **displacive halite**

no halite
In outcrop

lots of halite
In subsurface

- 25’ of Blaine Fm at Lone Mtn and other outcrops in OK and KS
- gypsum/anhydrite with cm-scale pedogenic carbonate

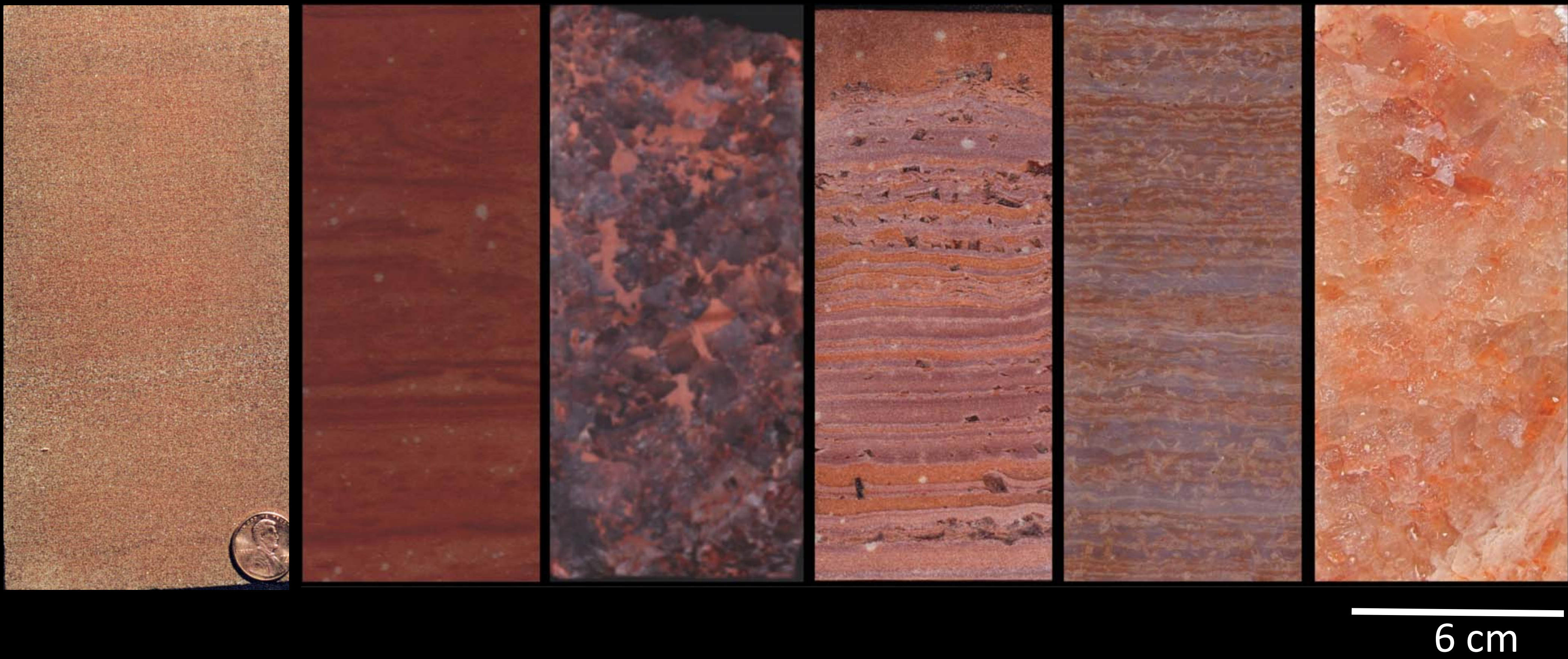
- 125’ of Blaine Fm in Amoco Rebecca K. Bounds core, KS
- >98% recovery over ~1800 foot interval (Permian)
- displacive halite (dh) most common lithofacies



A
Rebecca K. Bounds #1 core, Greeley County, Kansas
1900'
1910'
1920'
1930'
1940'
1950'
1960'
1970'
1980'
1990'
2000'
2010'
2020'
2030'
2040'
2050'
2060'
2070'
2080'
2090'
2100'
top of Blaine ?
base of Blaine
2100'
2110'
2120'
2130'
2140'
2150'
2160'
2170'
2180'
2190'
2200'
2210'
2220'
2230'
2240'
2250'
2260'
2270'
2280'
2290'
2300'
B
Scenic Overlook, Rte. 160, Barber County, Kansas
60'
50'
40'
30'
20'
10'
0'
base of Blaine
C
National Gypsum Mine, Barber County, Kansas
30'
20'
10'
0'
top of Blaine
base of Blaine
KEY
bedded halite
laminated anhydrite/gypsum
anhydrite/gypsum with pseudomorphs after bottom-growth gypsum
displacive halite
red siliciclastic mudstone
red siliciclastic fine sandstone
dolomite with spherulitic texture
halite casts and/or pseudomorphs

different lithofacies have same mineralogy

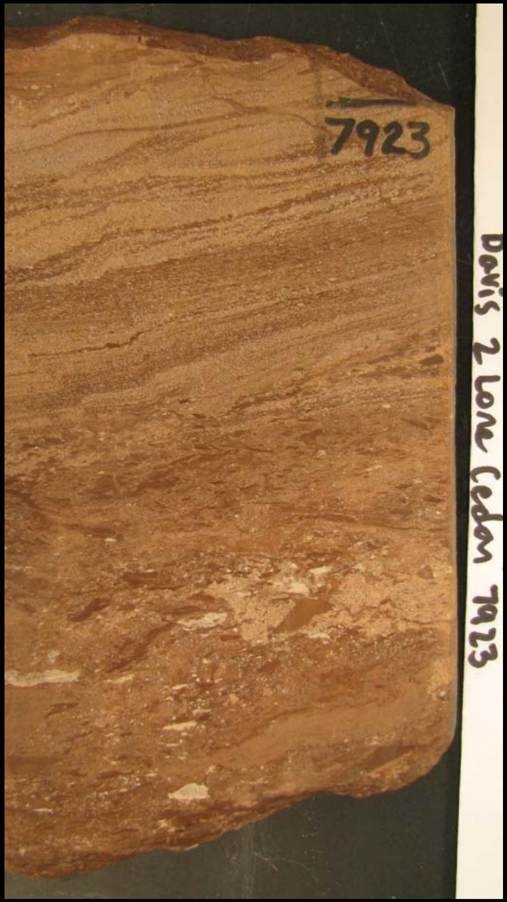
Nippewalla Group cores, Kansas

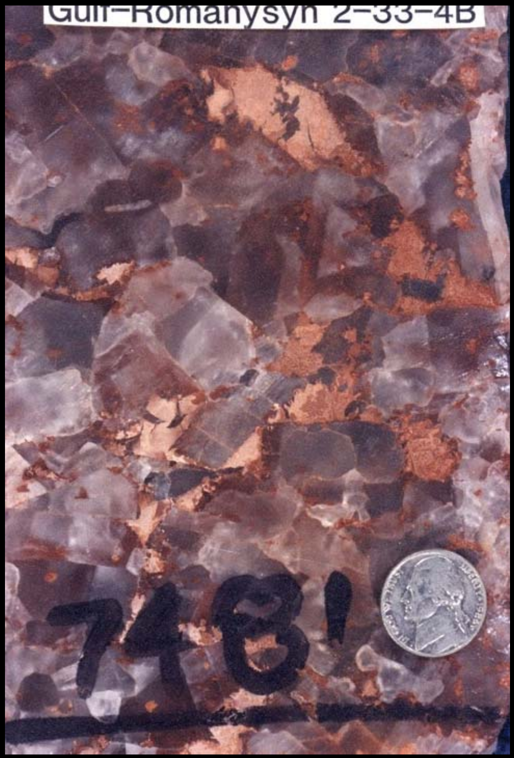


halite, quartz, and hematite in all rocks

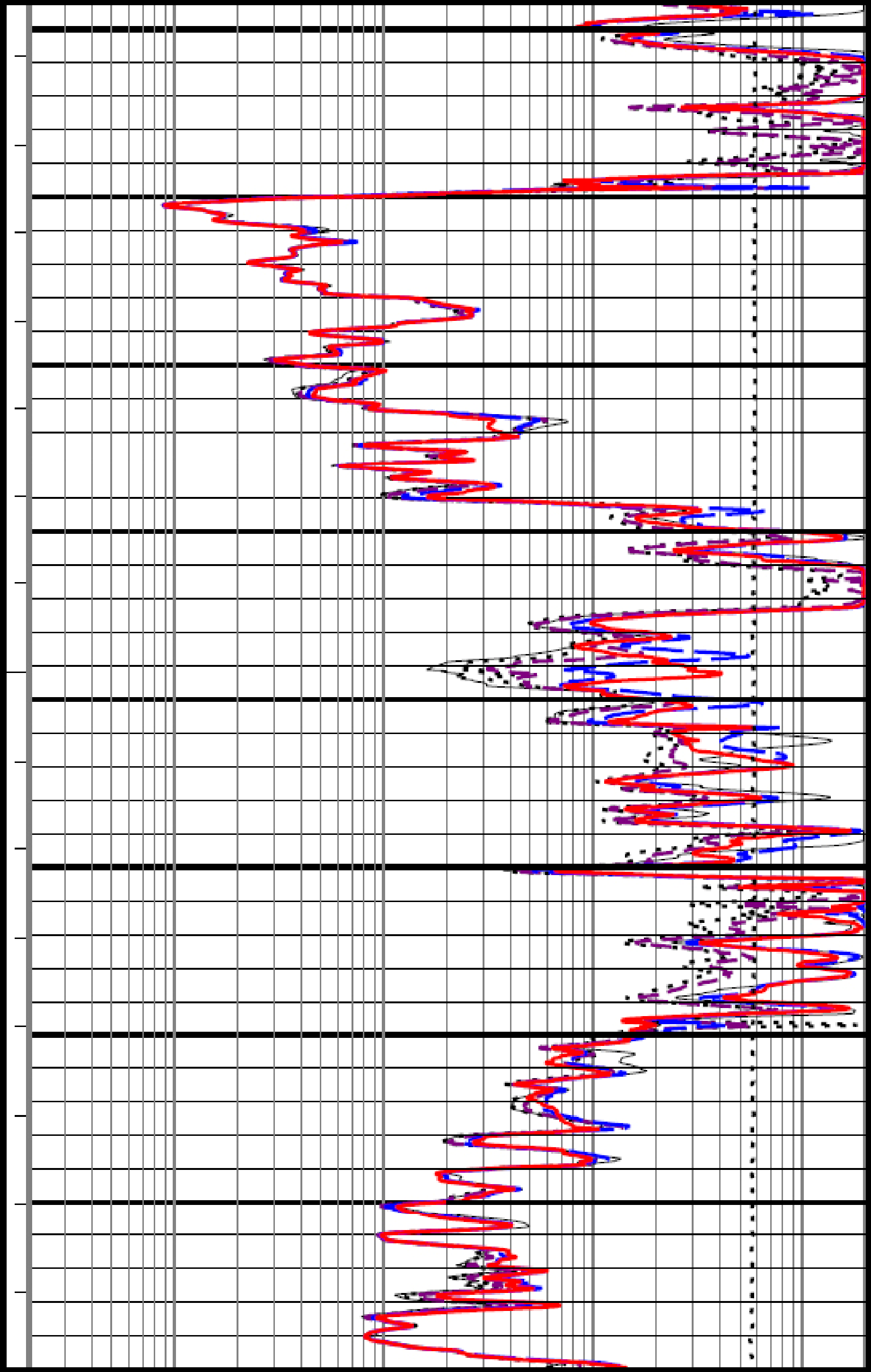
different lithofacies have same mineralogy

Opeche Shale cores, North Dakota





halite, quartz, and hematite in all rocks resistivity log for part of Williston Basin

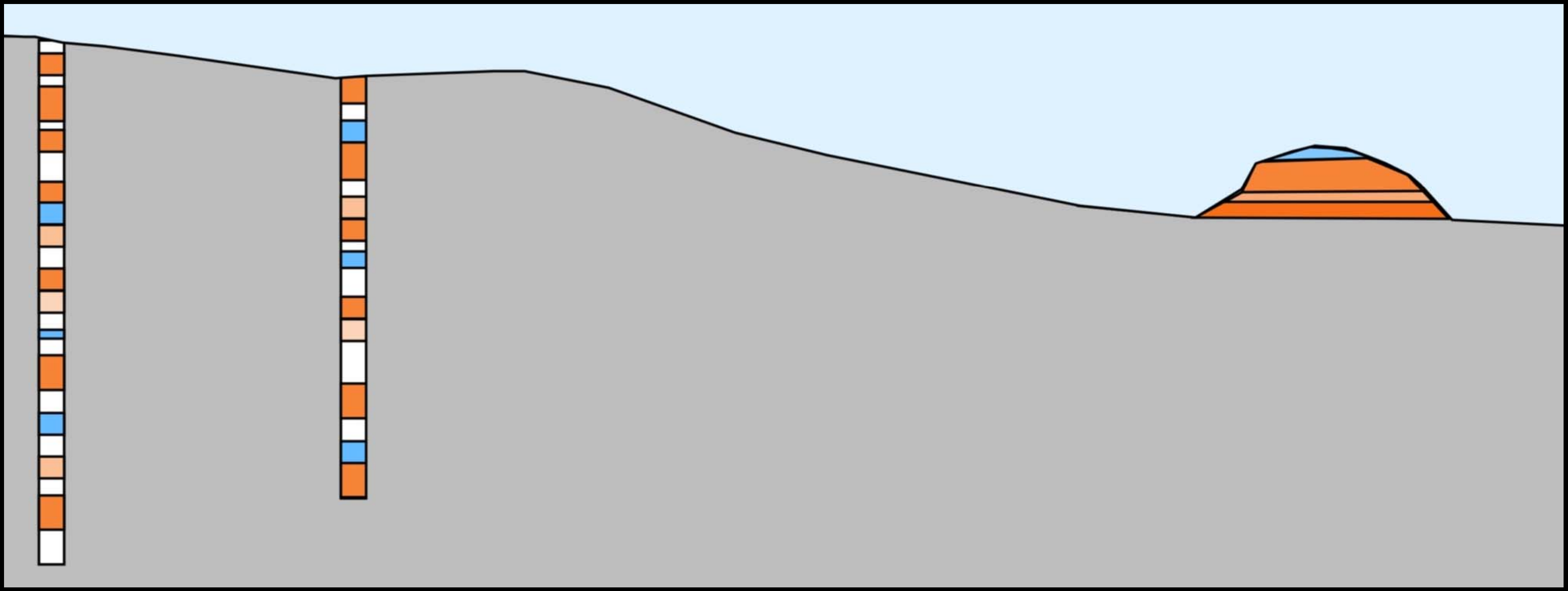


high resistivity = high salinity

assumption: all salt is bedded halite

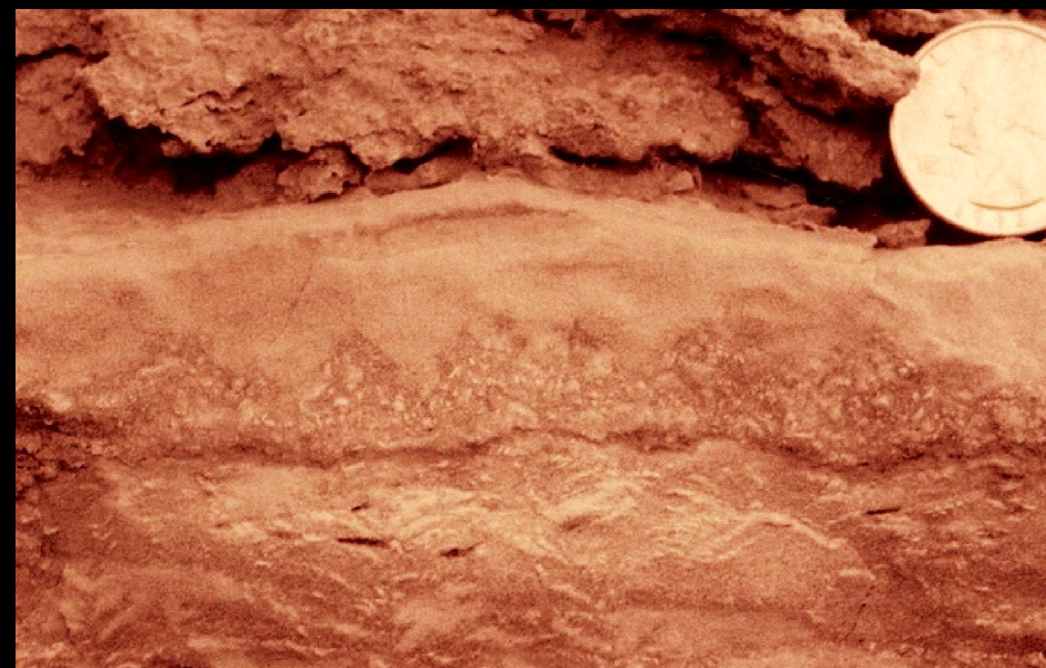
local and regional correlation is based on perceived identification of individual halite beds

How do we know that halite once existed In high abundance in the outcrops?



How do we know that halite once existed In high abundance in the outcrops?

beds of pseudomorphs of halite chevron crystals



indicate past shallow saline lakes

How do we know that halite once existed In high abundance in the outcrops?

cumulate halite crystal casts on bedding planes

indicate past saline lakes

How do we know that halite once existed In high abundance in the outcrops?

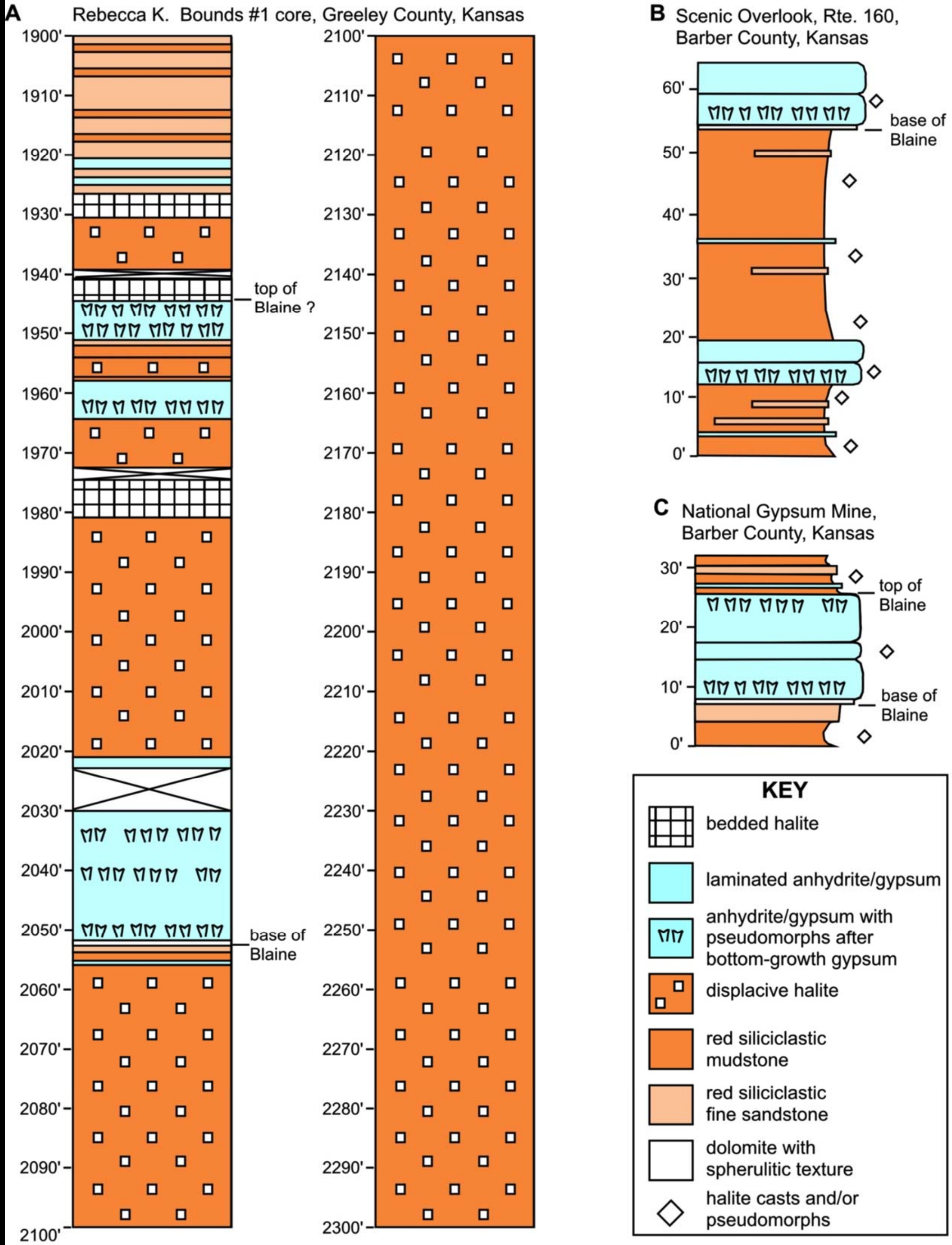
randomly oriented halite “pagoda” casts

indicate past groundwaters

How do we know that halite once existed In high abundance in the outcrops?

collapse structures

indicate late dissolution near surface



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Rebecca K. Bounds #1 core, Greeley County, Kansas
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2020'
2030'
2040'
2050'
2060'
2070'
2080'
2090'
2100'
top of Blaine ?
base of Blaine
2100'
2110'
2120'
2130'
2140'
2150'
2160'
2170'
2180'
2190'
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displacive halite
red siliciclastic mudstone
red siliciclastic fine sandstone
dolomite with spherulitic texture
halite casts and/or pseudomorphs

Experiment:

How much red sed would remain if halite dissolved?

(1) measure height and weight of displacive halite

(2) dissolve in freshwater

(3) dry remaining red sed

(4) measure height and weight of remaining red sed

Experiment:

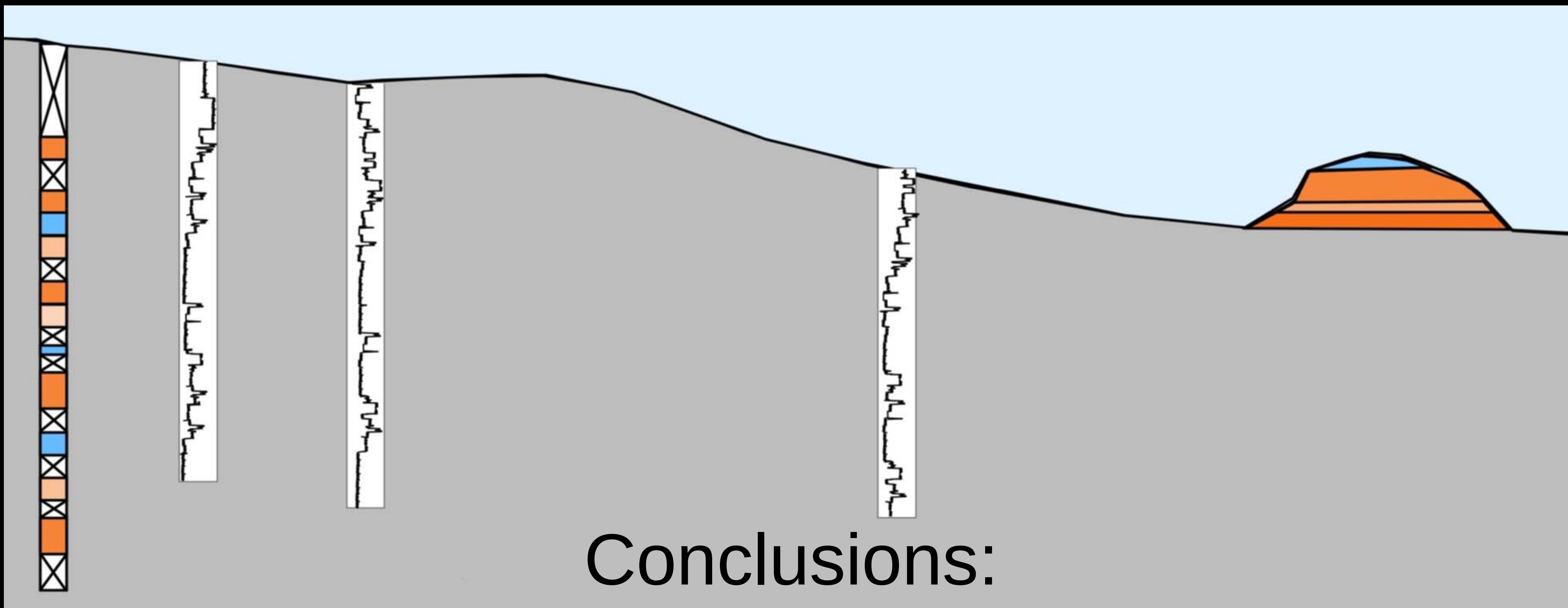
How much red sed would remain if halite dissolved?

	Sample	before dissolution: displacive halite height (cm)	before dissolution: displacive halite mass (g)	after dissolution: red sediment height (cm)	after dissolution: red sediment mass (g)	% rock lost to dissolution by height	% rock lost to dissolution by mass
#1	Blaine Fm., 2016'10-2017' (614.73-614.78 m)	5.0	330.37	1.0	38.749	80.0	88.3
#2	Blaine Fm., 1974'6"-1975' (601.84-601.98 m)	14.0	866.65	5.5	158.314	60.7	81.7
#3	Flowerpot Sh., 2181'8"-2182'3" (665.02-665.18 m)	20.0	1139.60	2.4	55.786	88.0	95.1
#4	Flowerpot Sh., 2301'5"-2302'4" (701.47-701.74 m)	26.7	1403.76	12.5	446.174	53.2	68.2
#5	Blaine Fm., 2016'-2016'10" (614.5-614.72 m)	22.0	1263.75	4.0	91.700	81.8	92.7
#6	Flowerpot Sh., 2056'2"-2057' (626.73-626.95)	22.0	2192.51	4.9	146.482	81.6	93.3

A great volume and thickness of halite may have been lost to late-stage, near-surface dissolution.

Is correlation possible between cores, and between cores and outcrops?

PROBABLY NOT SO EASILY……

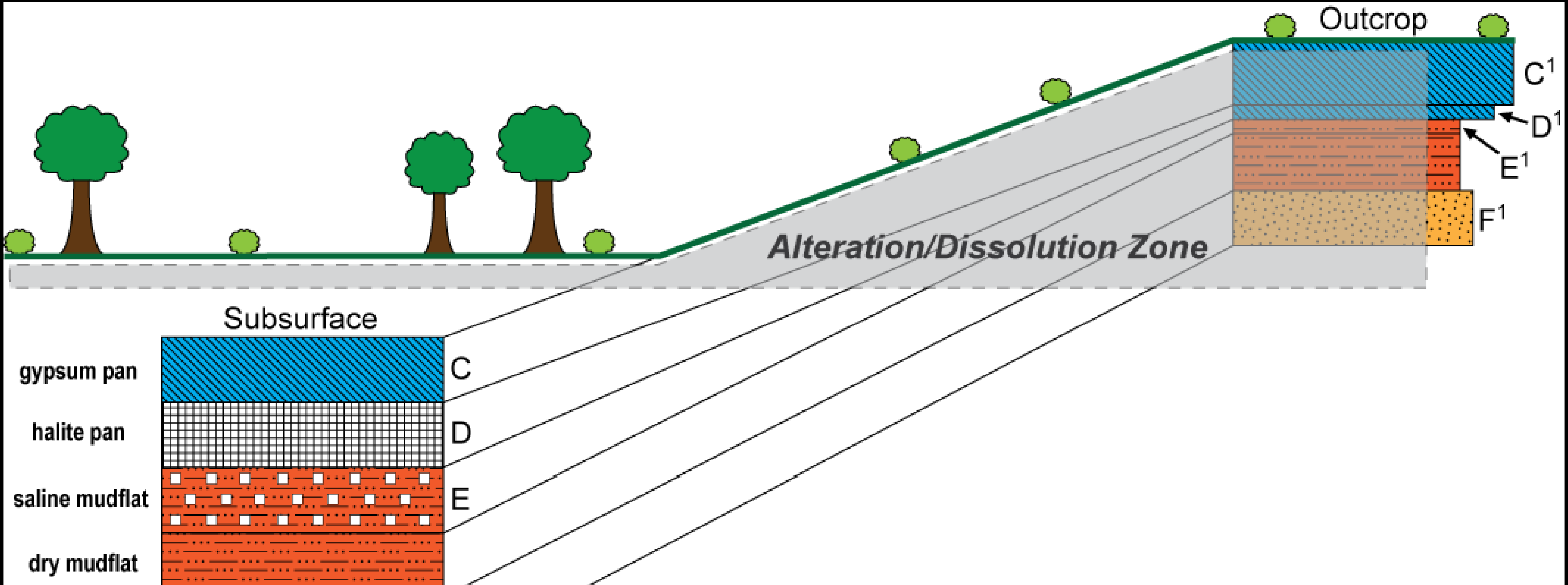


Conclusions:

- Similar mineralogy for different lithofacies makes well log interpretations difficult.
- Late-stage dissolution near surface presents challenges in estimating subsurface lithology and thicknesses.

Is correlation possible between cores, and between cores and outcrops?

BUT THERE IS HOPE……



Conclusions:

- High-quality cores and detailed lithologic studies of field and cores samples are most important techniques for understanding these rocks and their stratigraphy

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