Controls on Porosity and Permeability Within the Carmel Formation: Implications for Carbon Sequestration*

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Abstract

Having quality data on reservoir and seal properties for proposed CO_2 injection sites is vital for predicting and modeling how CO_2 will behave in the subsurface. For a proposed sequestration site at the Gordon Creek Field (Carbon County, Utah), the reservoir for the proposed injection unit is the Navajo Sandstone, with the Carmel Formation acting as the primary seal. We are investigating the controls on porosity and permeability in both units, with a specific interest in the sealing behavior of the Carmel Formation using a regional outcrop analog study.

The Carmel is a near-shore assemblage of limestone, siltstone, mudstone, sandstone, and gypsum. It changes laterally across Utah, from more carbonate-dominated lithofacies in the west, to more clastic-dominated lithofacies in the east. Because of the lateral changes in lithology, it was necessary to examine outcrops of the Carmel at Mt. Carmel Junction and on the San Rafael Swell; equivalent beds of the Twin Creek-Arapien were also examined at Thistle. The Mt. Carmel Junction site is thought to best represent what is at Gordon Creek Field.

Samples collected from the three outcrop locations, as well as subsurface samples from the proposed injection site, were analyzed using a combination of petrography, stable isotope geochemistry, and scanning electron microprobe. From preliminary data, quartz overgrowths and pore-filling calcite cements account for most of the porosity loss in the Carmel. Relatively high IGVs and a

dominance of tangential contacts indicate that compaction was not of great importance in reducing porosity. Porosity in the limestone beds in the Carmel is low, because they are dominantly carbonate muds. Some detrital quartz grains in both the limestone and sandstone beds were partially replaced by calcite. In the shale and mudstone beds, the only macroscopic porosity is fracture related. There are multiple mineralized fractures throughout the Carmel (gypsum, calcite) that may be preserved at depth. The fractures are mainly developed in limestone and, to a lesser extent, sandstone beds. In a few places they can be seen to extend into adjacent mudstone beds.

The underlying Navajo Sandstone is an eolian cross-bedded sandstone that has relatively high porosity and permeability. In all study localities, the Navajo is cut by prominent deformation bands that would clearly influence flow in potential reservoirs.

References

Bottrell, S.H., and R.J. Newton, 2006, Reconstruction of changes in global sulfur cycling from marine sulfate isotopes: Earth-Science Reviews, v. 75**,** pp.59-83. DOI:10.1016/j.earscirev.2005.10.004

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SWP

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NETL National Energy Technology Laboratory

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New Mexico Firefighters Training Academy

Wagner Petrographic

Porotechnology

Notes by Presenter: Jennifer Wilson – permeameter description in her thesis

Outline

- Study Area
- Research Questions
- Petrography/Diagenesis
- Stable Isotopes
- CO_2 Column Height Calculations
- Conclusions

Study Area

- San Rafael Swell (Interstate-70)
- Mount Carmel Junction
- Injection site at Gordon Creek Field (Carbon County, UT)

Google Maps, 2011

Gordon Creek

- Injection unit: Navajo Sandstone
- Seal unit: Carmel Formation

Period	Symb†	Formation / Member		Thickness (feet)	Depth (feet)*	Lith.
CRET	Km	Mancos Shale	Emery Ss Mbr		0	
			Blue Gate Sh Mbr	<250	3115	
			Ferron Ss Mbr	10-110	3250	
			Tununk Sh Mbr	200-300	4000	
	Kd	Dakota Sandstone		0-30	4025	
	Kcm	Cedar Mtn Fm	Upper member	150-750	4120	
			Buckhorn Cg Mbr	0-50		
JURASSIC	Jm	Morrison Formation		800±	4460	
	Js	Summerville Formation		120-180	5895	
	Jct	Curtis Formation		140-180	6275	
	Je	Entrada Formation		150-950	6585	
	Jc	Carmel Formation		300-700	7650	
	Jc	Page Sandstone		<70		
	Jgc	Navajo Sandstone		150-300	8400	
		Kayenta Formation		120-200	8750	
		Wingate Sandstone		300-400	8885	
TRIASSIC	Trc	Chinle Fm	Upper member	200-300	9225	
			Moss Back Mbr	20-60		
	Trmt	Moenkopi Fm	Upper member	550-700	9520	
	Trms		Sinbad Ls Mbr	50	10460	
	Trmbd		Black Dragon Mbr	250-350		
PERM	Ppc	Kaibab/Park City Fm		170	10890	
	Pwr	White Rim Sandstone		500-700	11135	

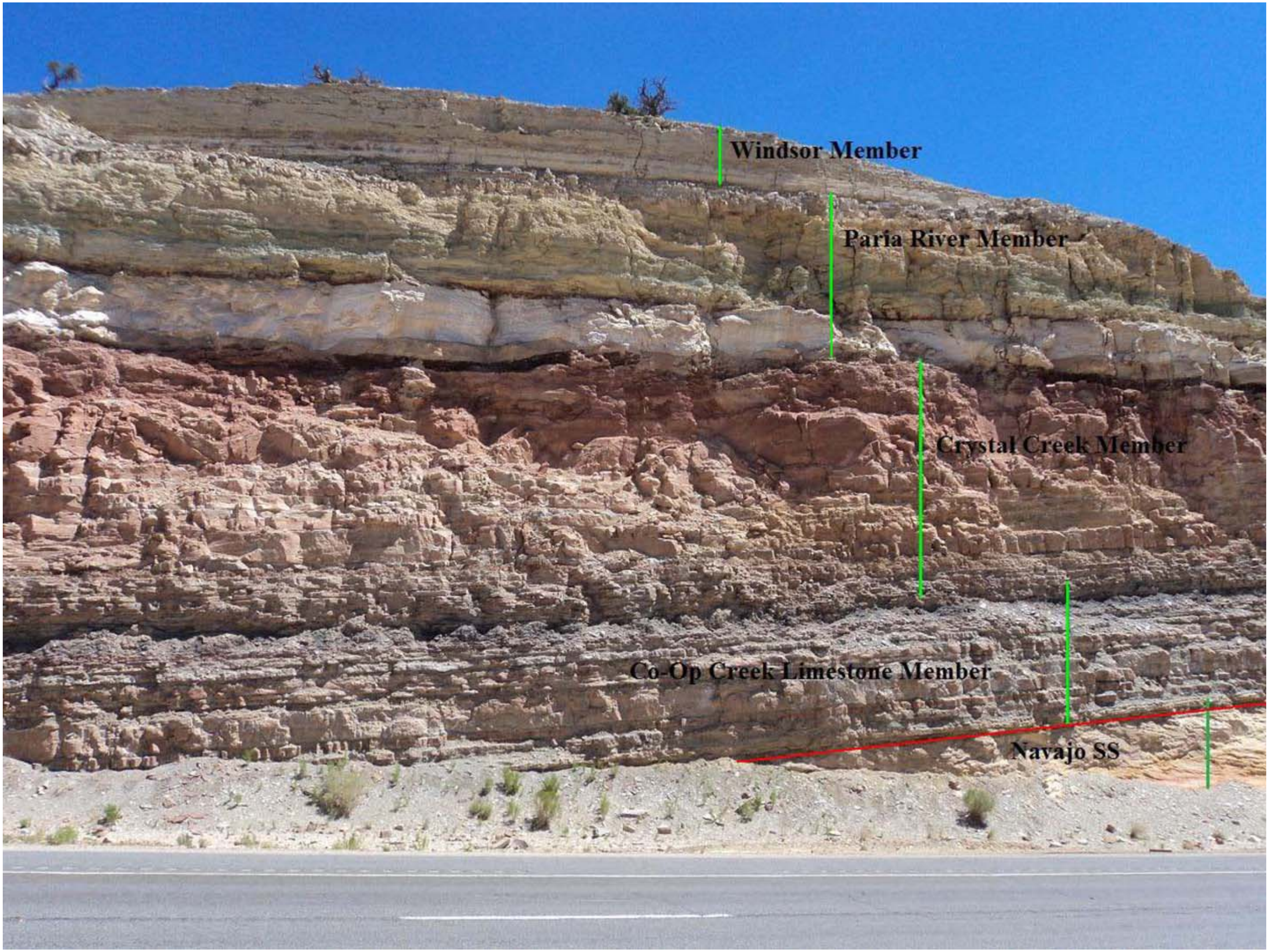
CO_2 Source — CO_2 Sink — Methane Producer — Seal

† Geologic symbols for correlation to units in Morgan (2007)

Modified from Hintze (1986)

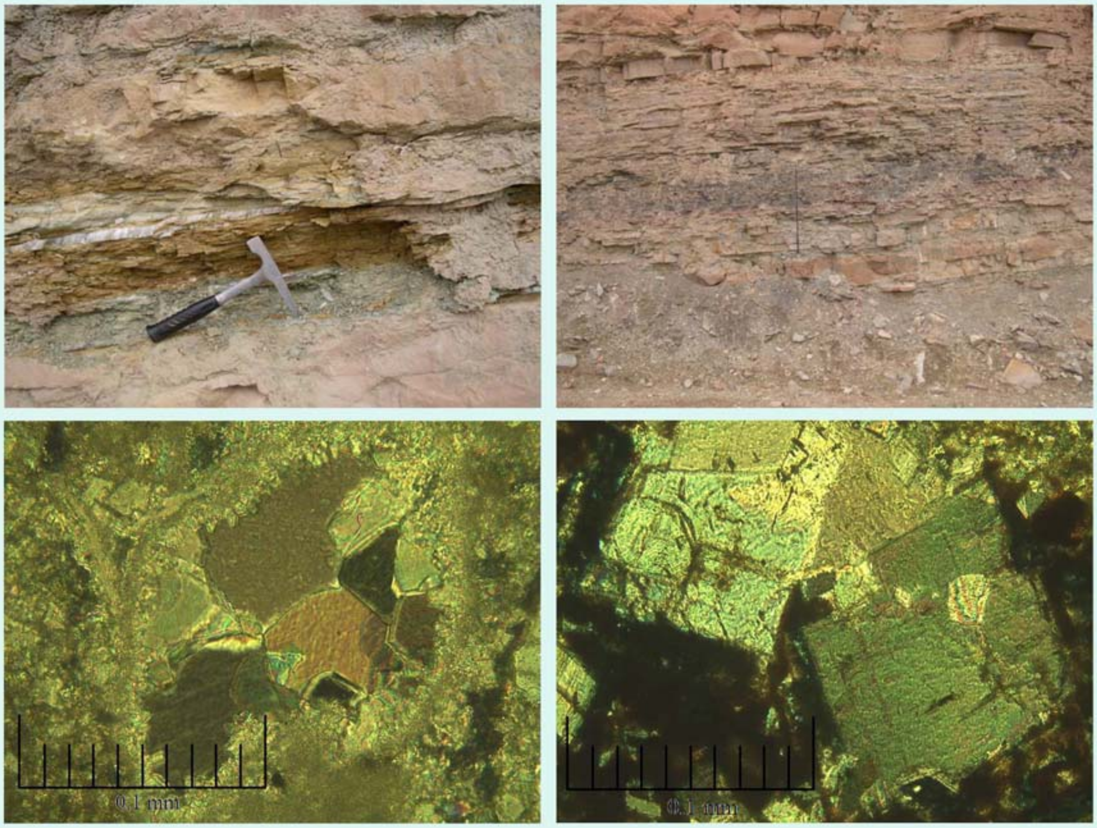
Research Questions

- Has the diagenesis in the Carmel mainly reduced or enhanced ϕ/k?
- Are mineralized fractures at surface also present at depth?
- What are the ϕ/k characteristics of each member?
- Is the Carmel an appropriate seal for CO_2 sequestration?



Notes by Presenter: Scale bar?

Co-Op Creek Limestone Member



Notes by Presenter:

Co-Op Creek Member of the Carmel Formation

Composition and texture

The Co-Op Creek Member consists of laminated shales containing small sandstone lenses with gypsum filled fractures immediately above the contact with the Navajo. Above these shales, there are intrasparite/sparitic quartz grainstones with thin gypsum filled fractures. At the top of the member there are mudstone/micritic limestone with quartz grains and gypsum, and claystones.

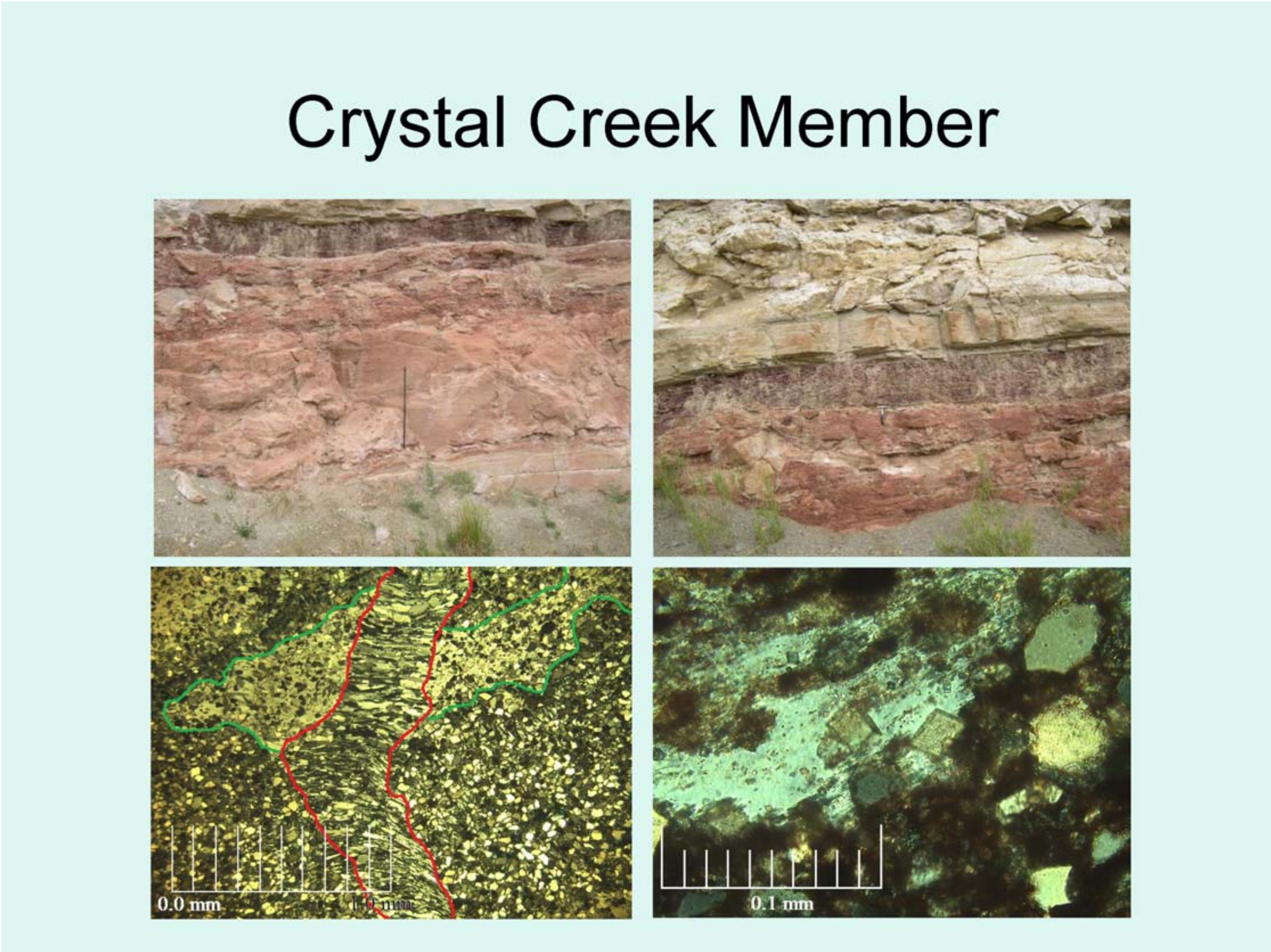
Diagenesis

- Fracturing of rock
- calcite precipitation in fractures and as patchy poikliotopic calcite cement
- partial calcite dissolution to create porosity
- additional calcite precipitation
- partial replacement of calcite with dolomite, along with some dolomite growth in porosity

In the shales, no real diagenetic alteration.

Petrophysics

The limestones present in the Co-Op Creek Member range in permeability from 0.000004 mD to 0.454 mD at the MCJ site, while at the I-70 site, they ranged from 0.000044 mD to 0.038 mD. In terms of porosity, values range from 0.78% to 15.6% at the MCJ site, while at the I-70 site, porosity ranges from 1.89% to 12.3%.



Notes by Presenter:

Crystal Creek Member of the Carmel Formation

Composition and texture

The Crystal Creek Member consists of mudstone/micritic limestone with small amounts of quartz grains and gypsum cement and gypsum nodules. At the MCJ site, there is also a unit of mixed laminated mud and siltstine/shaley sandstone just below the gypsum bed.

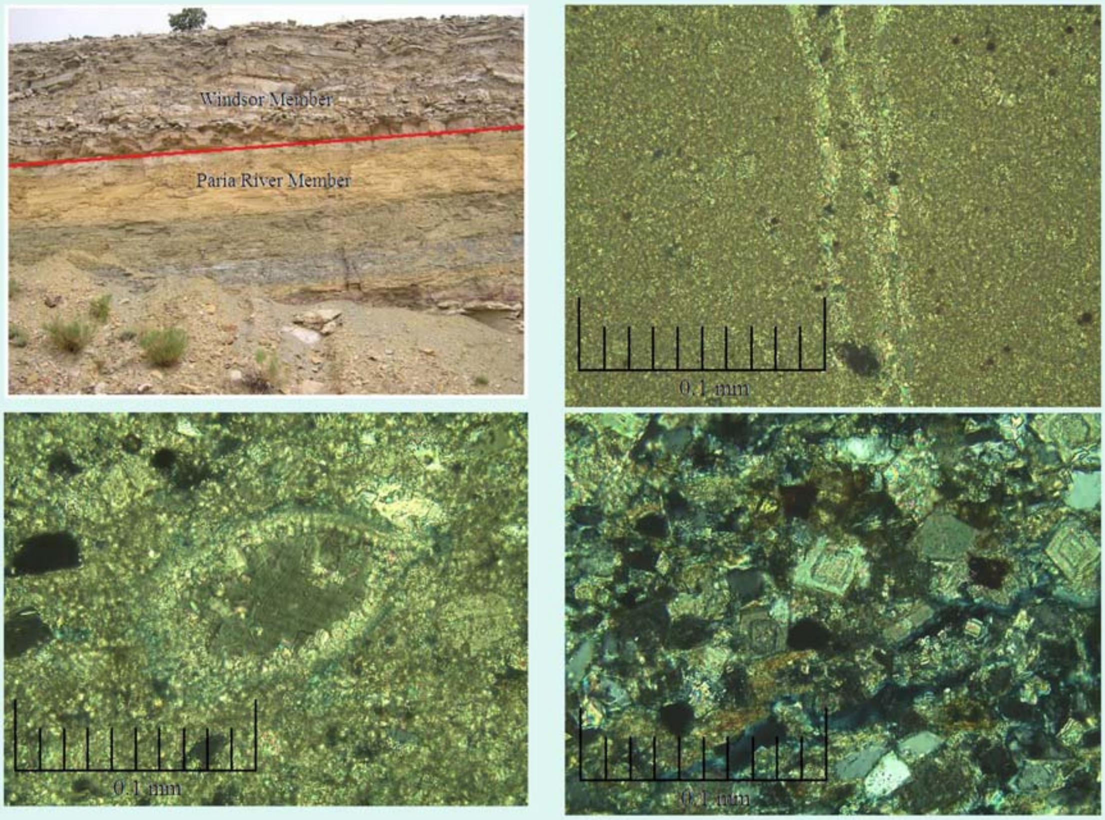
Diagenesis

- Poikliotopic gypsum cement and replacement of fossils
- fracturing of rock
- precipitation gypsum
- partial replacement of calcite and gypsum with dolomite

Petrophysics

There is only one (1) sample from the Crystal Creek Member from the I-70 site, which has a permeability of 0.105 mD and a porosity of 12.3%.

Paria River Member



Notes by Presenter:

Paria River Member of the Carmel Formation

Composition and texture

At the base of the Paria River Member, there is a thick bed of gypsum with small amounts of calcite. Above this are thinly bedded limestones with minor amounts of chert and shales. Above these are mudstone/micritic limestones that have undergone fracturing

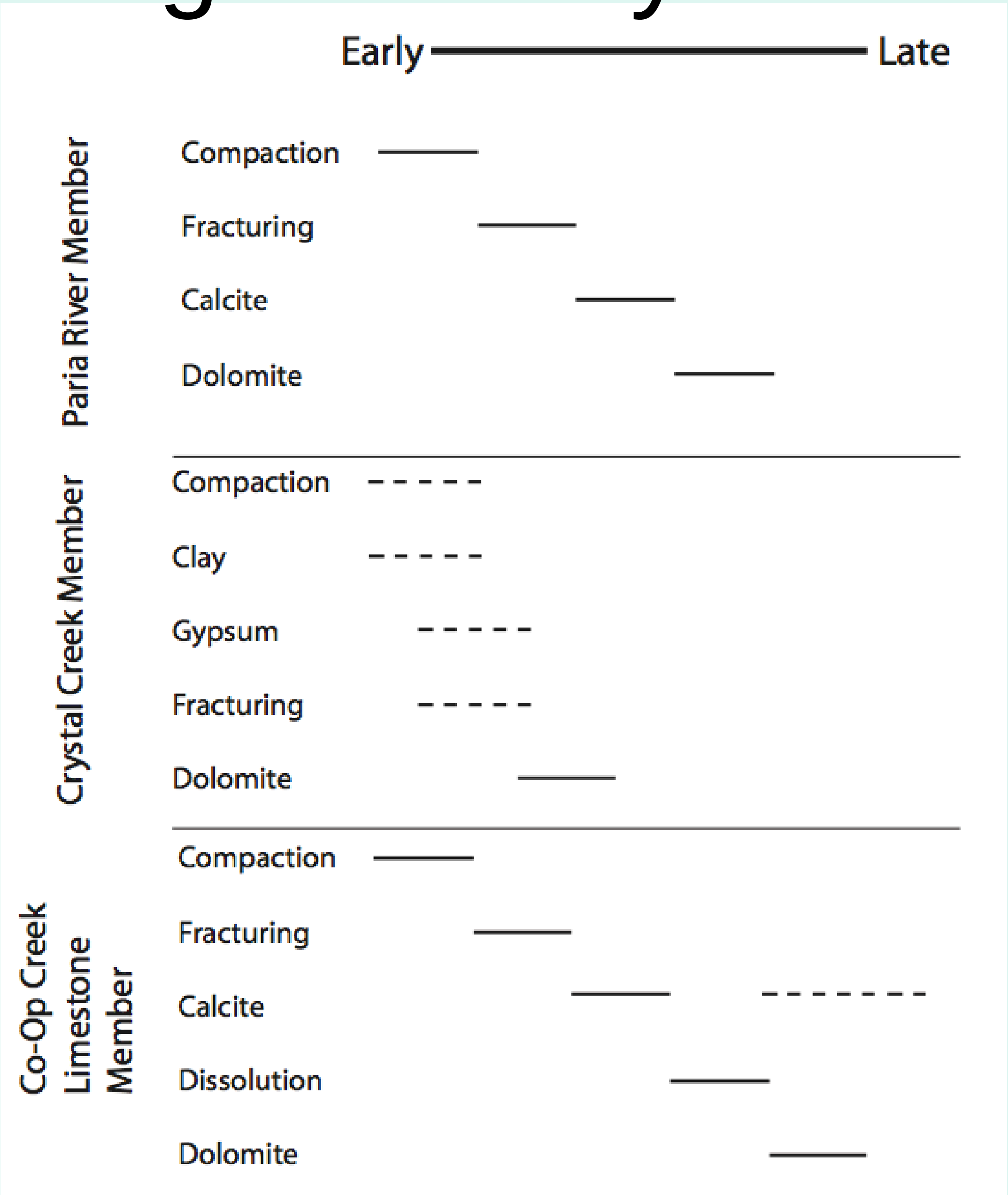
Diagenesis

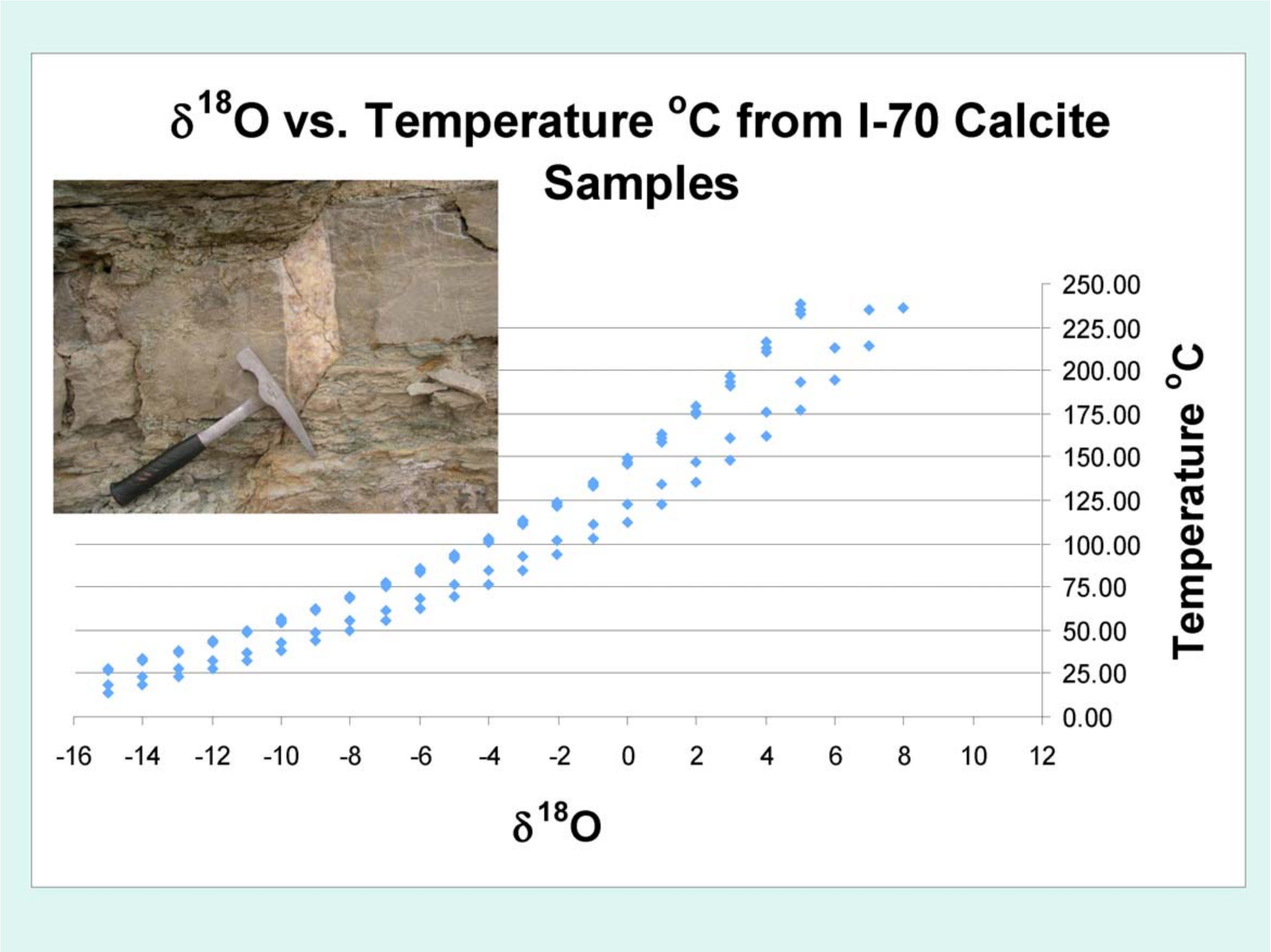
- Fracturing of rock
- Calcite precipitation in porosity and fractures
- Partial replacement of calcite with dolomite
- Dolomite overgrowths

Petrophysics

The Crystal Creek member ranges in permeability from 0.000008 mD to 0.000993 mD at the I-70 site. In terms of porosity, values range from 1.70 to 8.14% at the I-70 site.

Diagenesis by Member

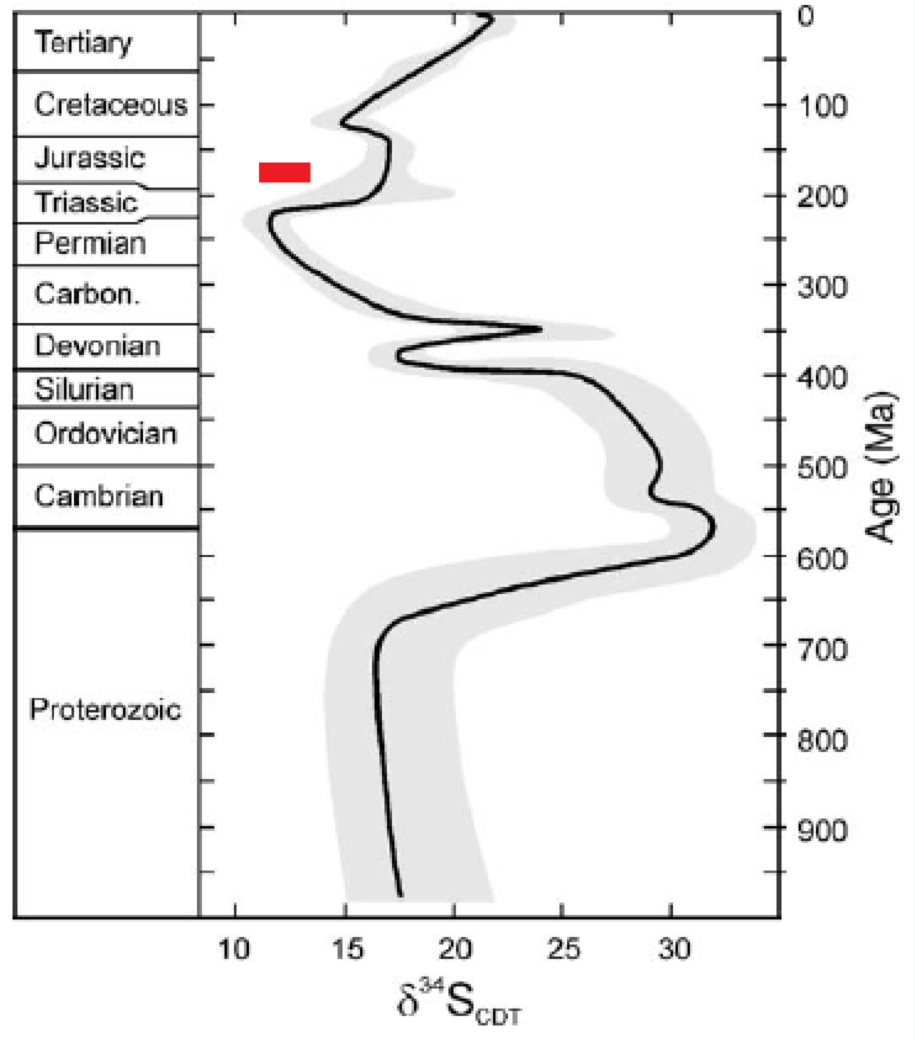




Notes by Presenter: Based on the calcite values and the restricted marine depositional environment, and assuming that these minerals were precipitated by waters not exceeding 100°C, the stable isotope data does not fit the model (please refer to Figure 23). We would expect the waters to have been depleted in terms of δ18O because of the increased rate of evaporation associated with restricted marine basins. Instead, what we observe is waters that are isotopically lighter. If we were assuming that the waters precipitating the calcite were associated with the isotopically heavier restricted marine waters, then the only explanation is that the waters were at a higher temperature.

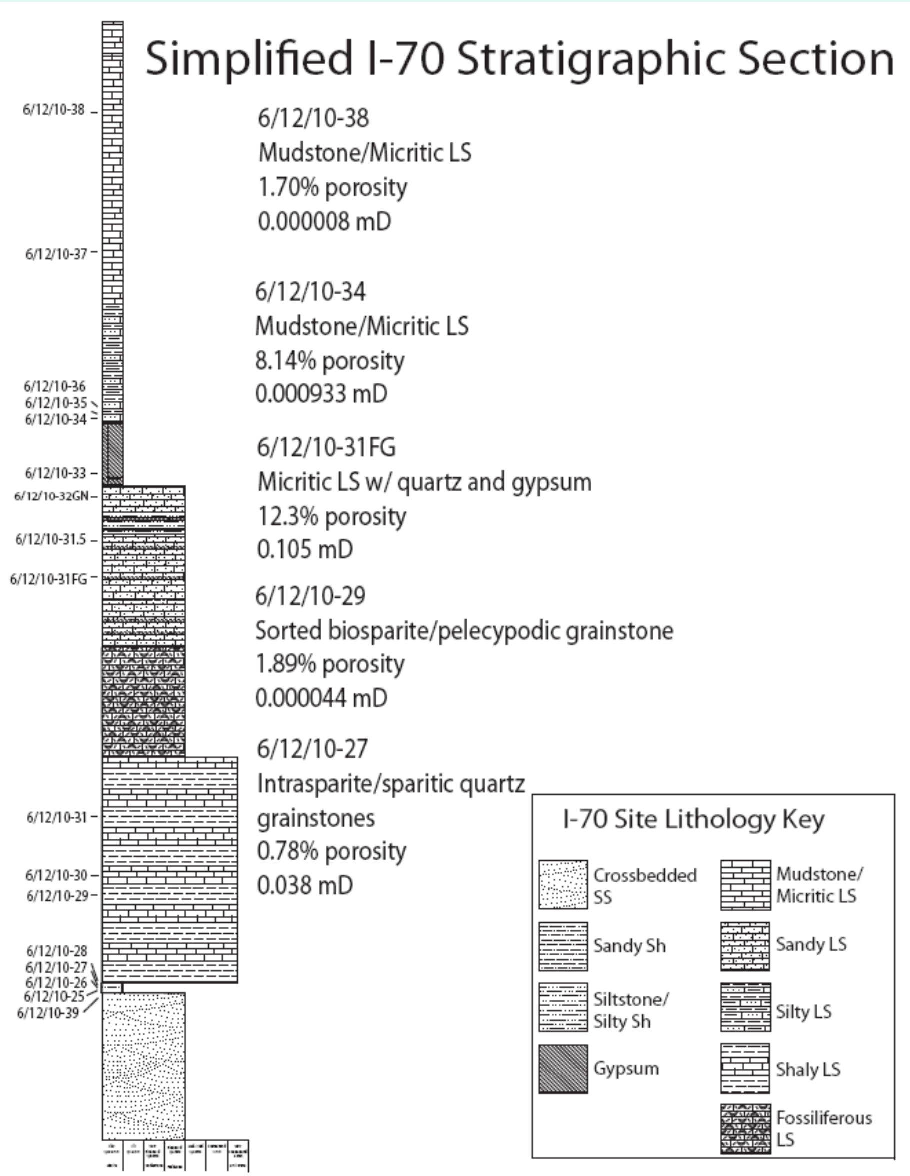
Isotopic values that were provided by mass spec don't match surficial mineralization. Therefore, calcite veins must have formed at depth, from some other water source.

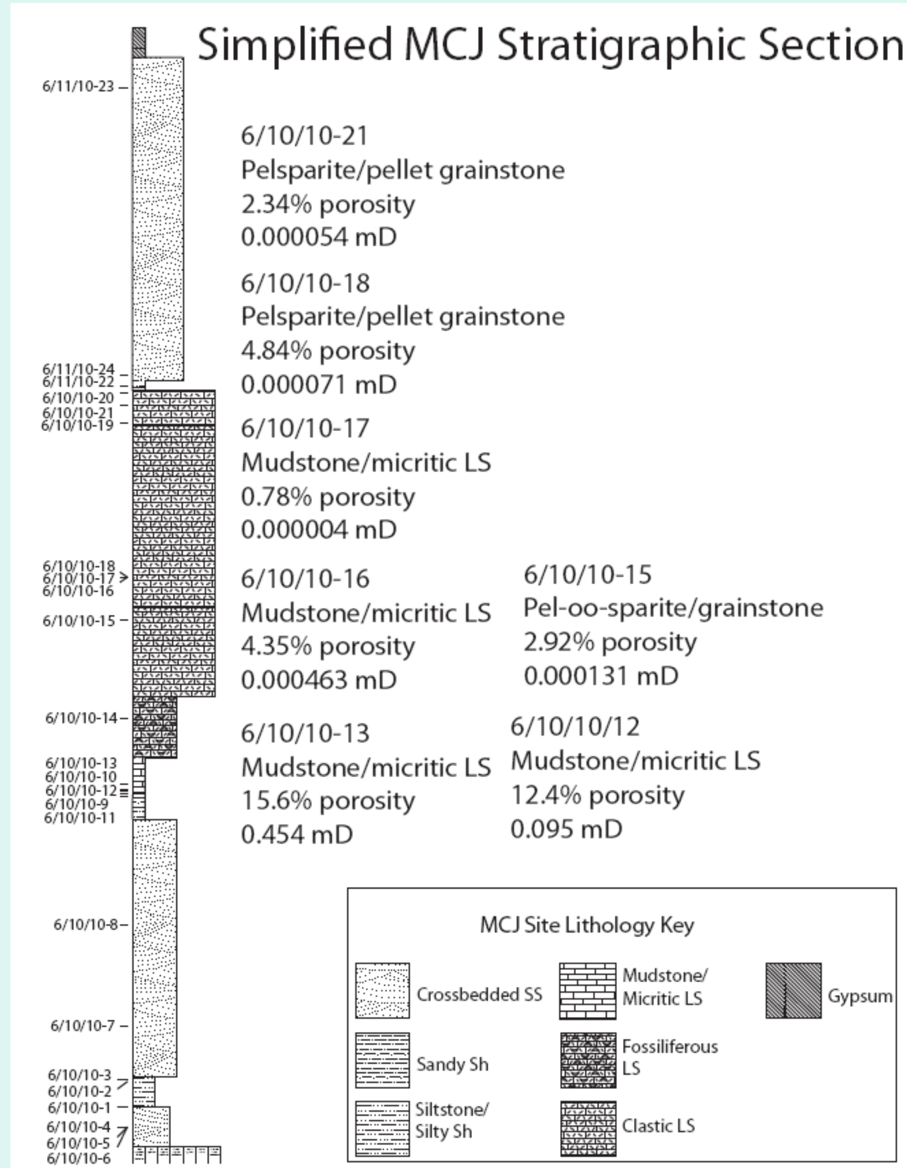
Stable Isotope - Gypsum



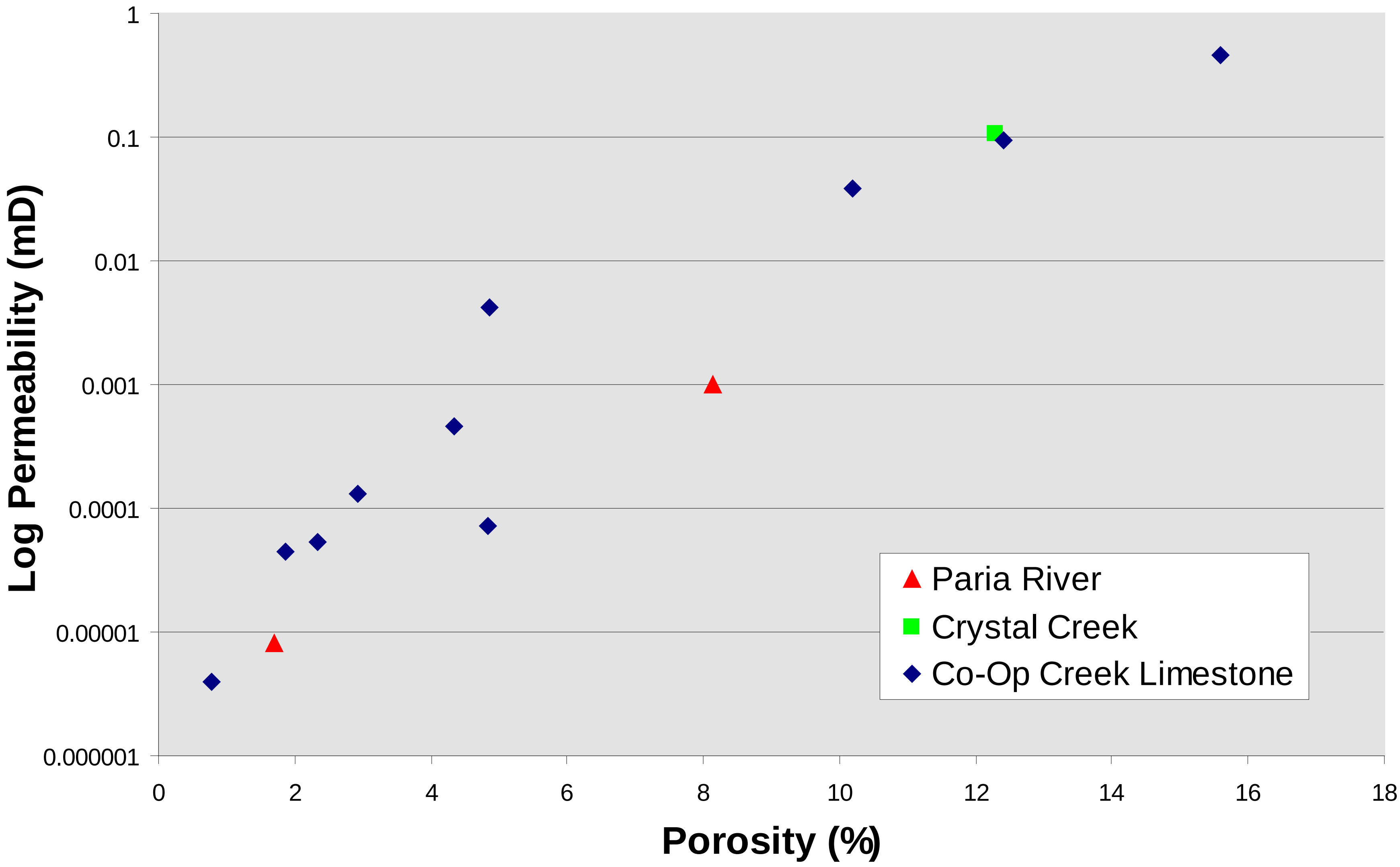
Bottrell and Newton, 2006

Carmel Stratigraphic sections





Log Permeability (mD) vs. Porosity (%)



CO_2 Column Height Equations

- Convert air/mercury system into brine/CO_2

$$P_{b/CO_2} = P_{a/m} (\sigma_{b/CO_2} cos\theta_{b/CO_2})/(\sigma_{a/m} cos\theta_{a/m})$$

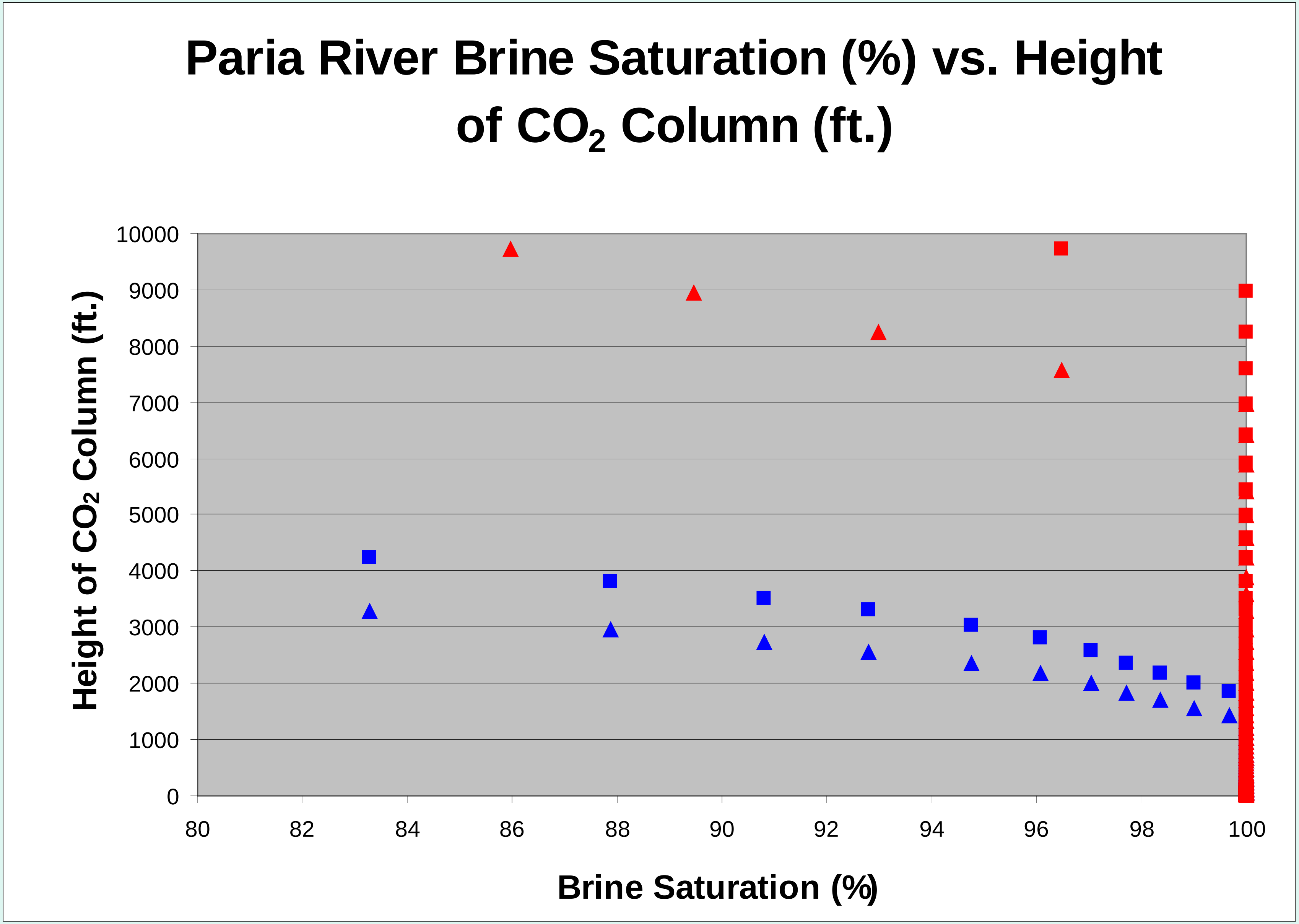
- Convert capillary pressure data into height above free water level

$$h = P_{b/CO_2}/(\rho_b - \rho_{CO_2})*0.433$$

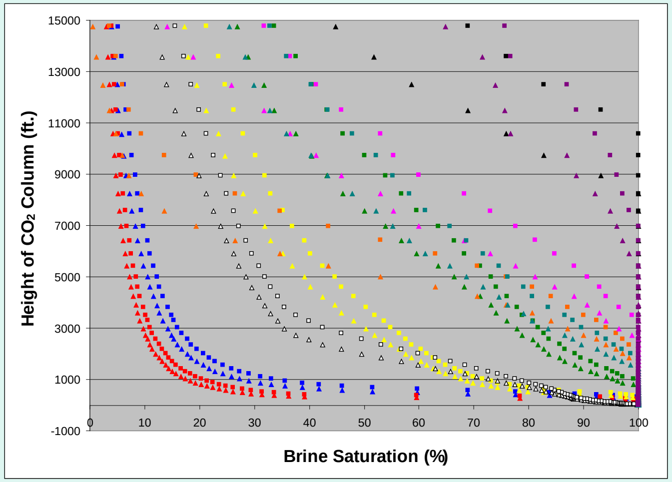
Daniel and Kaldi, 2009

Notes by Presenter: Where *PbCO2* is the capillary pressure in water-CO2 system, *Pa/m* is the capillary pressure in the air-mercury system, *σbCO2* and *σa/m* are the IFTs (interfacial tension) of the water-CO2 and air-mercury systems, respectively, and *θbCO2* and *θa/m* are the contact angles of the water-CO2-solid and air-mercury-solid systems, respectively (Daniel and Kaldi, 2009). *PbCO2* and *Pa/m* were provided by Poro-Technology and their MICP measurements.

where *Pc b/CO2* is the capillary pressure reservoir water-CO2 system in psi, *h* is the height in feet, *ρb* is the subsurface water density in g/cm3, and *ρCO2* is the subsurface CO2 density in g/cm3.

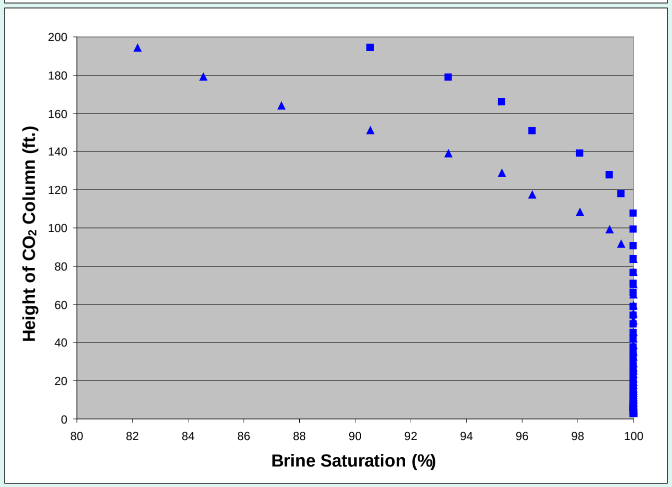


Sequester ~1,400-9,800 ft. CO2



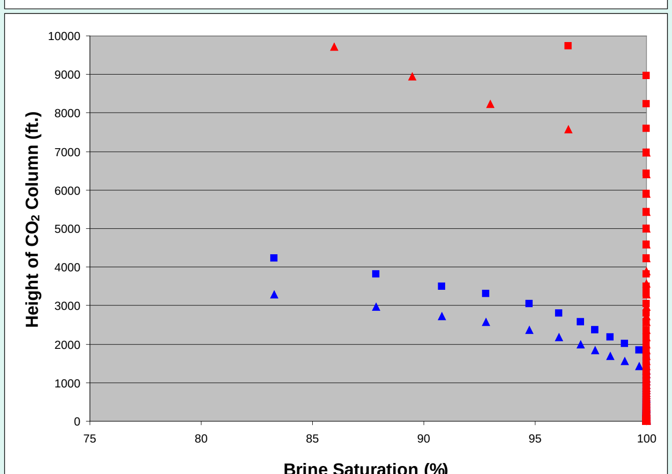
Co-Op Creek Limestone Member

Sequester ~25-11,000 ft. CO_2



Crystal Creek Member

Sequester ~90-120 ft. CO_2



Paria River Member

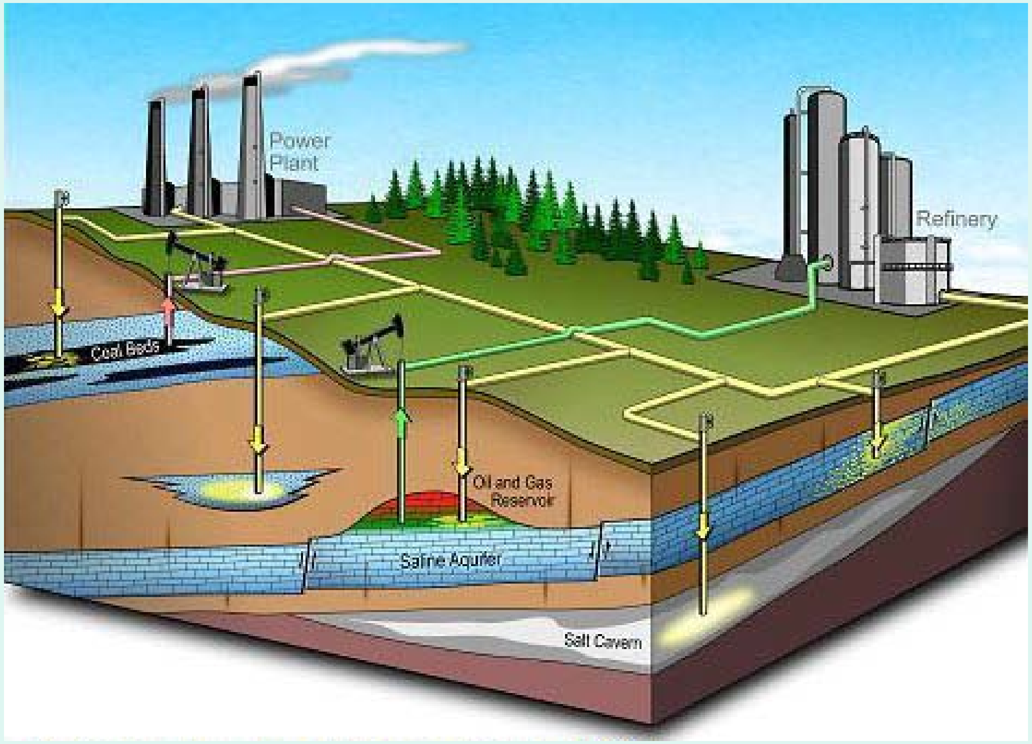
Sequester ~1,400-9,800 ft. CO_2

Conclusions

- Diagenetic alteration porosity/permeability reducing
  - Calcite/gypsum cementation
- Fractures should be mineralized at depth
- Co-Op Creek and Paria River Members least permeable
  - Should be able to safely sequester CO_2


Questions?

Introduction – What is CO_2 sequestration?



- Capture
- Compression
- Transportation
- Injection
- Monitoring

http://coalgasificationnews.com/2009/05/23/significant-co2-sequestration-project-is-announced/

Methodology

- Field work
  - Outcrop descriptions as framework for sampling
  - Fracture analysis
- Petrography
  - Lithologies
  - Paragenesis
- Stable Isotopes
  - Depositional environment
  - Fracture analysis
- Permeability
  - MICP

MICP

Sample	Porosity (%)	Perm (mD)	Density (g/c^3)
6/10/10-12	12.4	0.095	2.723
6/10/10-13	15.6	0.454	2.5
6/10/10/14	4.87	0.00421	2.648
6/10/10-15	2.92	0.000131	2.666
6/10/10-16	4.35	0.000463	2.677
6/10/10-17	0.78	0.000004	2.684
6/10/10-18	4.84	0.000071	2.606
6/10/10-21	2.34	0.000054	2.64
6/12/10-27	10.2	0.38000	2.69
6/12/10-29	1.89	0.000044	2.627
6/12/10-31 FG	12.3	0.105	2.644
6/12/10-34	8.14	0.000993	2.655
6/12/10-38	1.70	0.000008	2.608

SI – Calcite

	$\delta^{13}C$	$\delta^{18}O$
F2B	-4.31	12.99
F2B Dup	-4.26	12.72
F2C	-4.00	14.89
F2C Dup	-3.21	15.81
F3B	-4.31	12.88
F3B Dup	-4.55	12.89

Notes by Presenter: Take out best fit line and throw in SMOW line, along with plot of where normal LS would plot.

SI – Gypsum Mineralization

	$\delta^{34}S$
7/10/10-F1	-11.33
7/10/10-F1(Dup)	-11.54
7/10/10-F4A	12.13
7/10/10-F4A(Dup)	11.82
7/10/10-F4B	12.14
7/10/10-F4B(Dup)	12.22
7/10/10-F5A	12.57
7/10/10-F5A(Dup)	13.25
7/10/10-F5B	12.59
7/10/10-F5B(Dup)	12.34
7/10/10-F6	13.16
7/10/10-F6 (Dup)	13.22

Notes by Presenter: The sulfur values are all grouped around 12‰, with the notable exception of sample 7/10/10-F1, with a value of -11.4‰. All of the gypsum samples were obtained from mineralized fractures and beds from the I-70 site. Having a difference of 23 parts per mil from the exact same depositional environment is very odd. One might think that this is a poor data point obtained from the mass spec, but a each sample was run twice, so its value is correct. I am unable to properly explain how this very different value could co-exist with the others.

Ask Andy about how this could have happened.

Results - Co-Op Creek Member

Notes by Presenter:

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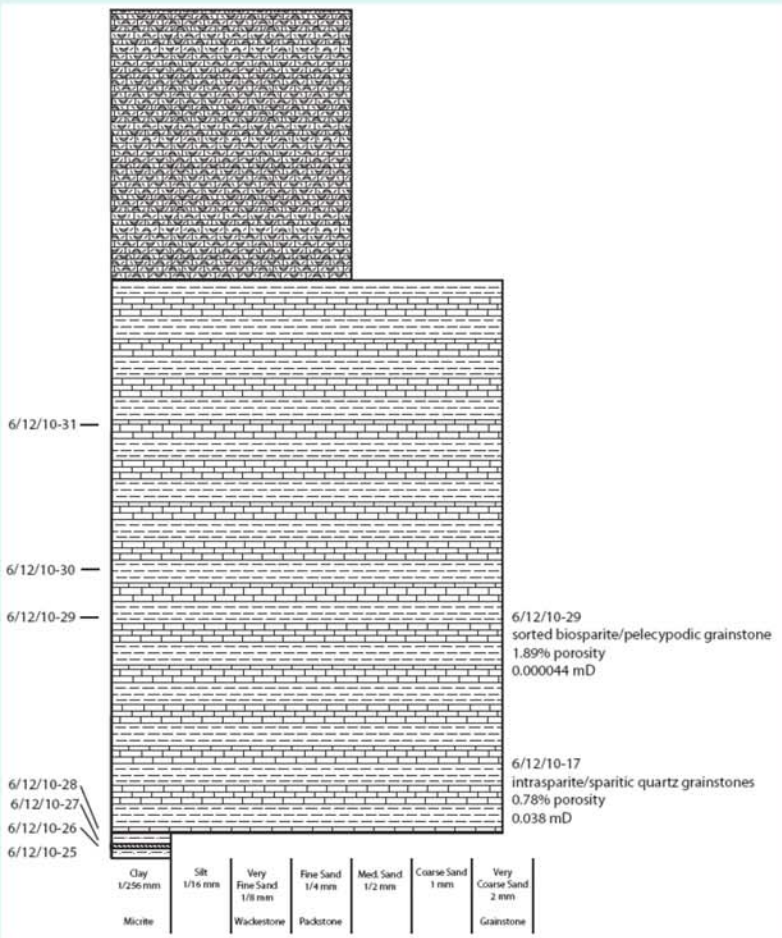
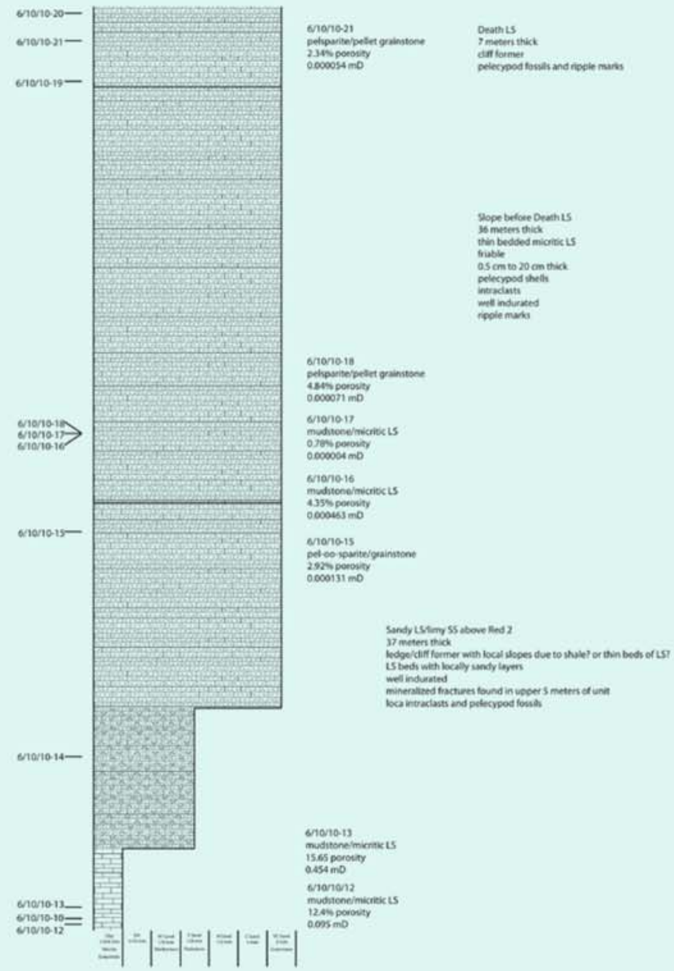
Co-Op Creek Properties





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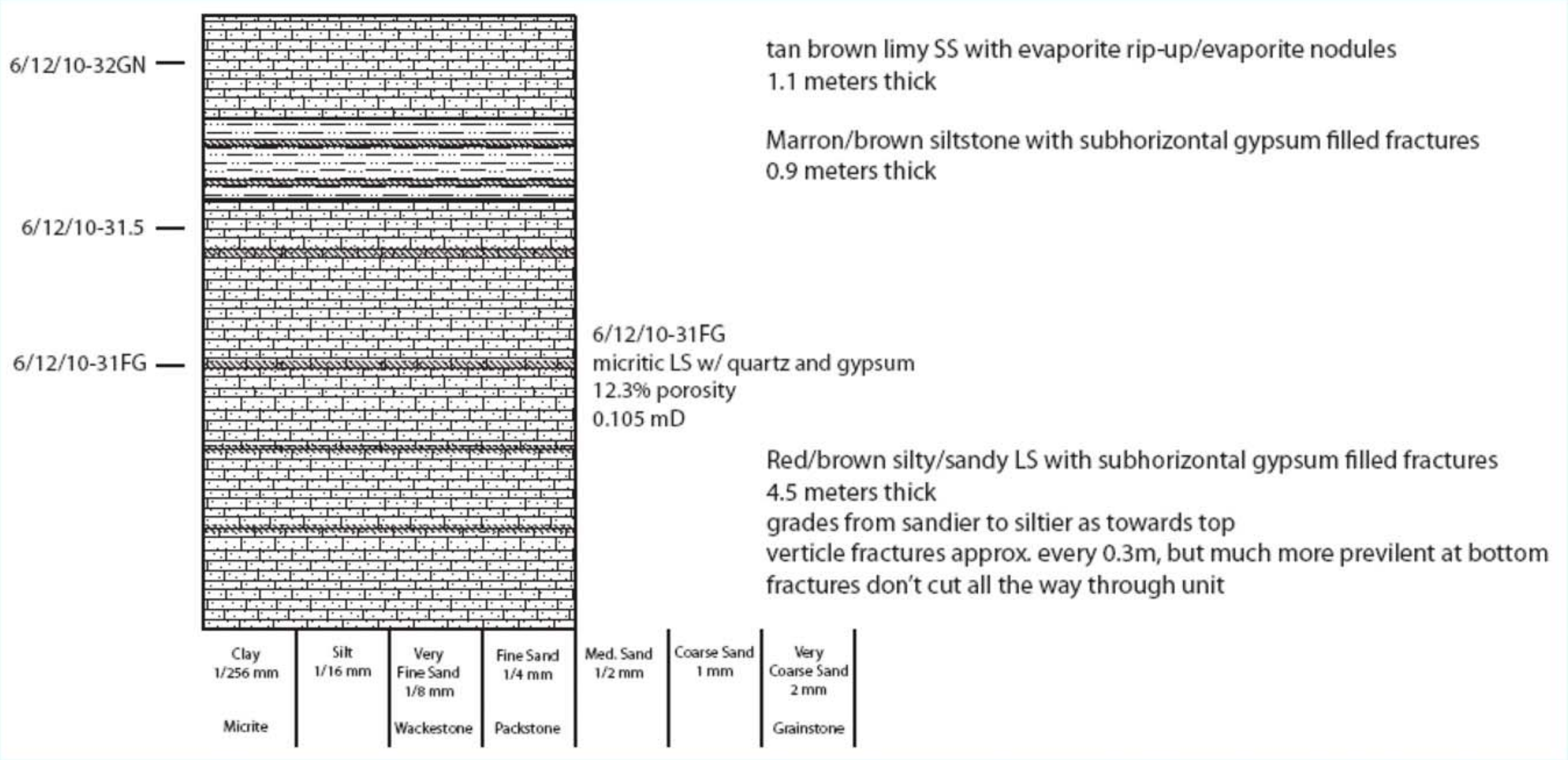
Crystal Creek Properties



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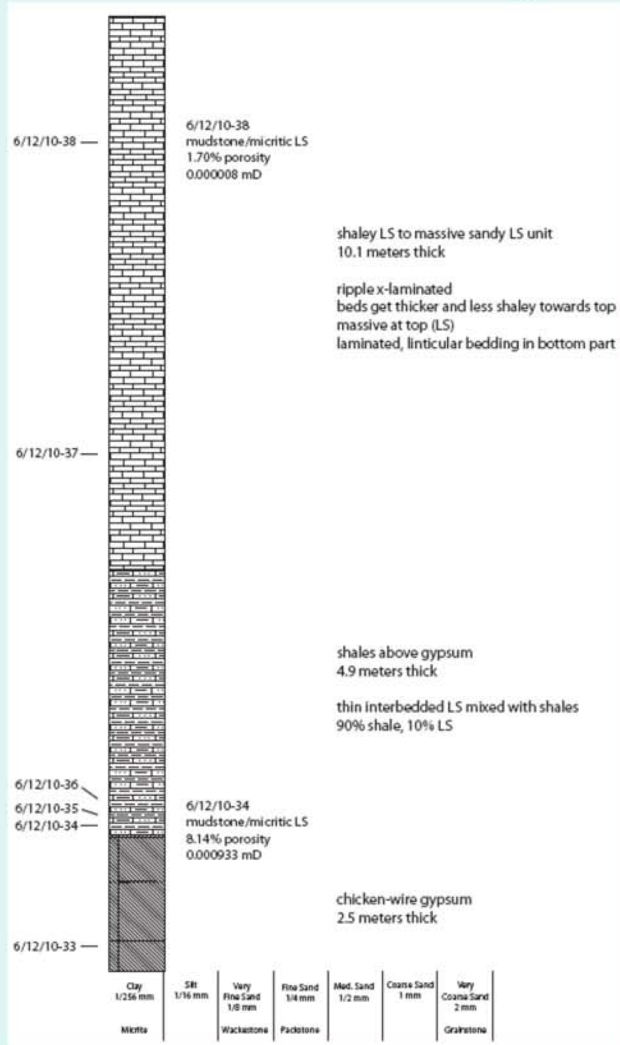
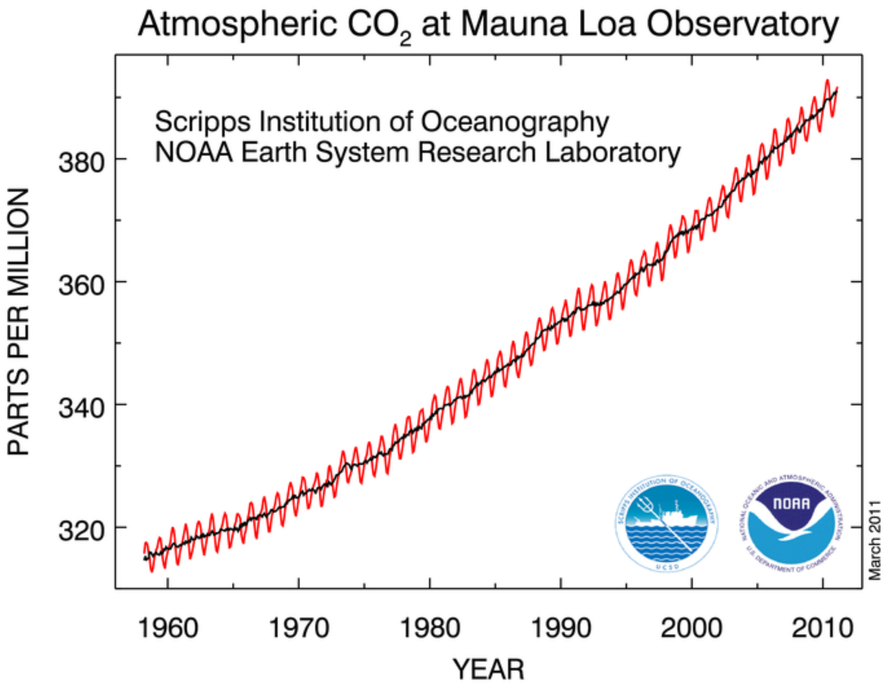
Paria River Properties



Notes by Presenter: The Crystal Creek member ranges in permeability from 0.000008 mD to 0.000993 mD at the I-70 site. In terms of porosity, values range from 1.70 to 8.14% at the I-70 site.

Who cares?



http://www.esrl.noaa.gov/gmd/ccgg/trends/

- Mitigation of global climate change
- Continued reliance on fossil fuels
- Potential economic incentives