[AV]Potential Paleozoic Shale Gas Resources in Utah*

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Abstract

Paleozoic shales in Utah have tremendous untapped gas potential. These include the Mississippian/Pennsylvanian Manning Canyon Shale and Pennsylvanian Paradox Formation of central and southeastern Utah, respectively. Shale beds within these formations are widespread, thick, buried deep enough to generate dry gas, and sufficiently rich in organic material and fractures to hold significant recoverable gas reserves.

The greatest Manning Canyon Shale potential is a 600-mi^2 area at the north end of the San Rafael Swell. The unit is 300-1500 ft thick; the average depth to the top of the formation is 7470 ft. Four major lithotypes are: (1) carbonate, (2) fine-grained quartz sand and silt, (3) illite, smectite, and chlorite clays, and (4) organic matter composed dominantly of degraded fragments of terrestrial plants. This organic matter has good to excellent richness (TOC up to 15%), distributed throughout the shale, limestone, and even siltstone. Vitrinite reflectance indicates that the kerogen is in the dry gas thermal maturity window. The Manning Canyon lacks the cyclicity and lateral continuity found in many Carboniferous cyclothem units. It may have been deposited in a shallow restricted marine, brackish, and freshwater setting not unlike the modern Everglades and Florida Bay.

The organic-rich "black shales" of the Paradox Formation cycles are well known as the source for hydrocarbons in stratigraphically proximal carbonate reservoirs. Recent drilling has successfully produced gas emanating from the shales themselves. Individual shale units generally range between 25 and 50 ft thick at depths of 5800-6500 ft. Cores reveal several important parameters: (1) most shales are organic mudstones containing significant amounts of silt, pyrite, and fossil debris, (2) TOC values are modest (1-5%), (3) maturity values fall within the oil (or oil-gas) window, and (4) porosity (2-3%) and permeability values are low. The bounding and interbedded carbonate units are silty or muddy dolostones, in many cases possessing modest amounts of intercrystalline and microvuggy pore space. These dolostones, as well as some shales, are also beset by numerous subvertical fractures. Therefore, the gas production very likely is derived not only from the shales,

but also from the associated carbonates. Thus, this shale play is likely an intermixed series of reservoir types, all of which could produce upon successful stimulation.

Selected References

Hintze, L.F., and B.J. Kowallis, 2009, Geologic History of Utah: Brigham Young University Geology Studies 9, 225 p.

Moyle, R.W., 1958, Paleoecology of the Manning Canyon Sahel in Central Utah: Master’s thesis, Brigham Young University Geology Series v. 5/7, 86 p.

Potential Paleozoic Shale Gas Resources in Utah

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Utah Geological Survey

American Association of Petroleum Geologists, Annual Convention
April 12, 2011
Houston, Texas

UTAH
DNR
GEOLOGICAL SURVEY

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Research Partnership to Secure Energy for America

“Paleozoic Shale-Gas Resources of the Colorado Plateau and Eastern Great Basin, Utah: Multiple Frontier Exploration Opportunities”

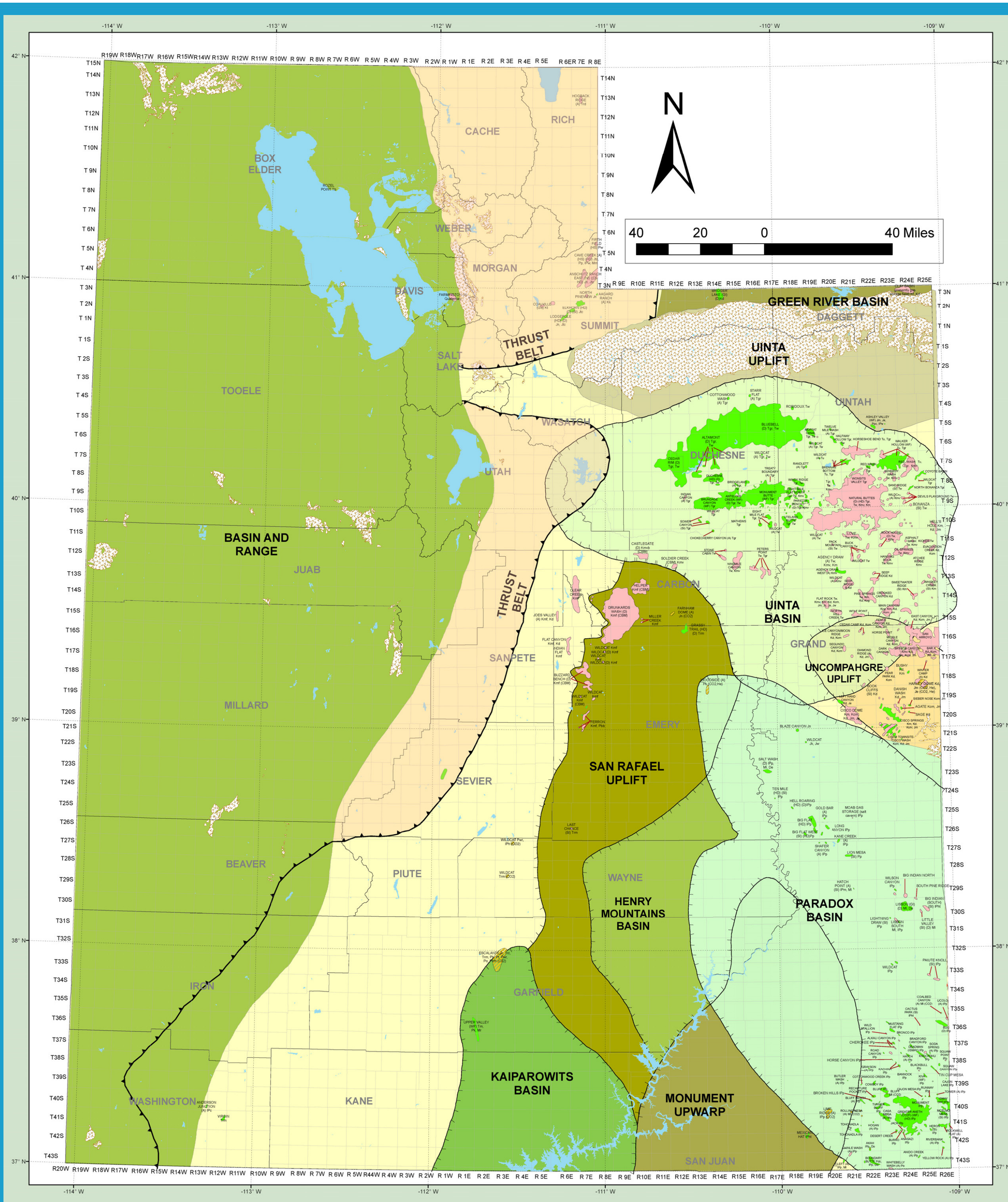
Project Goal

Provide basin specific analyses of shale-gas reservoir properties to develop the best local completion practices that can be applied to the emerging Manning Canyon and Paradox frontier gas shales.

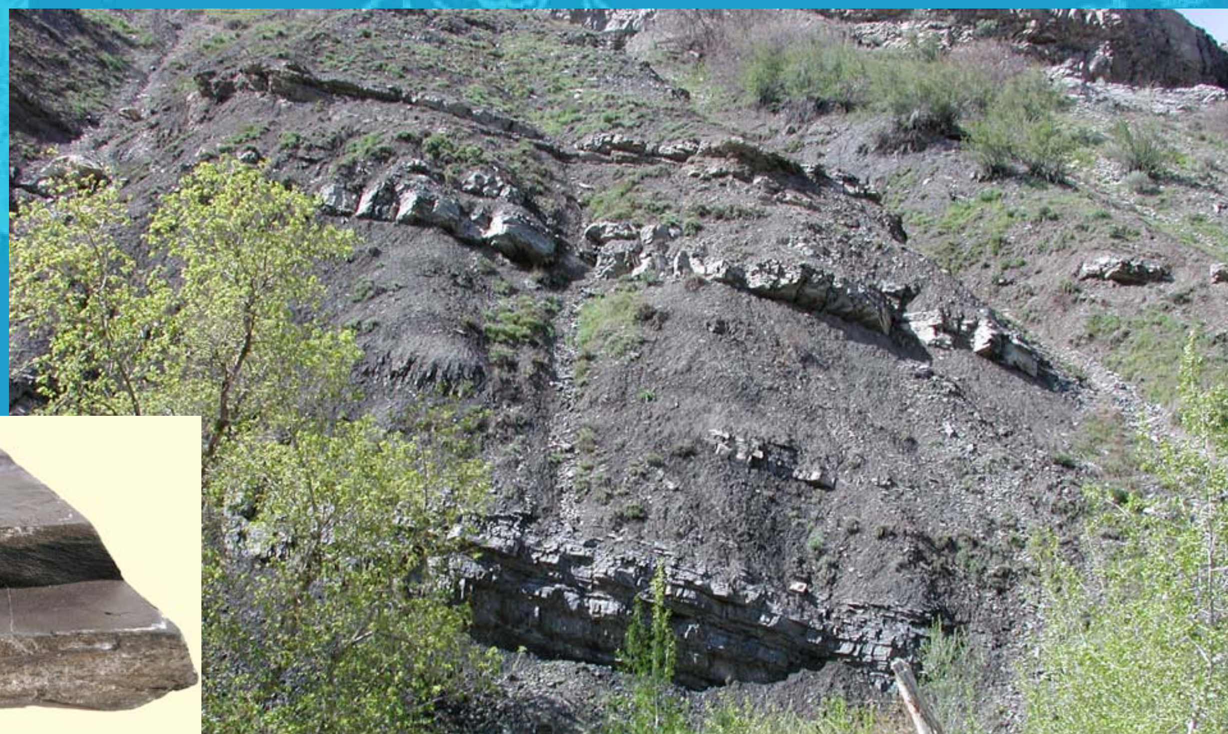
Objectives

- Identify and map the major trends for frontier gas shale
- Identify areas with the greatest gas potential
- Characterize the geologic, geochemical, petrophysical, & geomechanical rock properties
- Reduce exploration costs & drilling risk especially in environmentally sensitive areas
- Recommend the best practices to complete & stimulate frontier gas shales to reduce development costs & maximize gas recovery

Geologic Overview



Mississippian/Pennsylvanian Manning Canyon Shale Petrographic, Geochemical, and Facies Analysis

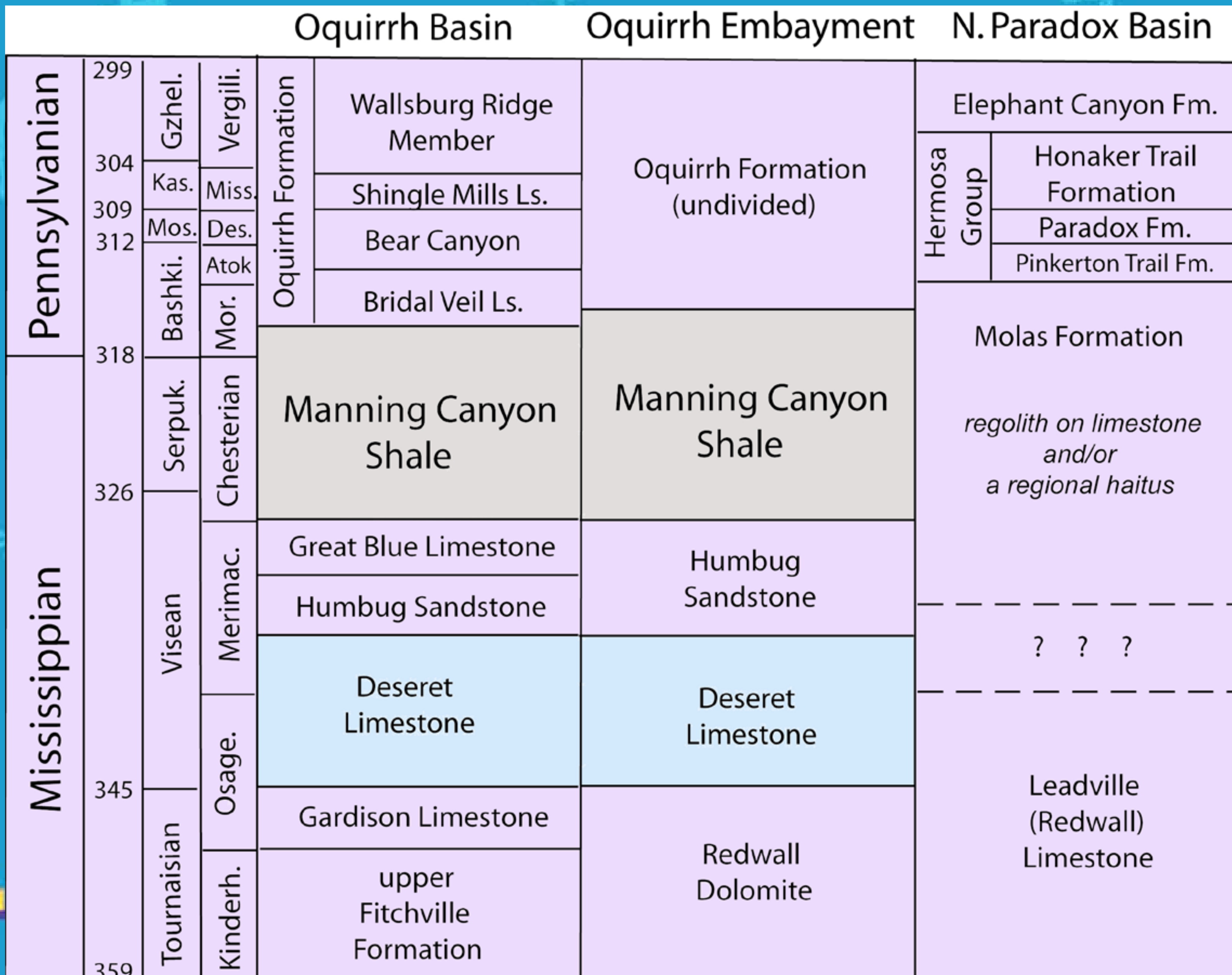


Organic-Rich Manning Canyon Shale Interbedded with Thin-Bedded Micritic Limestone, Western Provo Canyon, North-Central Utah

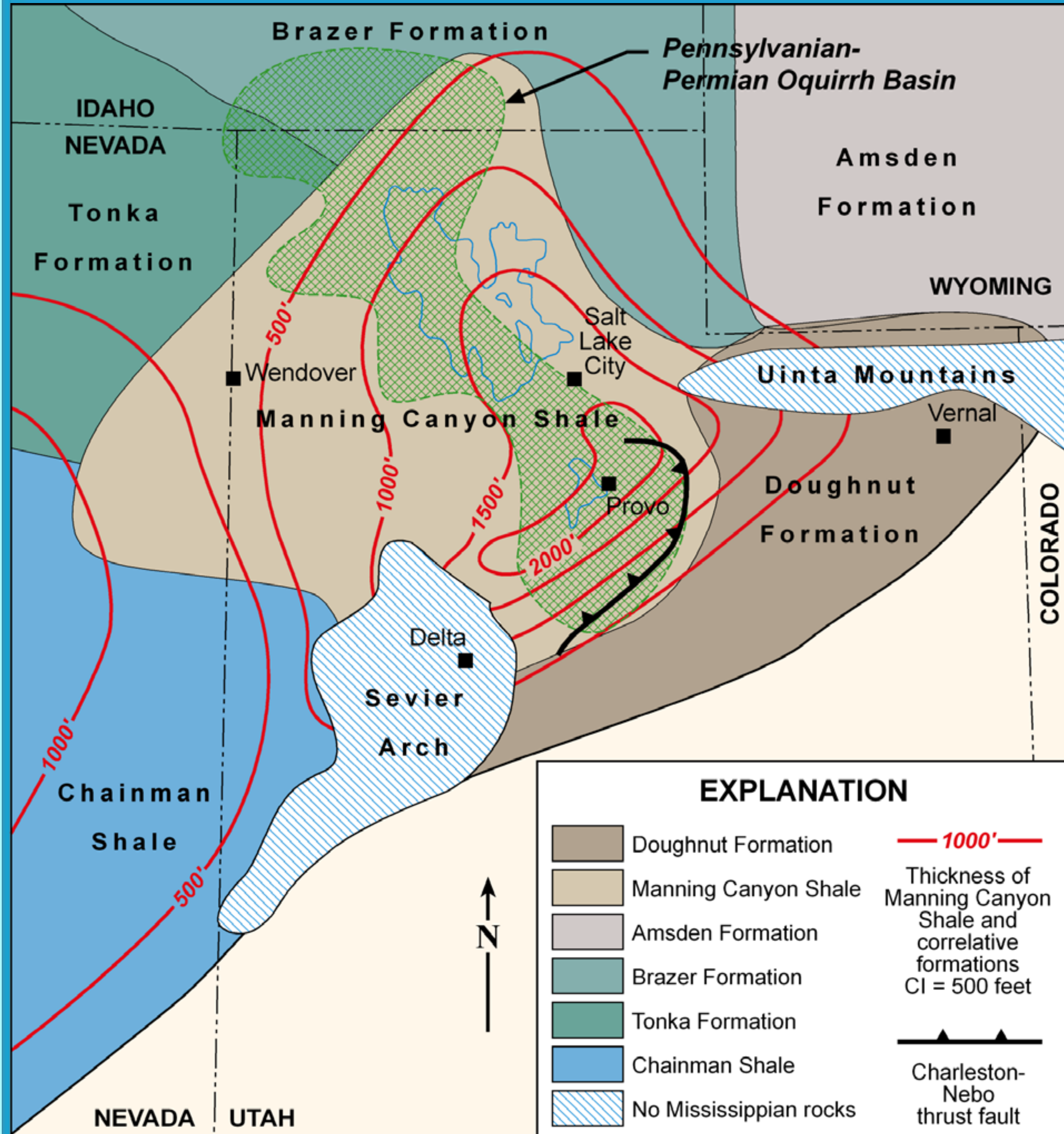
Mississippian/Pennsylvanian Manning Canyon Shale

- Mainly claystone with interbeds of limestone, sandstone, siltstone, and mudstone
- Maximum thickness of 2000 ft
- TOC varies from 1% to 15%
- Type III (?) kerogen
- In north-central Utah, the Manning Canyon was deeply buried by sediments in the Pennsylvanian-Permian-aged Oquirrh basin and is very thermally mature

Mississippian Stratigraphic Chart

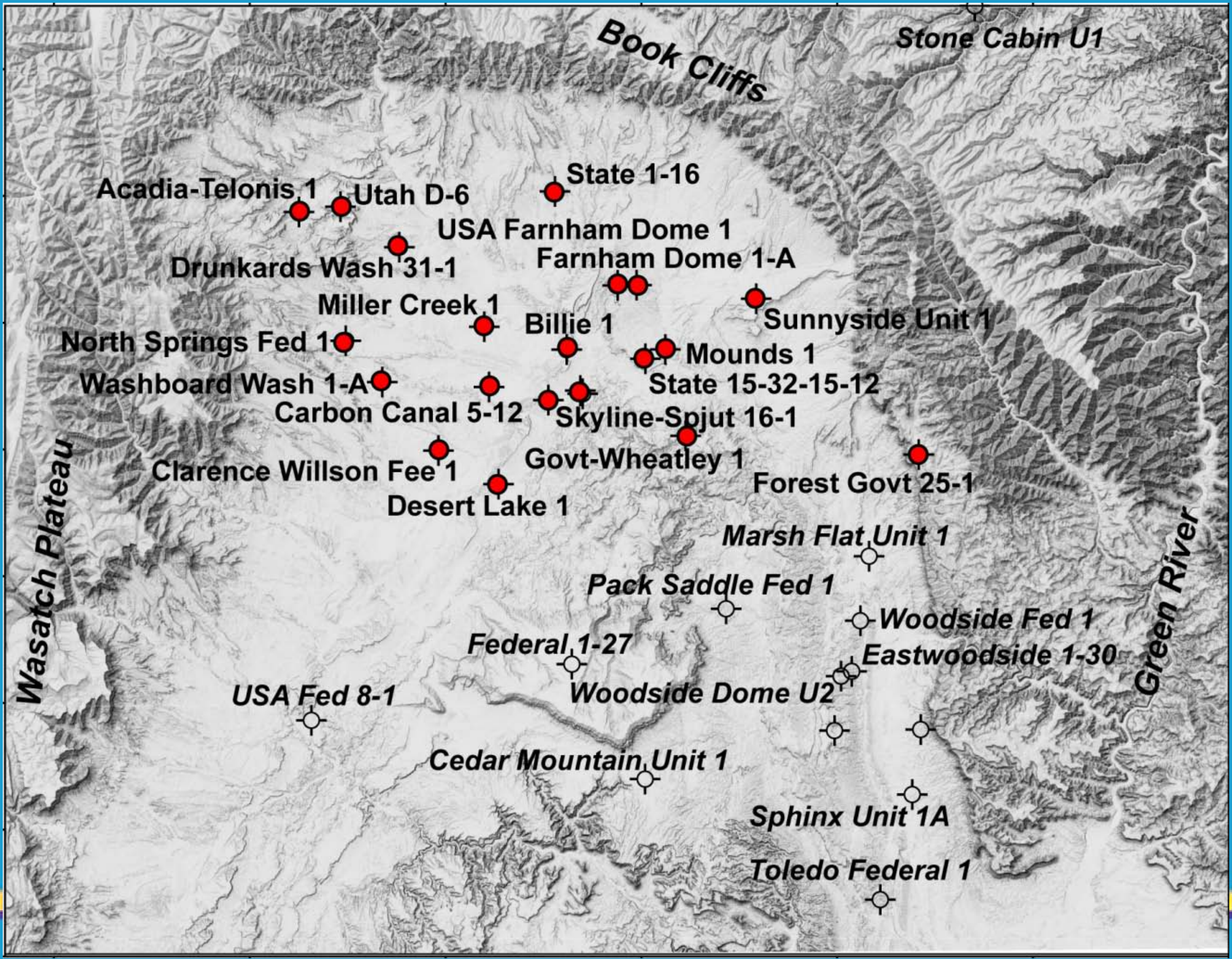


Thickness and Distribution of Manning Canyon Shale in Northern Utah and Correlative Formations in Adjacent Areas

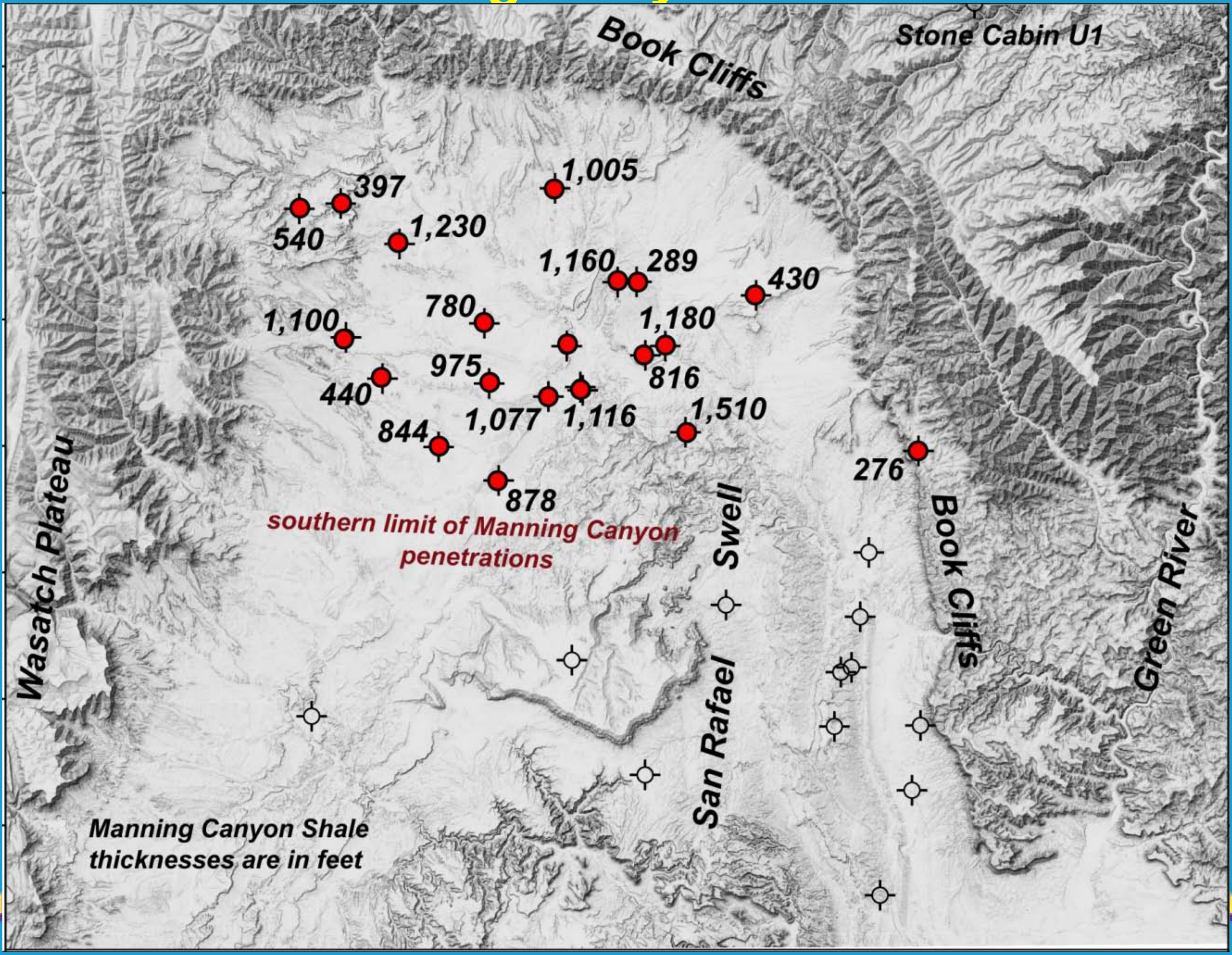


Modified from Moyle, 1958

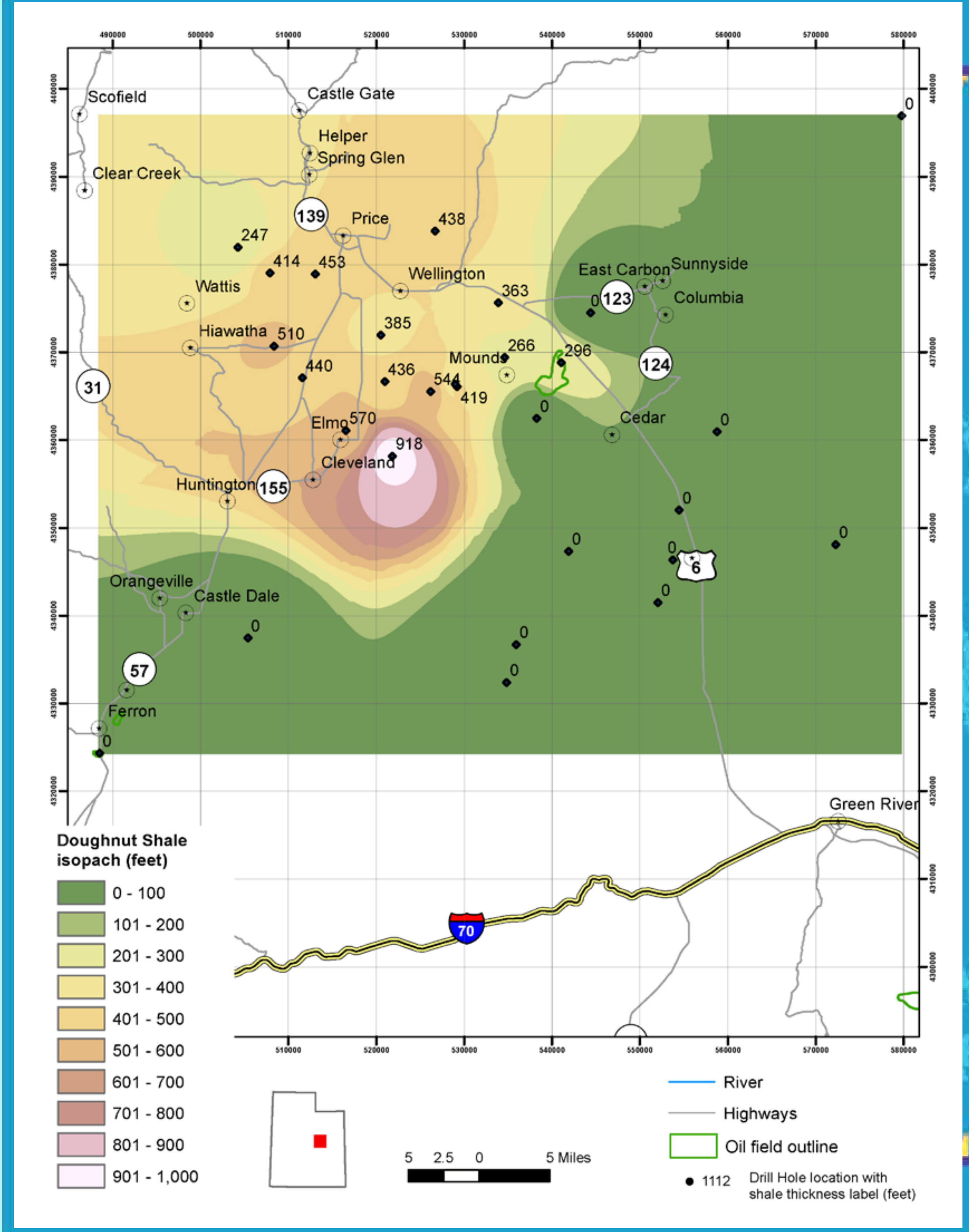
Manning Canyon Shale Well Penetrations, Northern San Rafael Swell Area

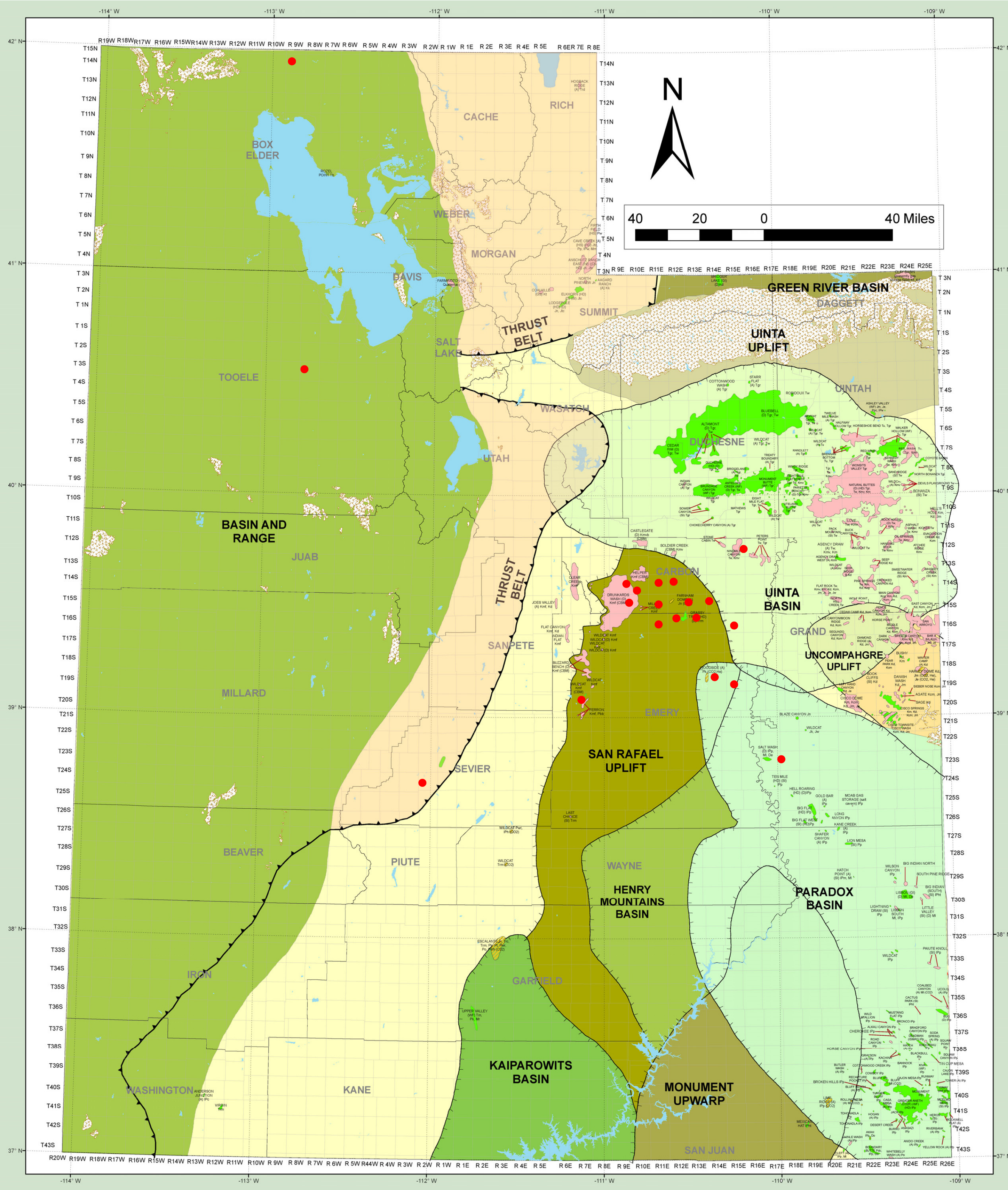


Reported Well Thickness of Manning Canyon Shale



Doughnut (Manning Canyon) Shale Isopach Map





Manning Canyon Cuttings and Core at the Utah Core Research Center

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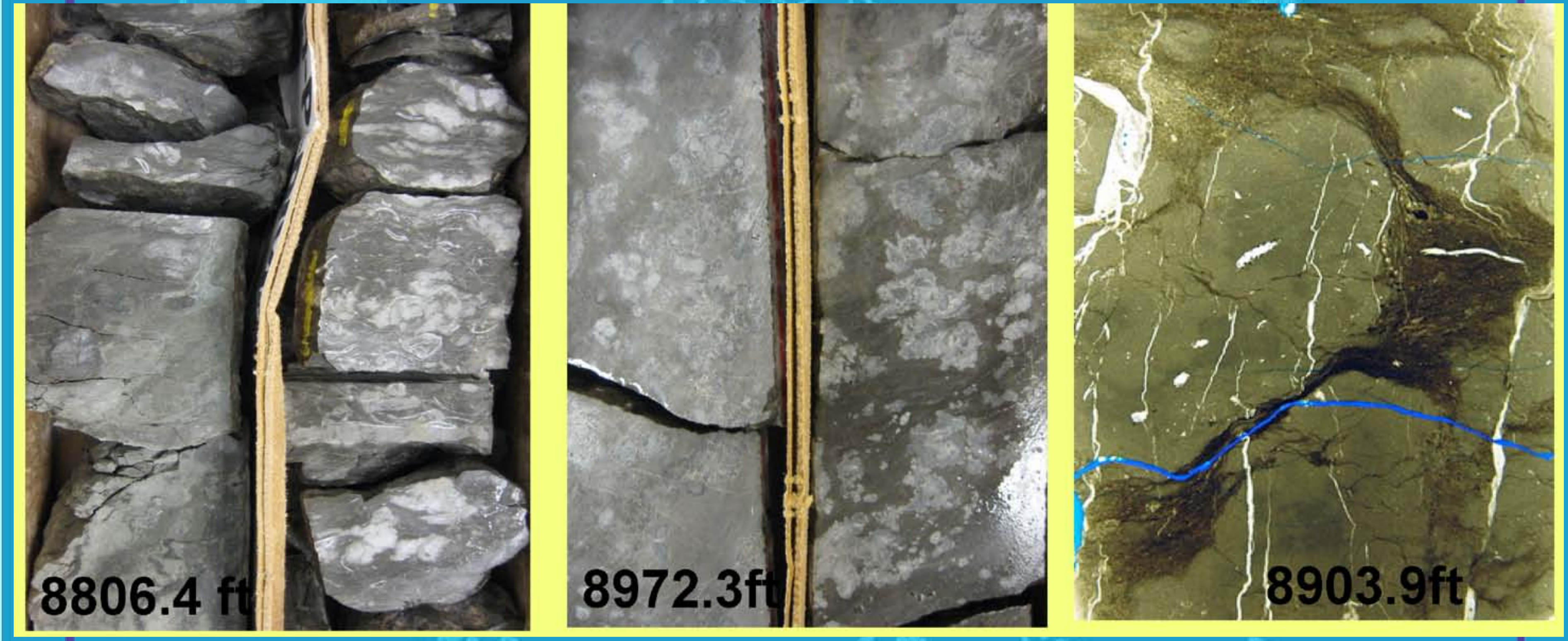
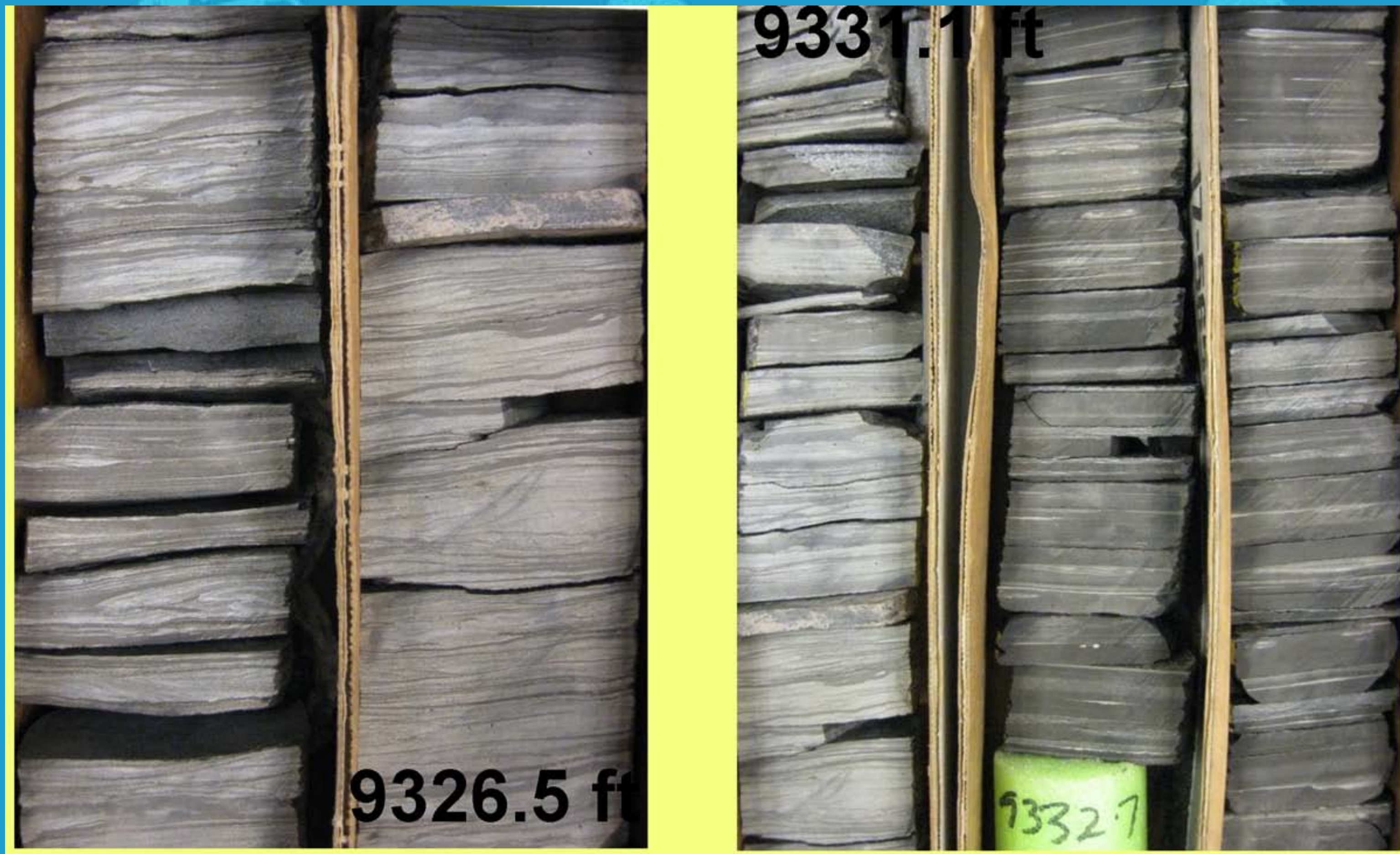
Limestone: Wackestone-Mudstone

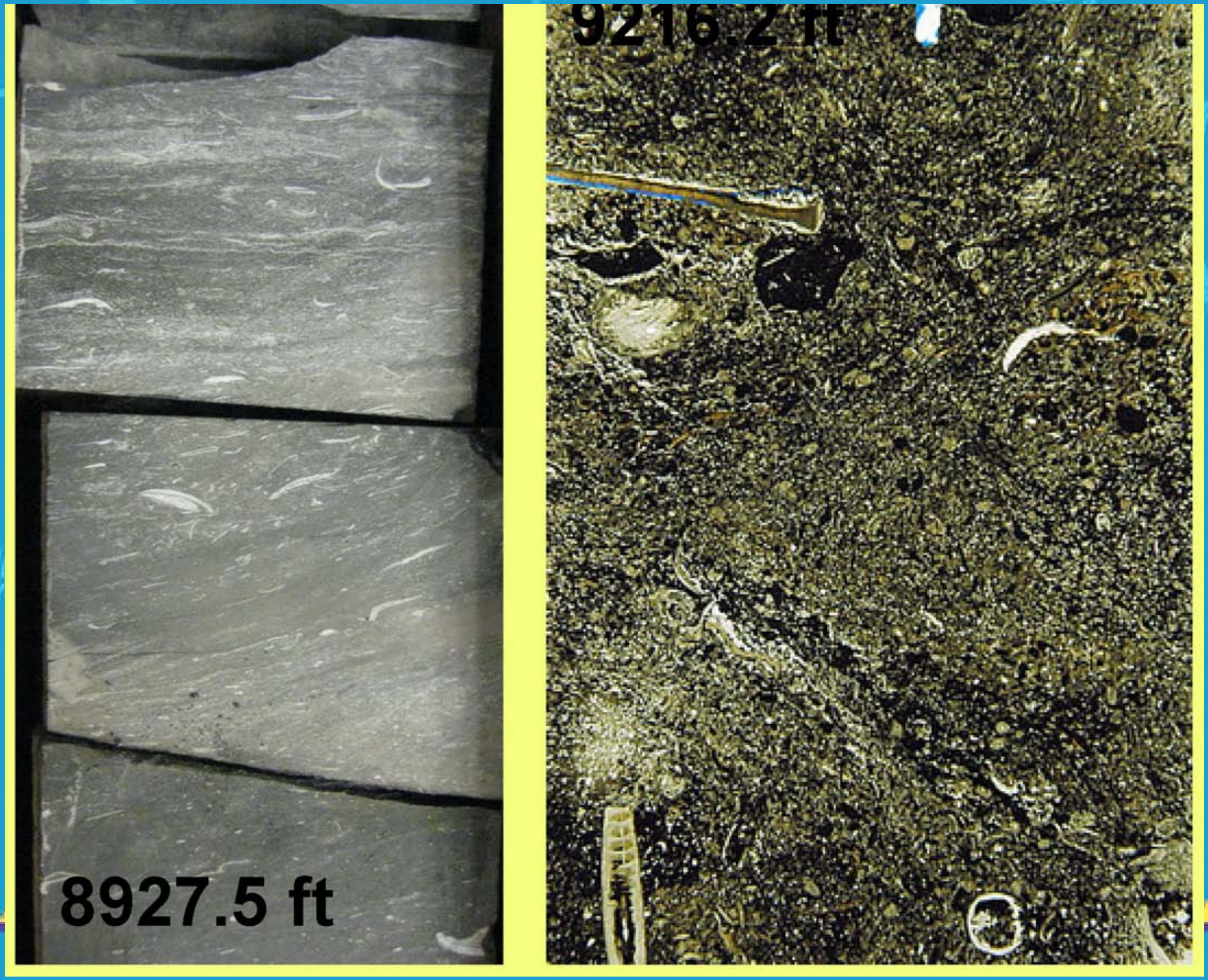


Fine-Grained Sandstone

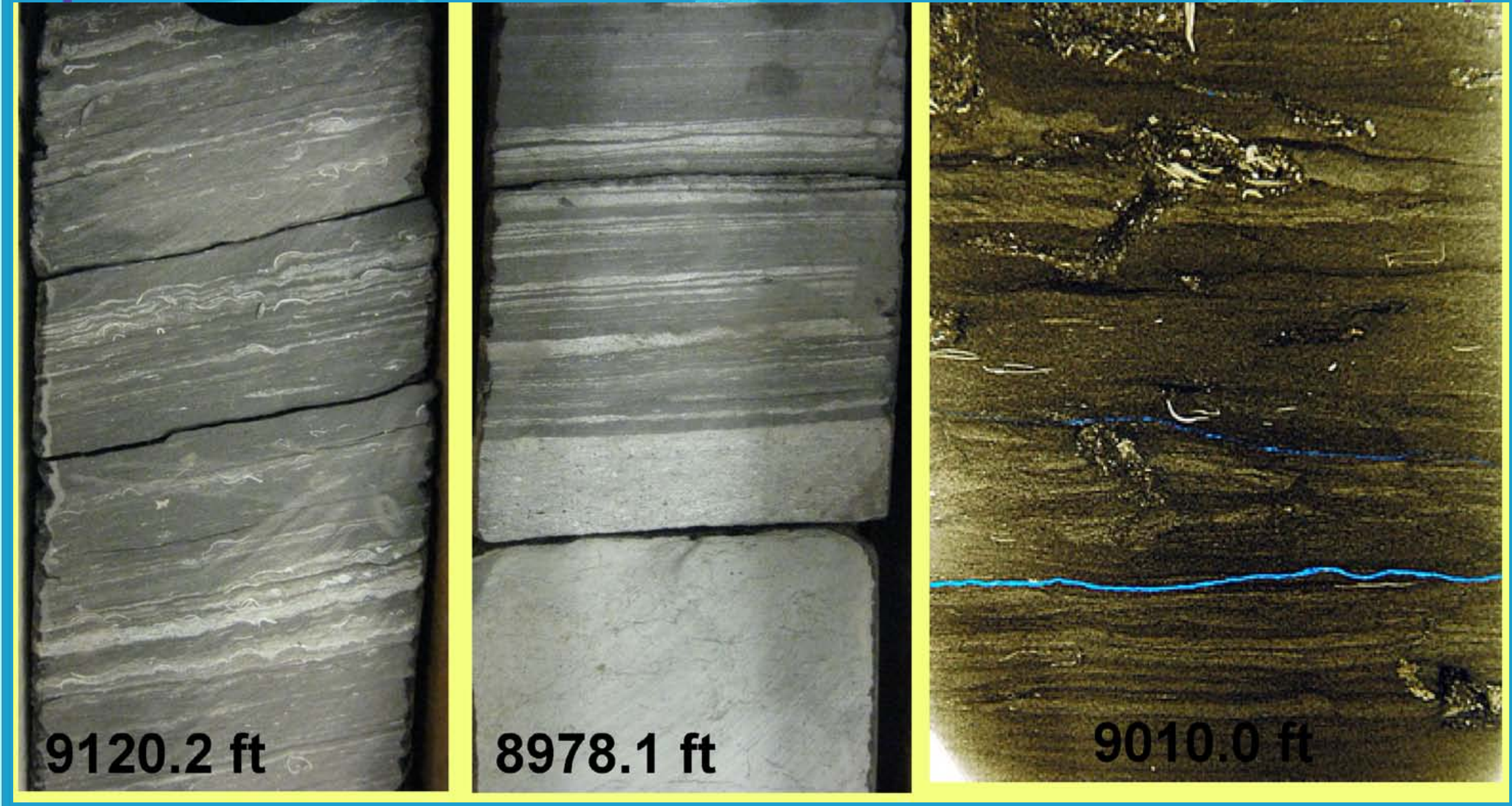
Laminar Siltstone



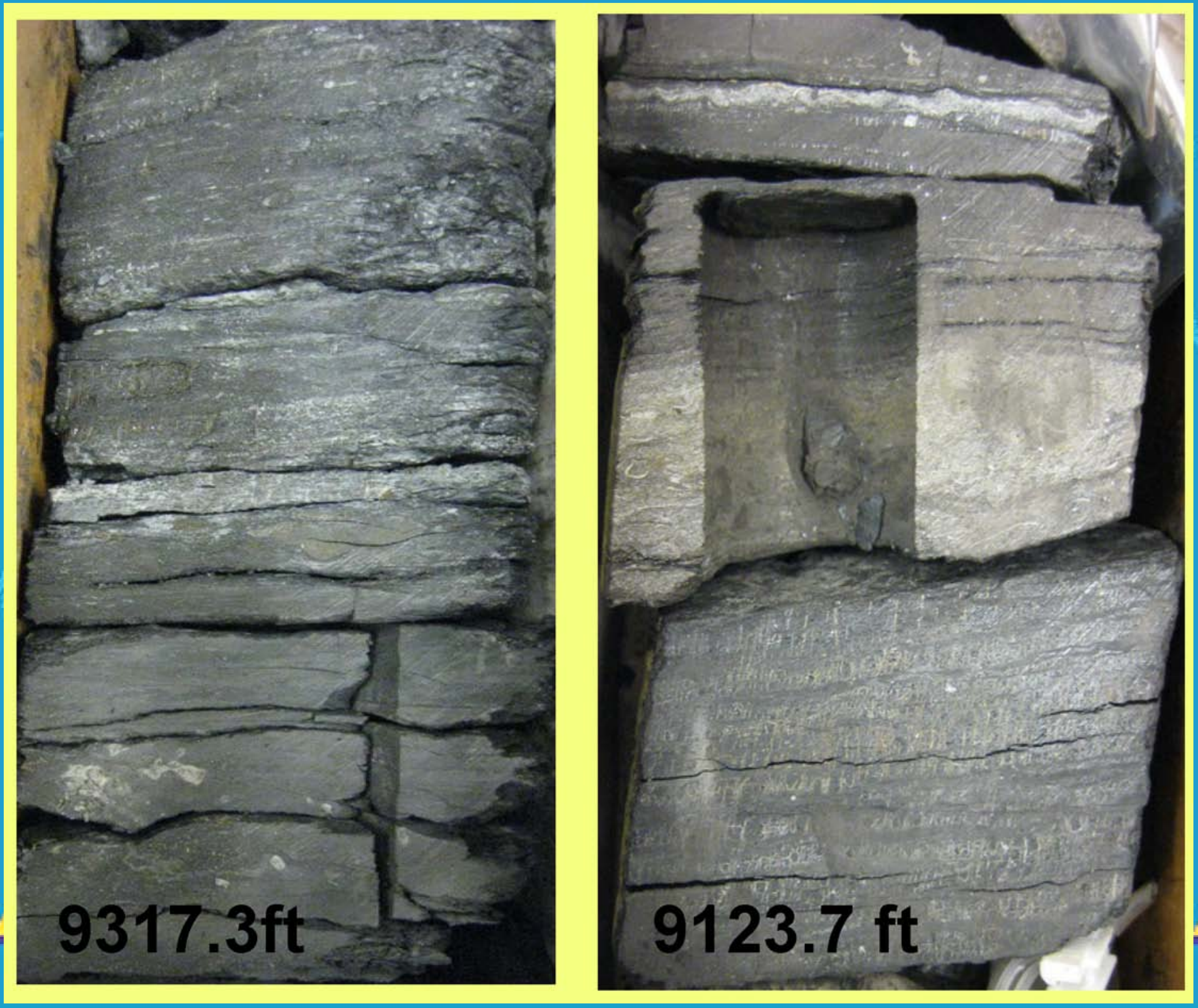
Carbonaceous-Shelly Limestone



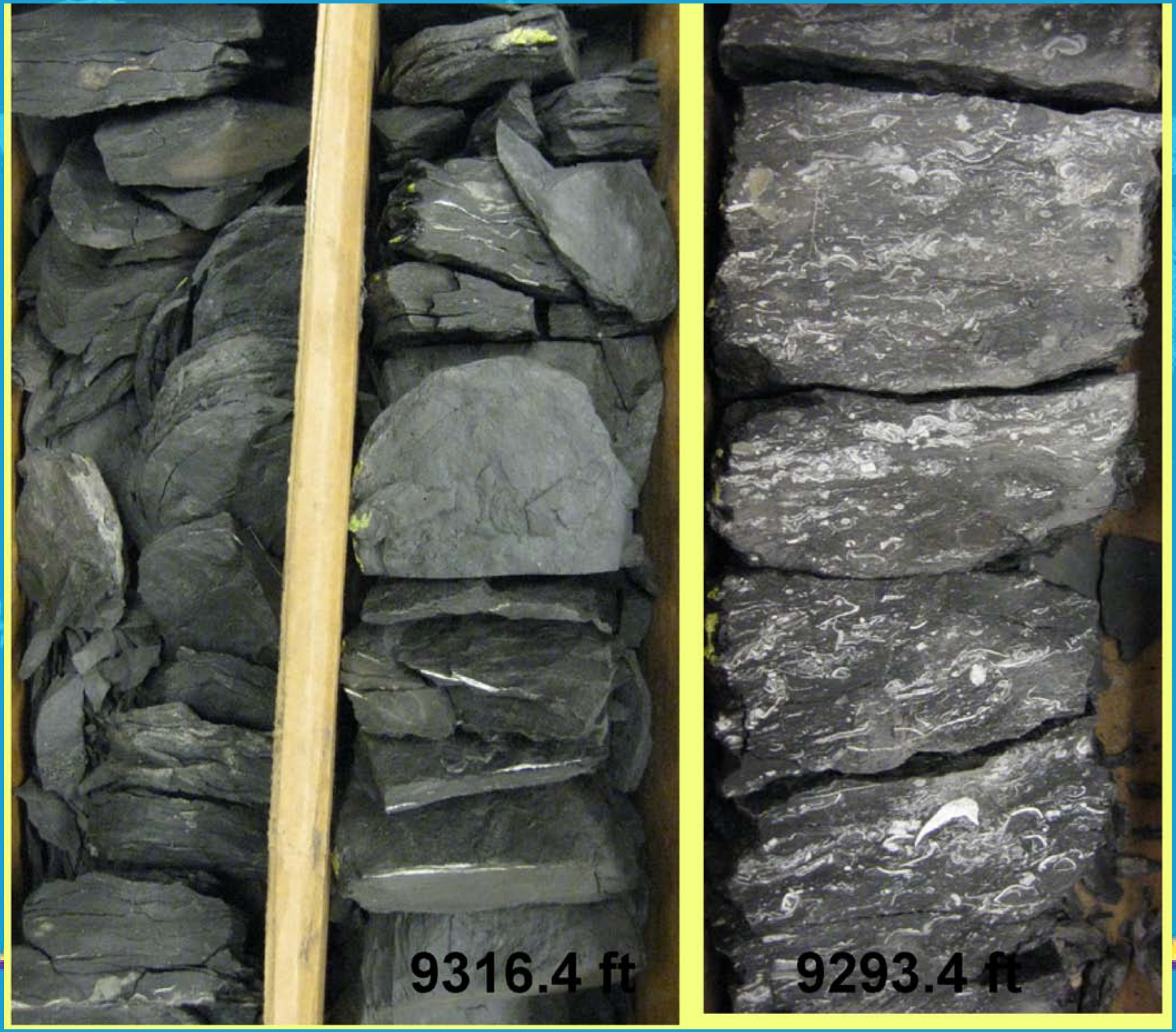
Carbonaceous-Laminar Limestone



Coal



Black Shale



Manning Canyon Lithotypes

Forest Govt 25-1 11,540 0.7X

Arcadia-Telonis 1 12,020 1.0X

Miller Creek 1 8,780 1.0X

Carbonate

Dominantly calcite microbioclasts and shelly debris organized into packstone, wackestone and limy mudstone.

Silt and Sand

Fine- and very fine-grained quartz sand, subrounded to subangular and angular silt.

Clays

Reported to be a mature assemblage of illite, smectite-illite and chlorite.

Organic Matter

Dominantly degraded fragments of terrestrial plants found as disseminated micron-size grains or as discrete plant parts.

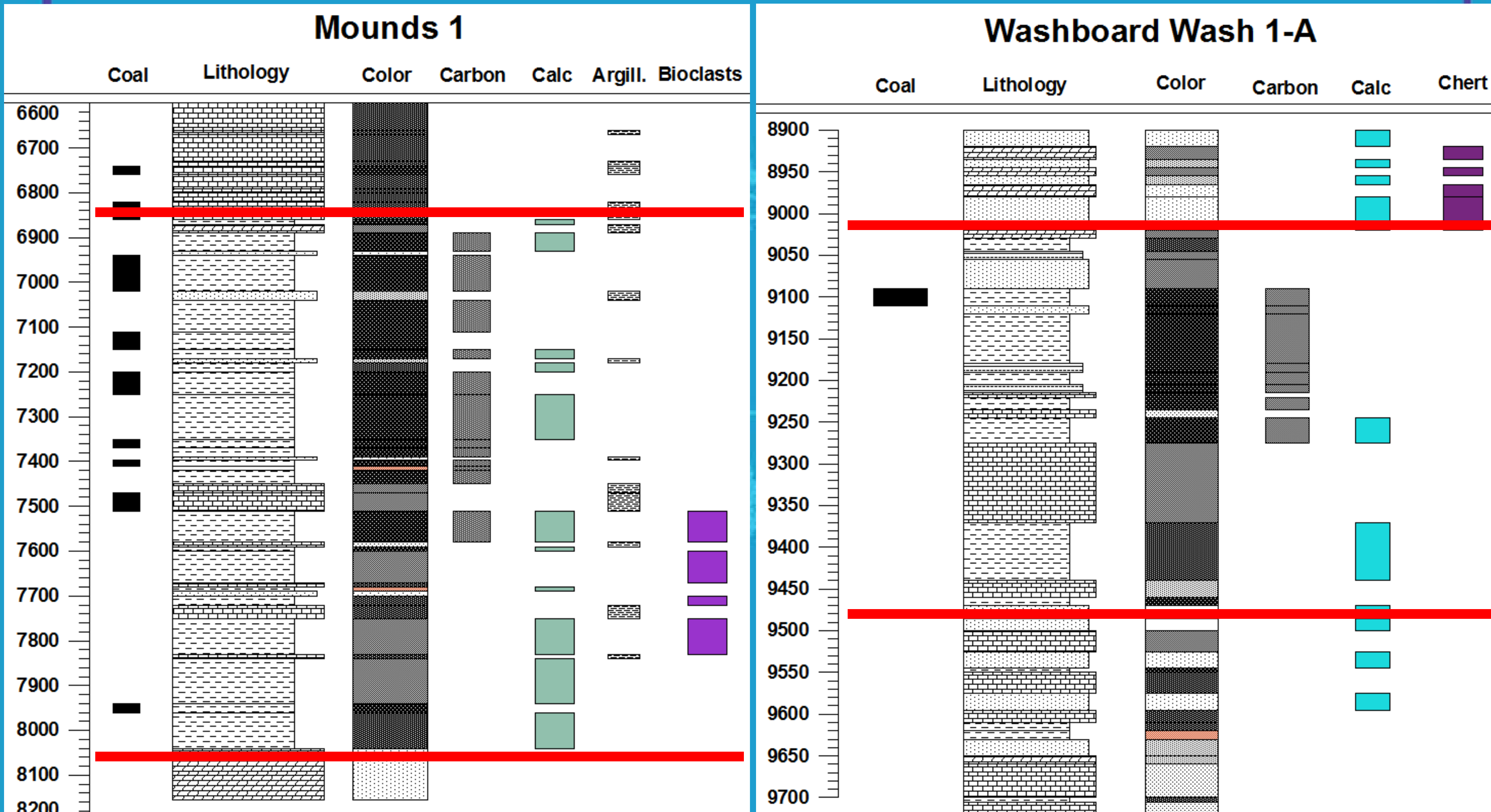
Siliciclastic rocks poor in organic matter are commonly light red to maroon.

Sunnyside 1 7,730 1.0X

Miller Creek 1 8,610 1.0X

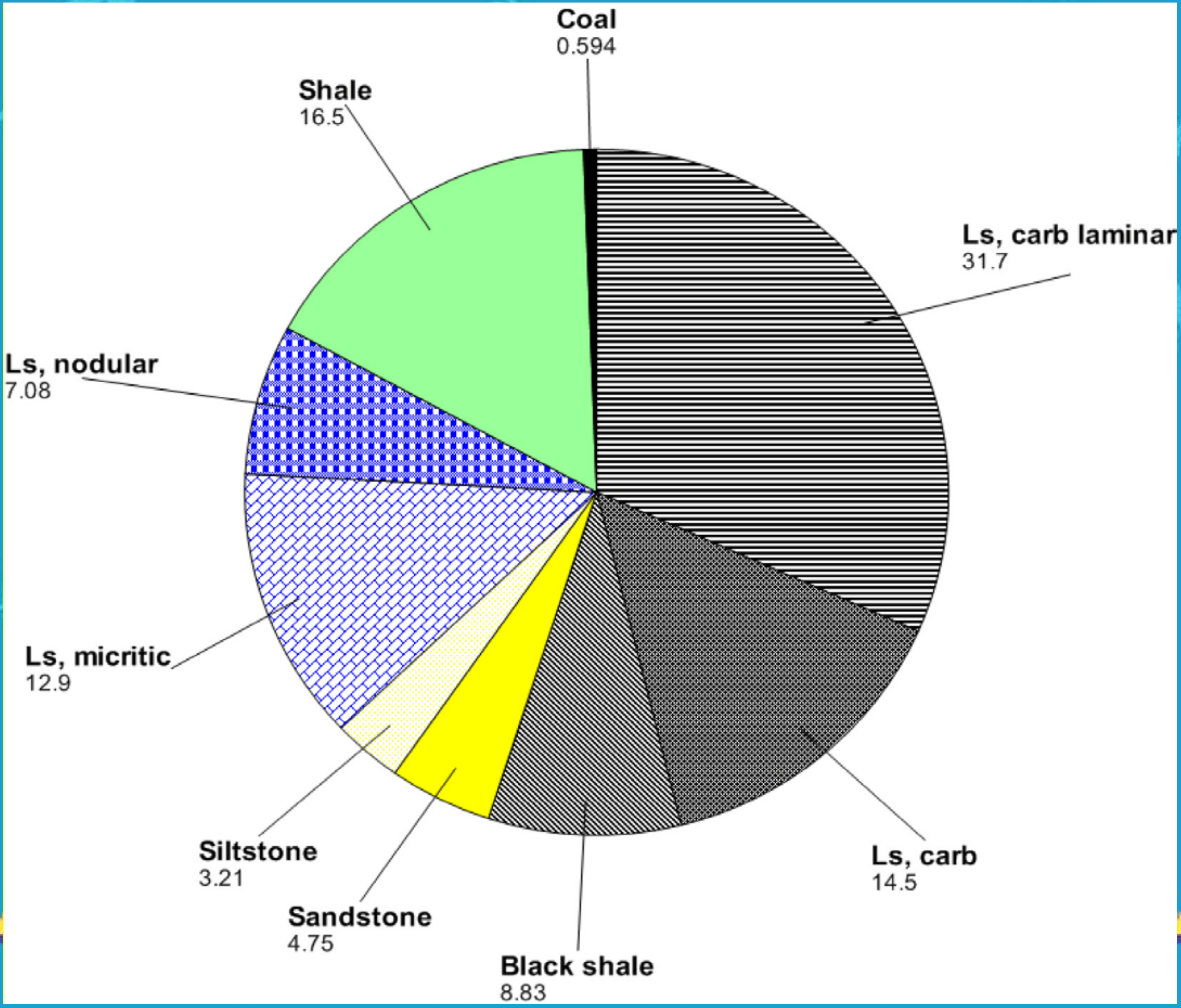
Farnham Dome 1-A 7,440 1.0X

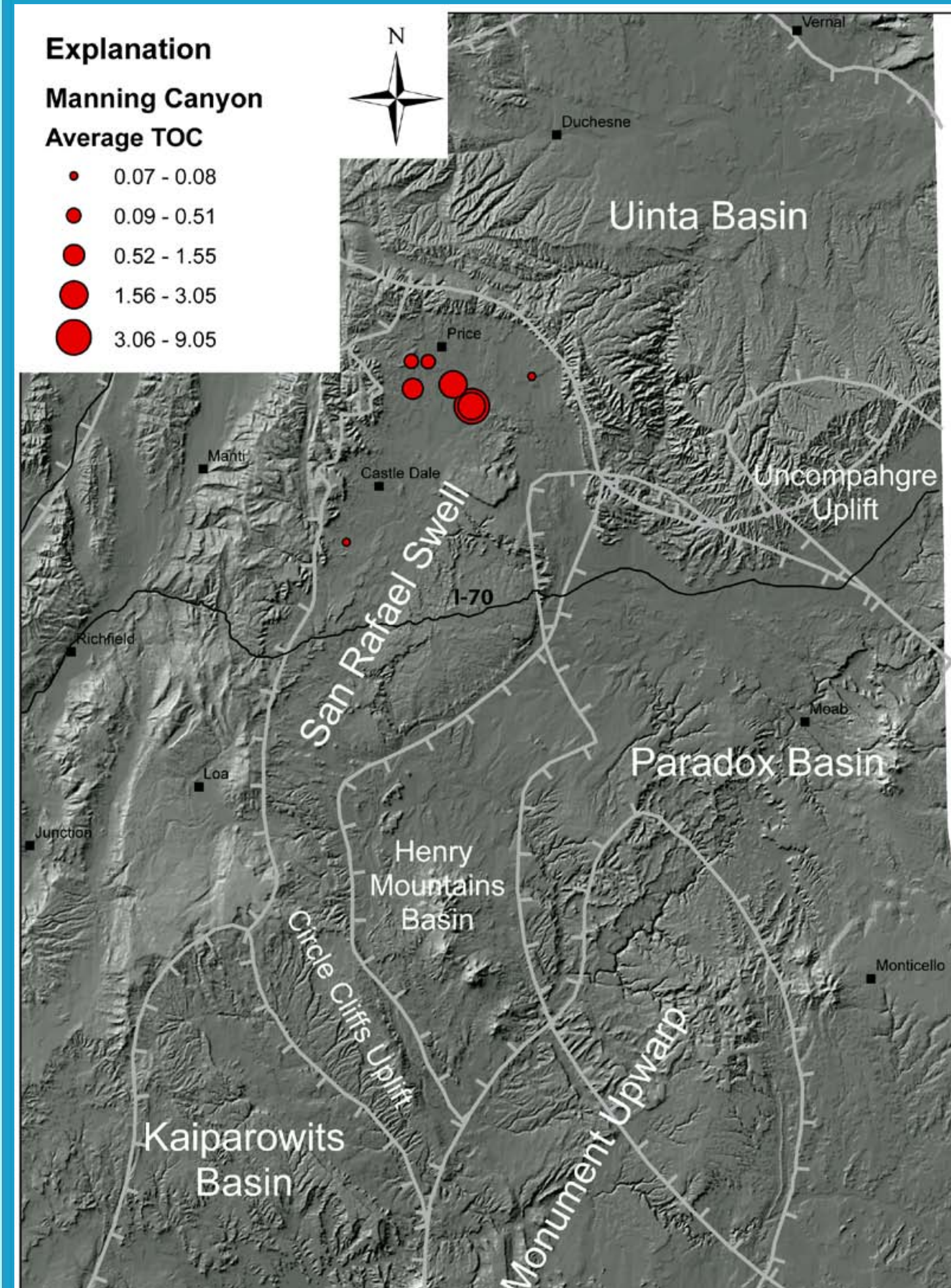
Representative Stratigraphic Columns from Well Reports



Drilling logs indicate the variability of lithotypes within the Manning Canyon Shale, both within a single well and between wells.

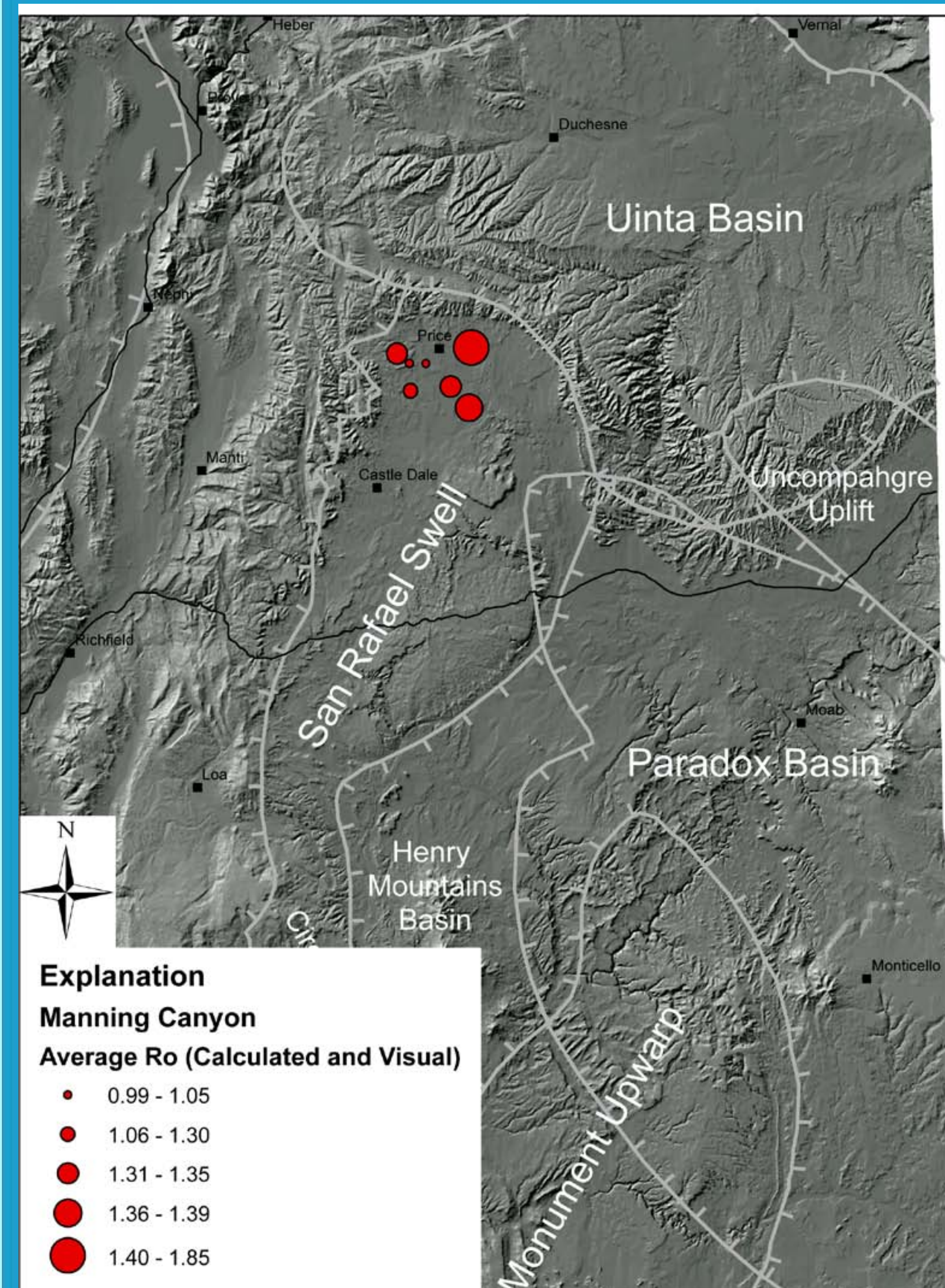
Lithotypes


Coal
0.594
Shale
16.5
Ls, carb laminar
31.7
Ls, nodular
7.08
Ls, micritic
12.9
Siltstone
3.21
Sandstone
4.75
Black shale
8.83
Ls, carb
14.5

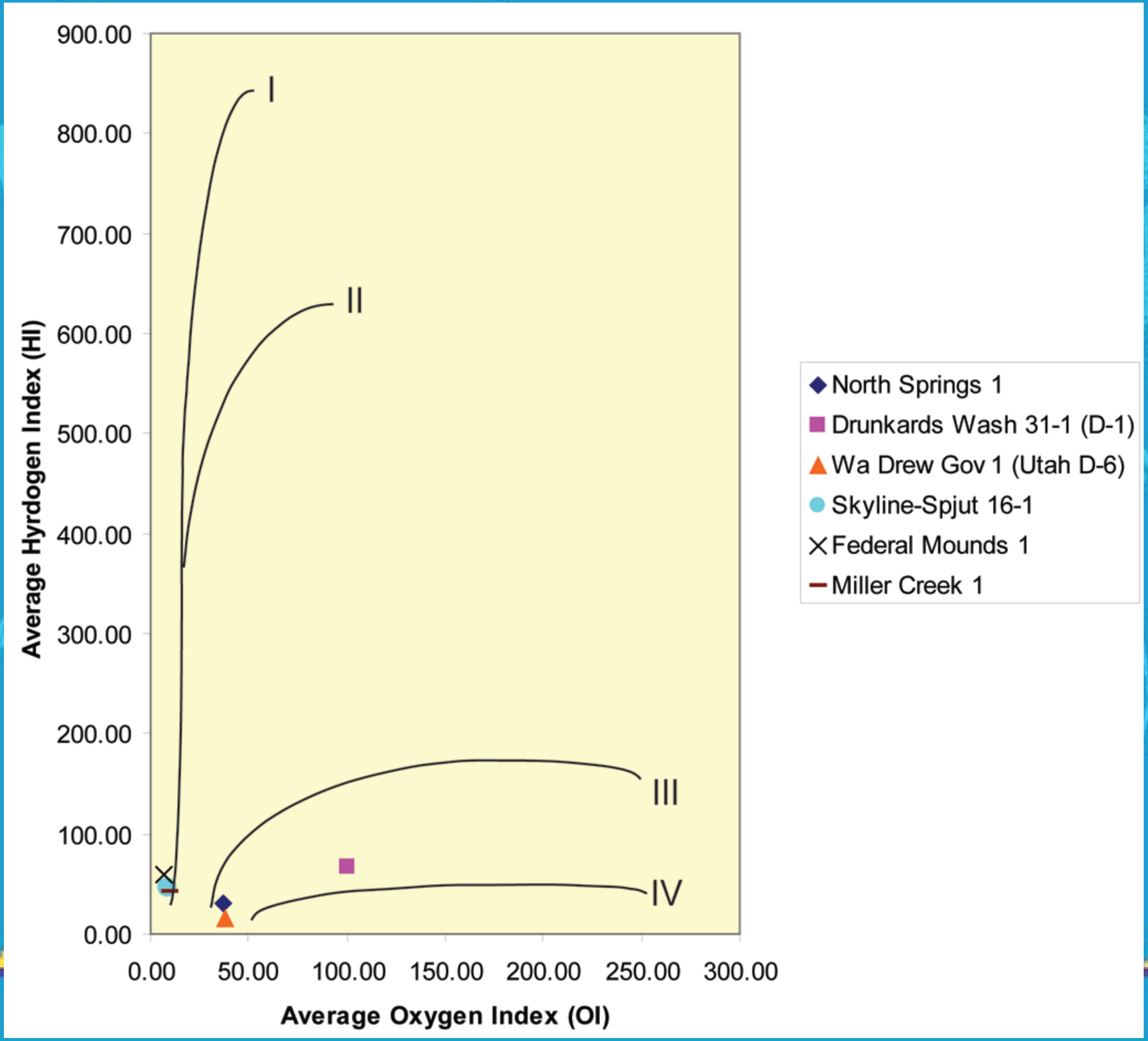


Total Organic Carbon: Manning Canyon

Vitrinite Reflectance: Manning Canyon



Pseudo van Krevelen: Manning Canyon



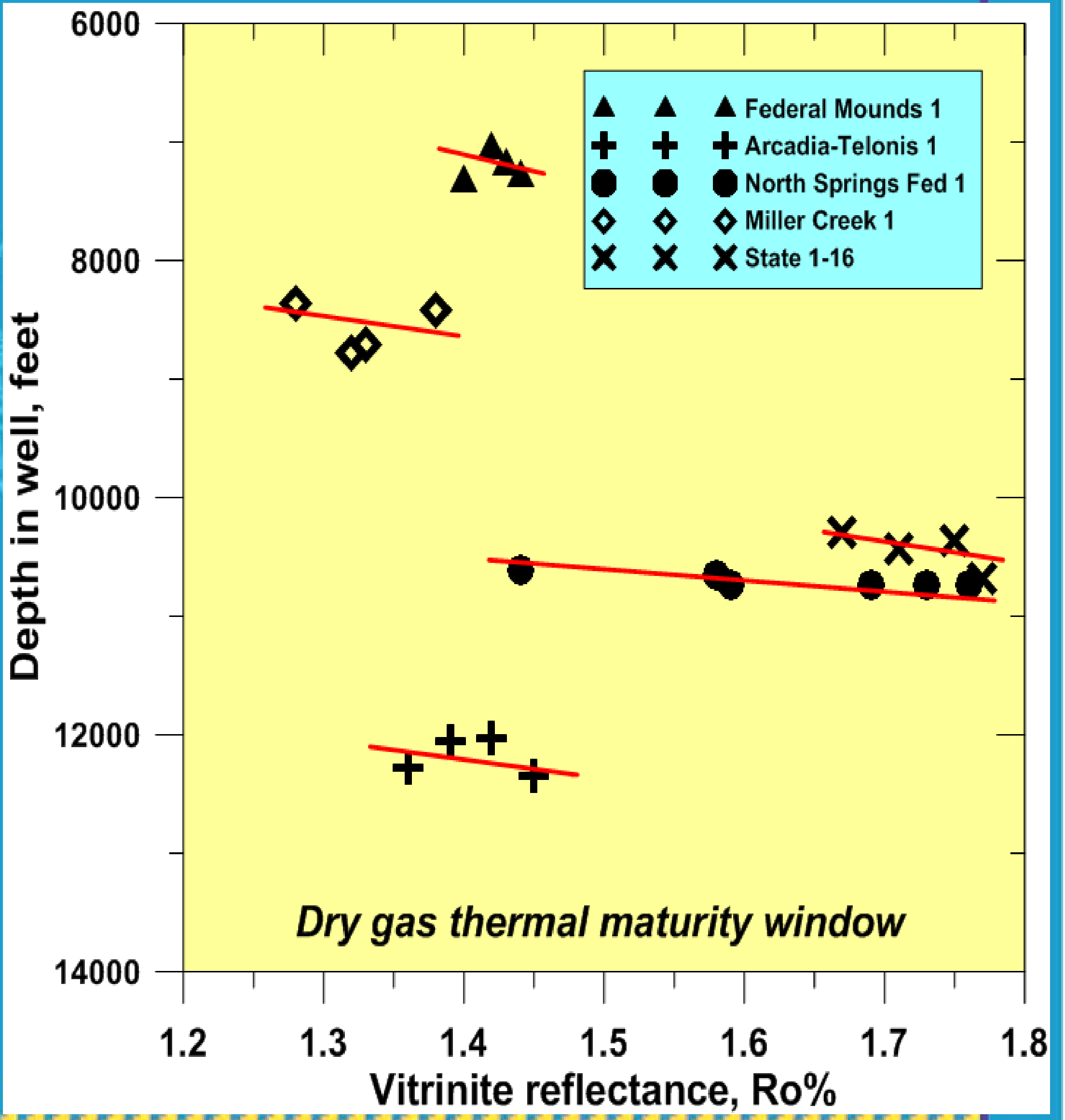
Thermal Maturity of Kerogen

Samples represent a range of present depths of burial.

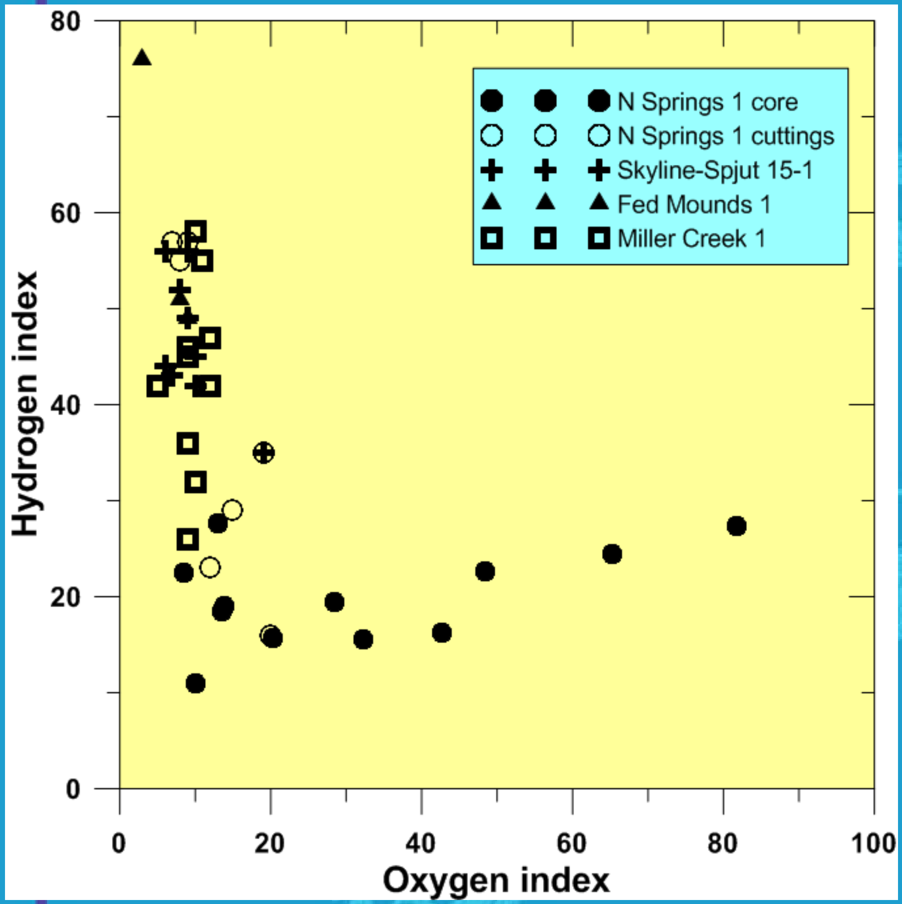
All vitrinite reflectance values are well within the dry gas thermal maturity window. Peak maturity was reached prior to uplift of the San Rafael Swell in latest Cretaceous-Paleocene time.

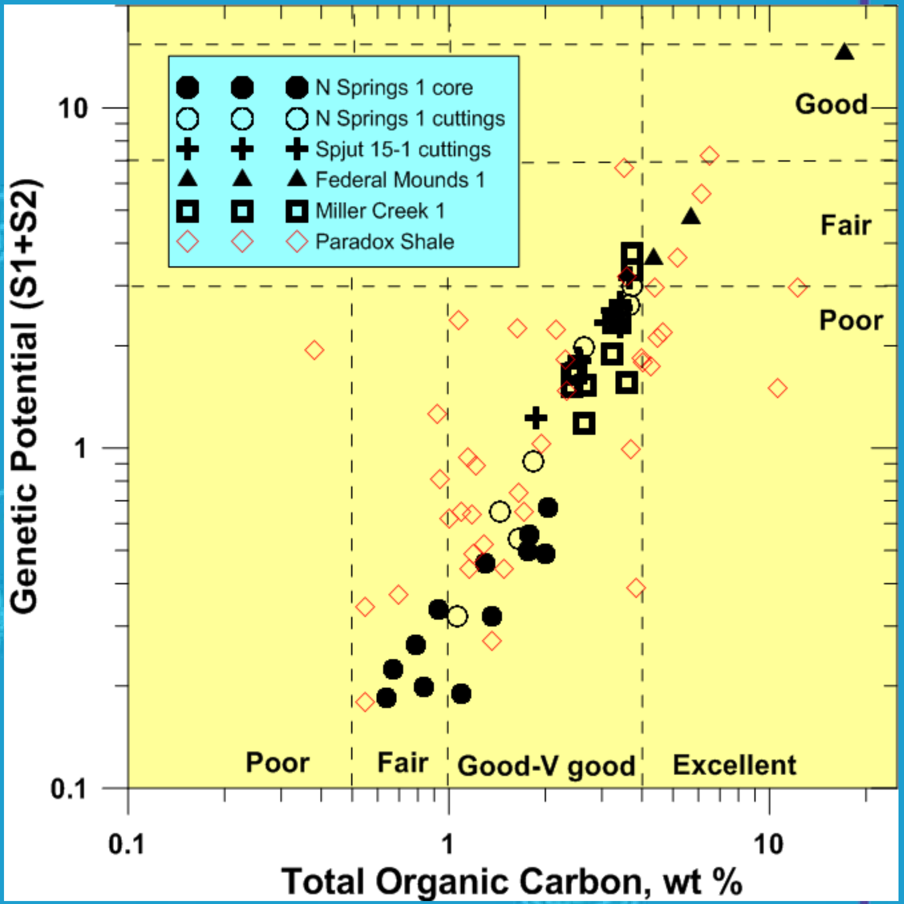
Inertinite is the dominant organic maceral type.

G. Waanders reports the presence of only terrestrial palynomorphs in these rocks.



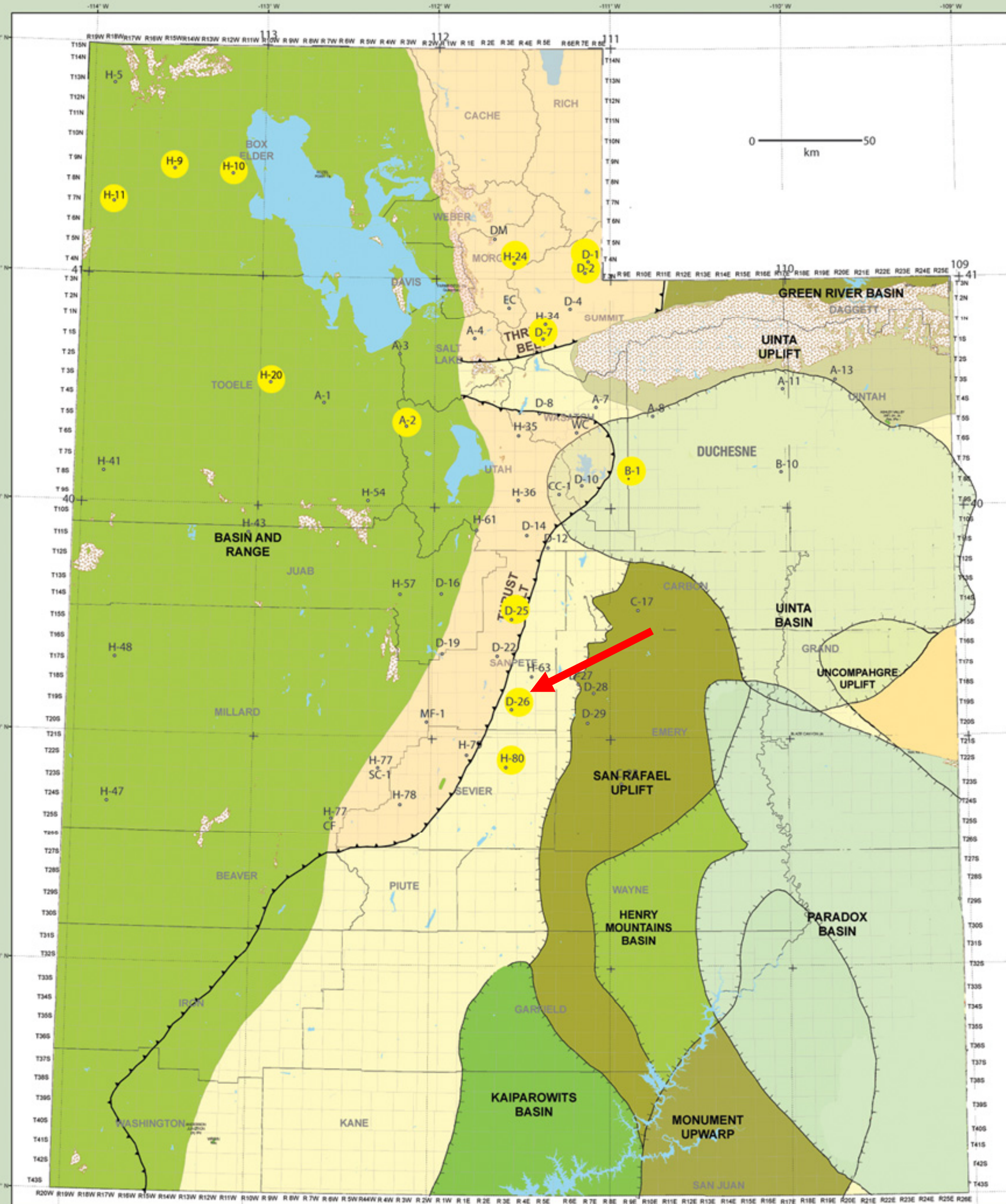
Rock-Eval Geochemistry





The low values of hydrogen index and genetic potential are consistent with the high thermal maturity of the kerogen and large inertinite content.

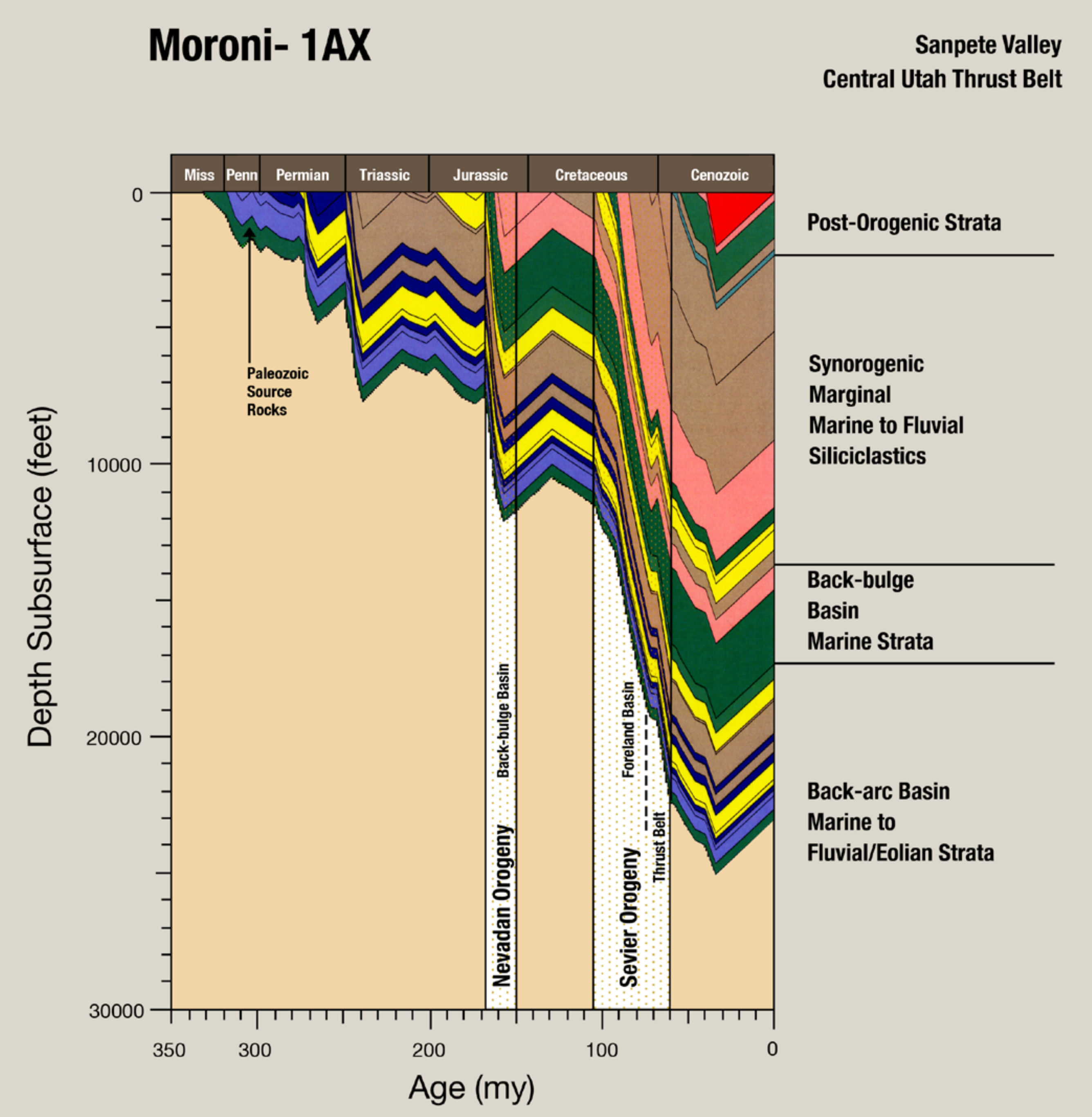
Burial History Plots for Central, Utah



Locations of data points for burial and maturation histories of Manning Canyon and Delle Phosphatic shales.

Preliminary burial history completed.

Burial History Plots for Central, Utah



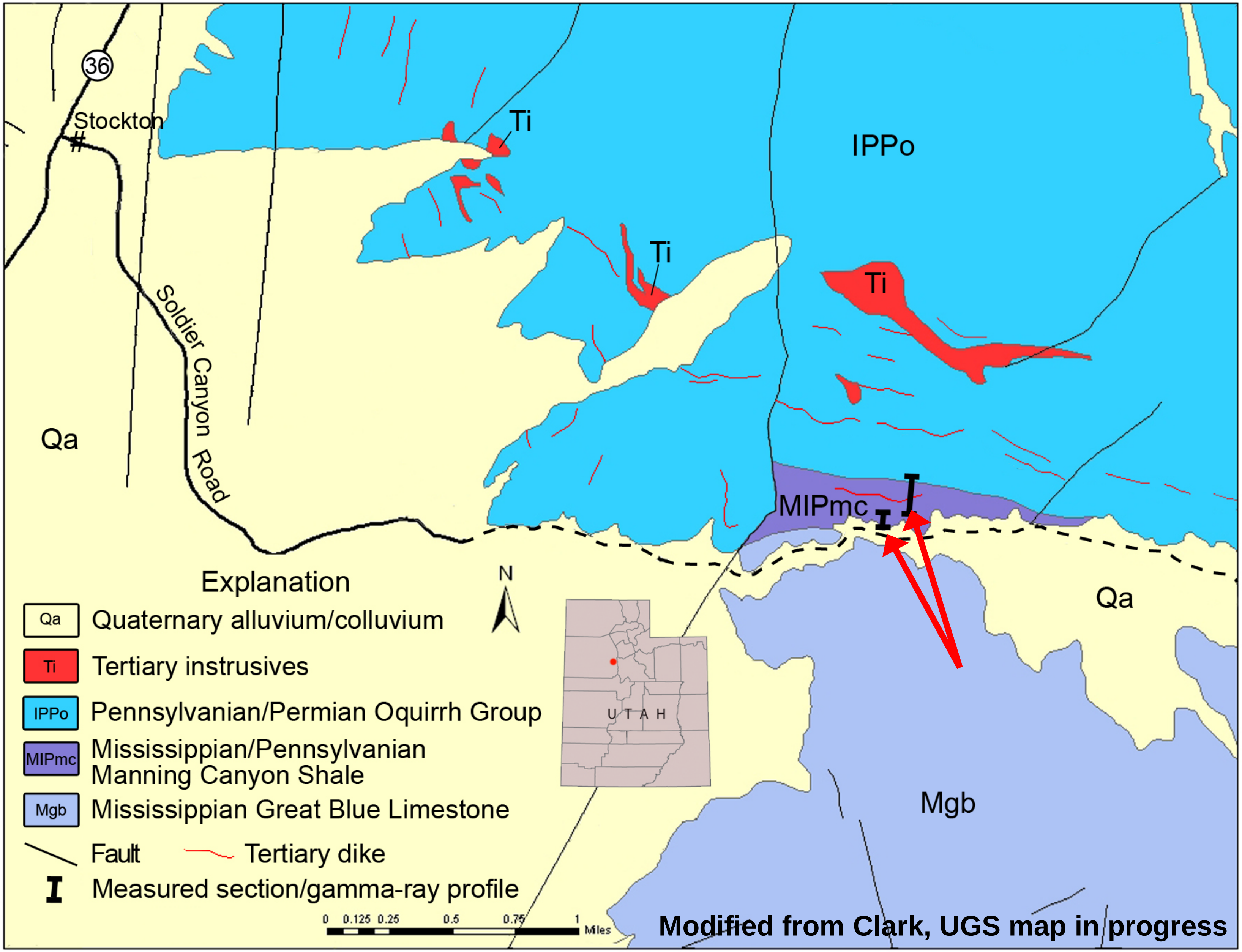
Burial History Conclusions

- Mississippian strata reached maximum burial depths of 18,000–40,000 feet.
- Pennsylvanian-Permian subsidence of the Oquirrh basin dominated the burial histories in north-central Utah.
- The Late Cretaceous Sevier orogeny further buried parts of the Mississippian section beneath foreland basin sediments and thrust sheets, but other sections were exhumed on the hanging walls of reverse faults.
- Maximum burial depths were reached during pronounced Late Cretaceous and Early Cenozoic subsidence of the Sevier foreland basin.
- Locally thick sediments and volcanics in Cenozoic extensional basins contributed to additional burial in both the thrust belt and the Basin and Range.

Outcrop Examination and Sample Analyses

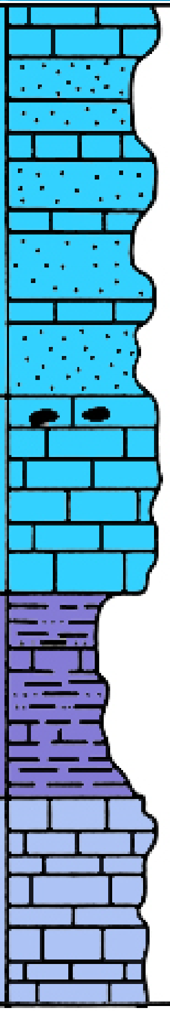
Manning Canyon Shale: Soldier Canyon Section, Tooele County, Utah

Location


36
Stockton
Soldier Canyon Road
Qa
Ti
IPPo
MIPmc
Mgb
Explanation
N
Qa Quaternary alluvium/colluvium
Ti Tertiary instrusives
IPPo Pennsylvanian/Permian Oquirrh Group
MIPmc Mississippian/Pennsylvanian Manning Canyon Shale
Mgb Mississippian Great Blue Limestone
Fault
Tertiary dike
Measured section/gamma-ray profile
U T A H
0 0.125 0.25 0.5 0.75 1 Miles
Modified from Clark, UGS map in progress

Stratigraphic Section

PEEN	Oquirrh Group+	Butterfield Peaks Formation	9000
		West Canyon Limestone	1450
MISS		Manning Canyon Shale	1330-1610
		Great Blue Limestone	1200-1950

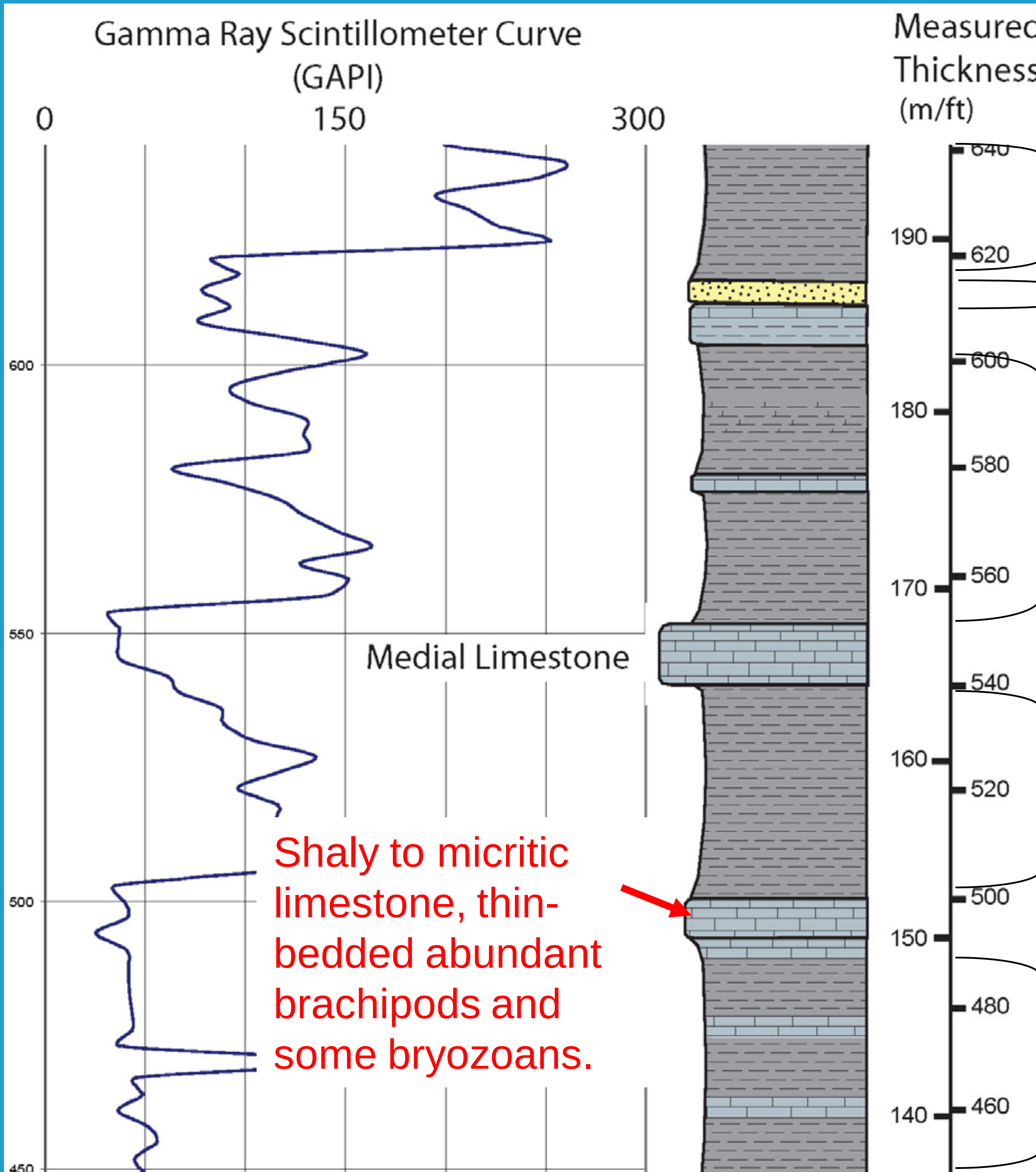


Modified after Hintze and Kowallis, 2009

Typical Manning Canyon Shale Section, Soldier Creek

Limestone

Sandstone



Description

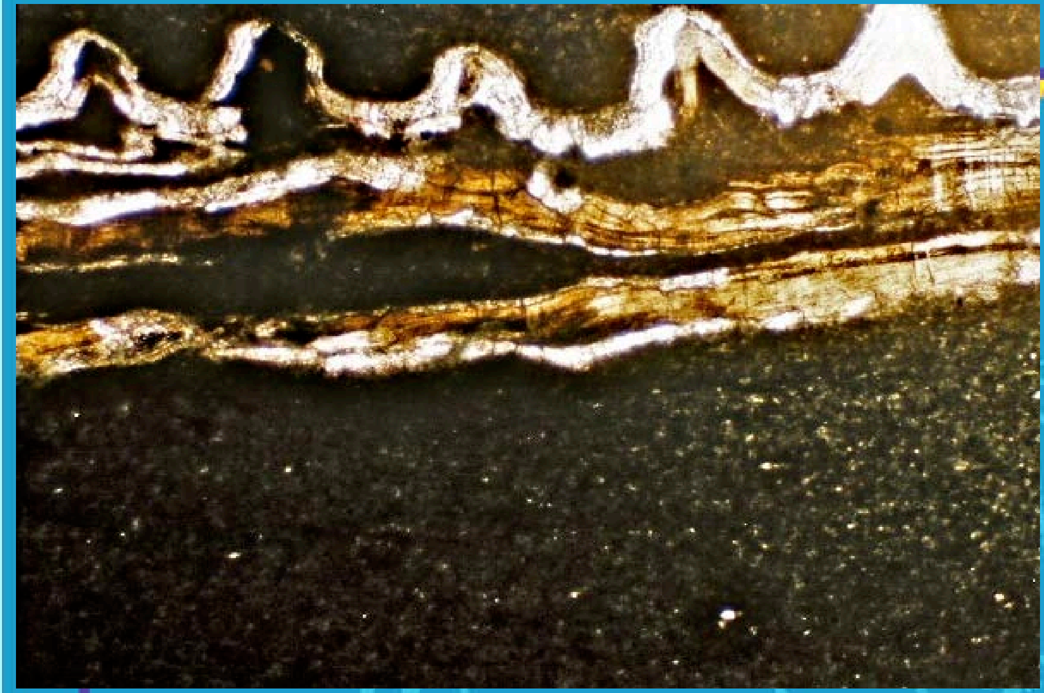
Non-calcareous black to gray shale, no fossils

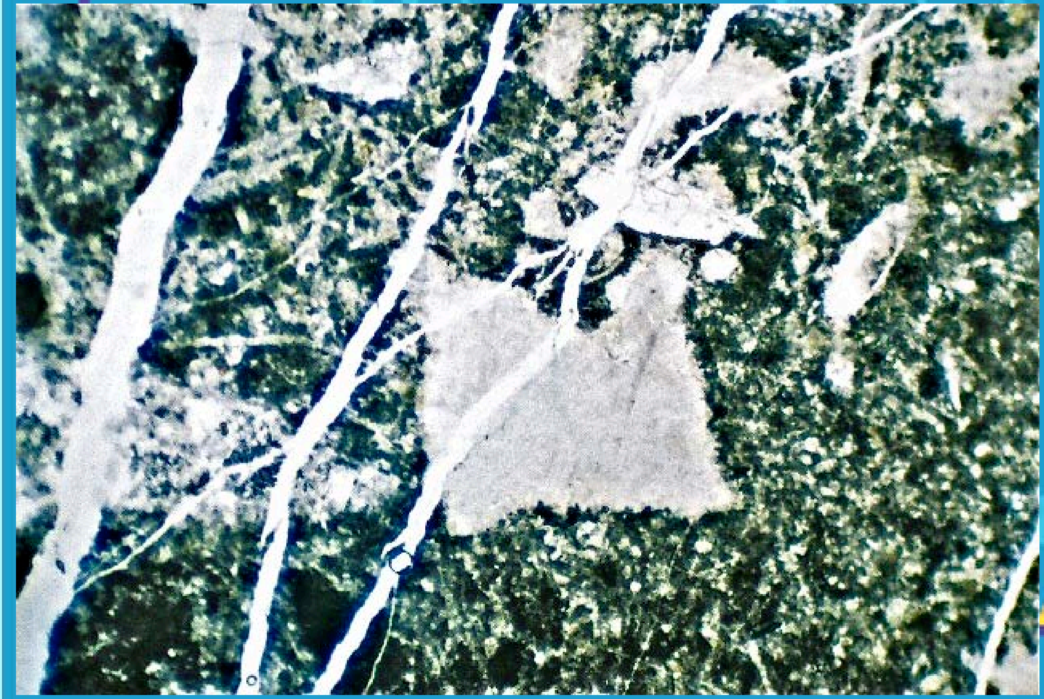
Quartzitic sandstone, tan-brown-maroon, coarse-grained, well sorted with subangular to subrounded grains

Non-calcareous black to gray shale, no fossils

Non-calcareous black to gray shale, no fossils

Calcareous gray shale, fossils (brachiopods) near top of unit





Carbonate Fabric

- microbial (leolite to thrombolite) lime mudstone to bioclastic wackestone
- trilobite carapaces and brachiopods, partially silicified, thin-shelled anaerobic bivalves

Depositional Environments

- Shale/claystone
  - lower coastal plain
  - marsh to restricted bay
  - open shelf
- Limestone
  - shallow, low- to moderate-energy subtidal
  - salinity-restricted platform interior
  - Moderate-energy, open- marine platform
  - quiet (below wave and storm base), deep, low-oxygenated water
  - high-energy, nearshore terrigenous settings
- Sandstone
  - upper shoreface

Depositional Setting: Modern Analog Model

- Evidence points to a restricted, shallow-water depositional setting that is dominantly nonmarine or brackish, with secondary marine influence.
- The organic matter is terrestrial.
- The marshes of the Everglades and shallow brackish to marine carbonate factory of the Florida Bay might serve as a conceptual model.

Shallow Marine-Nonmarine Embayment

Mississippian Manning Canyon Shale: Conclusions

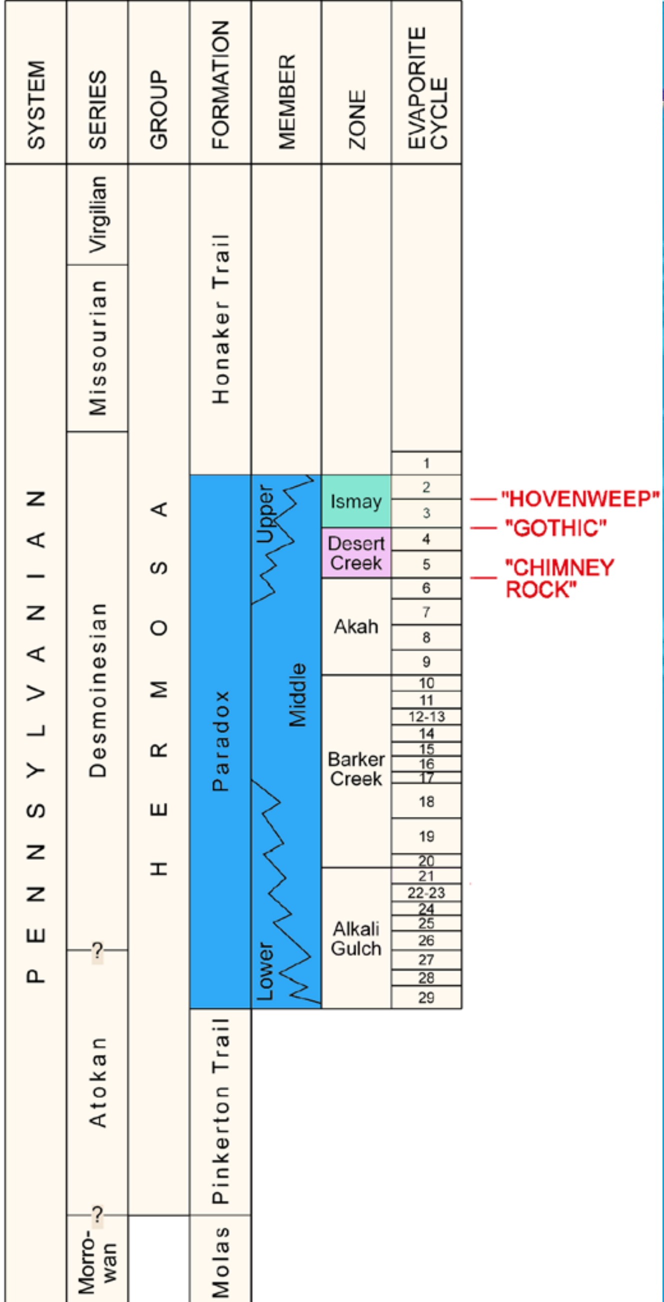
- 600 mi^2 potential area at north end of San Rafael Swell
- Manning Canyon is 300-1500 feet thick.
- Organic matter of terrestrial origin and of good to excellent richness is distributed throughout the shale, limestone and even siltstones that comprise the unit. Vitrinite reflectance measurements indicate that the kerogen is in the dry gas thermal maturity window.
- Manning Canyon may have been deposited in a shallow restricted carbonate- and organic-rich marine, brackish and fresh-water setting like the modern Everglades and Florida Bay.

Pennsylvanian (Paradox Formation) Hovenweep, Gothic, and Chimney Rock, Petrographic, Geochemical and Geomechanical Analysis

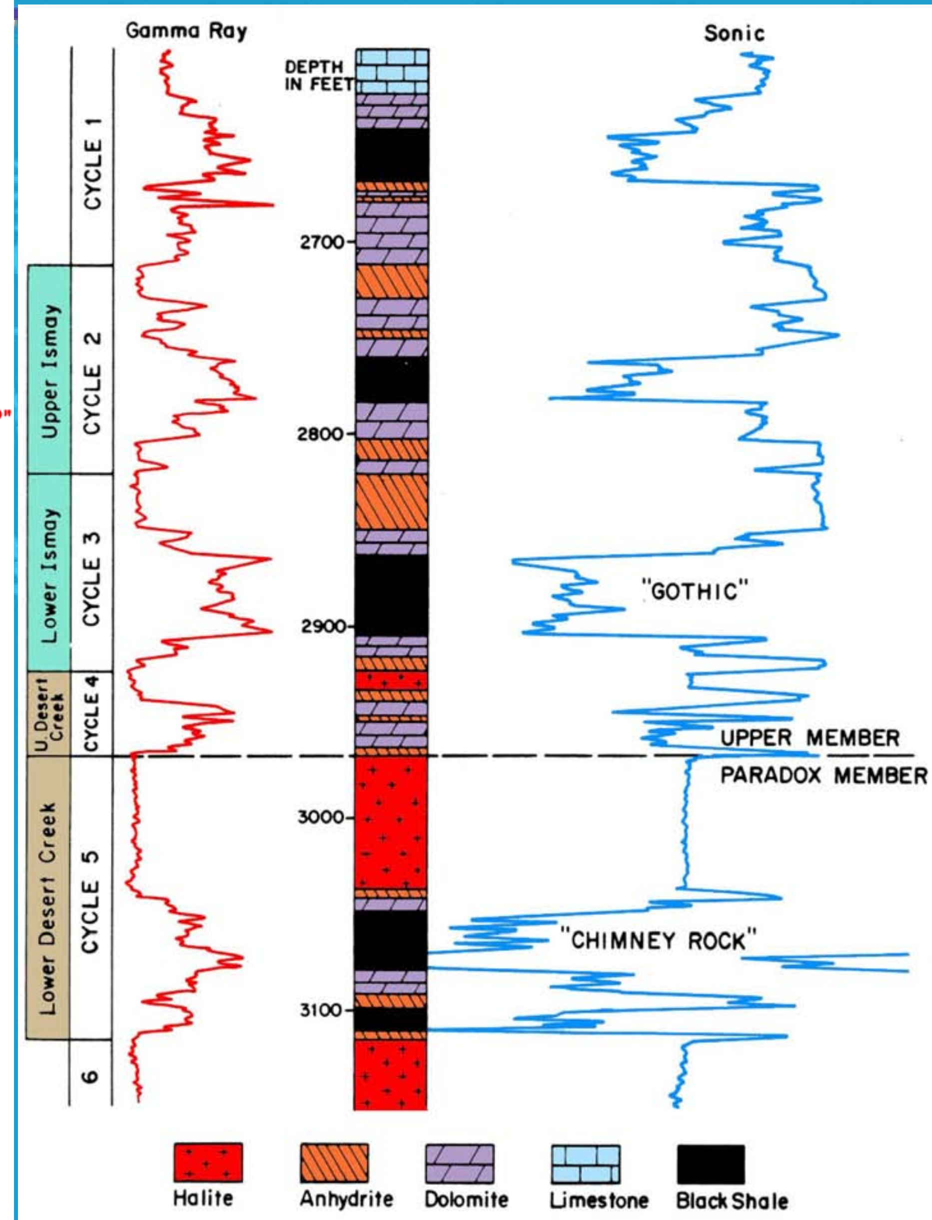
Gothic Shale along the Honaker Trail, San Juan River Canyon, SE Utah

Pennsylvanian Paradox Formation

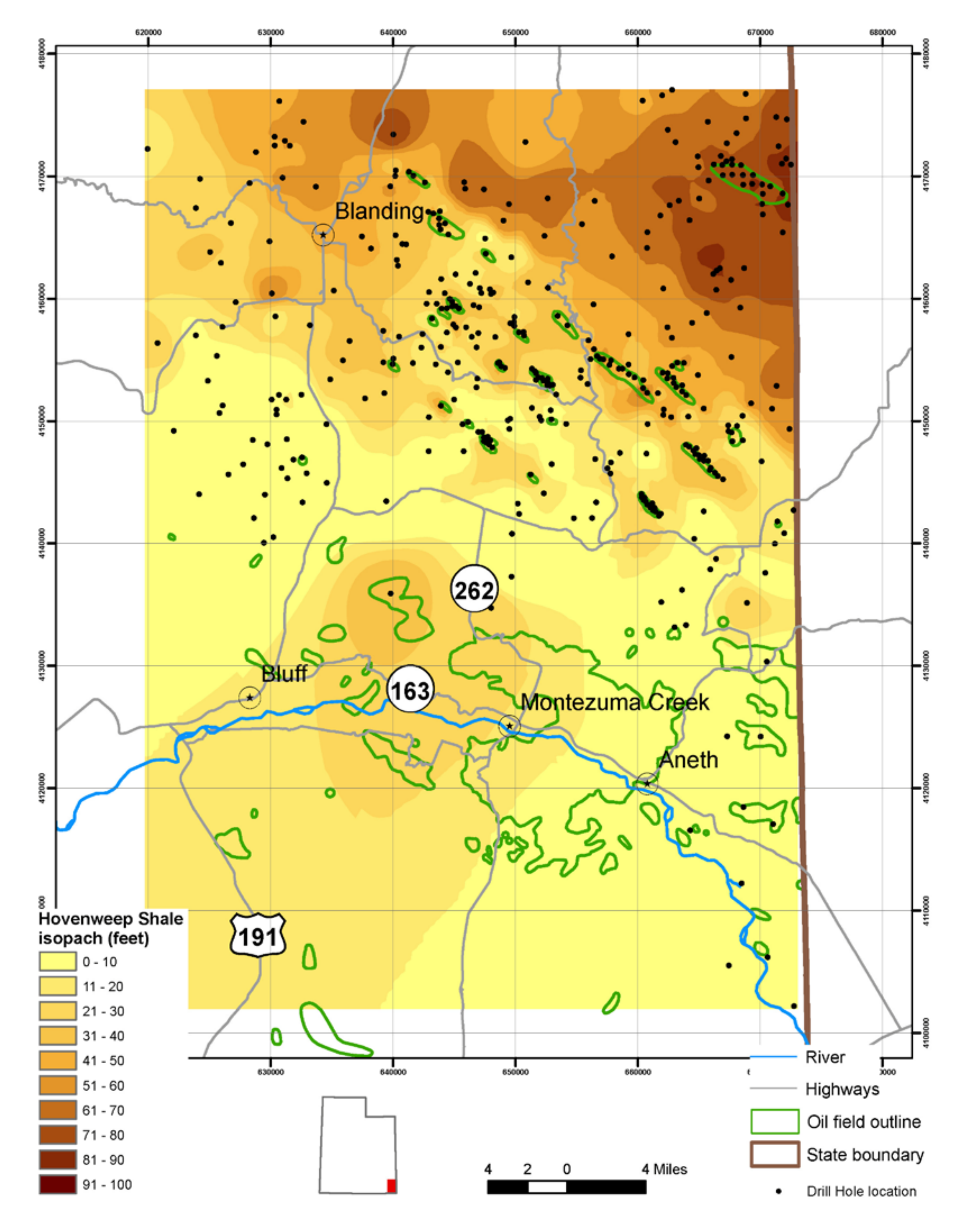
- Cyclic shale units (Hovenweep, Gothic, and Chimney Rock)
- Thinly interbedded, black, organic-rich marine shale
- Dolomitic siltstone; dolomite; and anhydrite.
- Thicknesses of individual shale units generally range in thickness between 25 and 50 ft; the cumulative shale thickness is typically 100 to 200 ft.
- TOC are modest – 1 to 5%
- Type III and mixed type II-III kerogen
- Naturally fractured (usually on the crest of anticlinal closures), and often overpressured



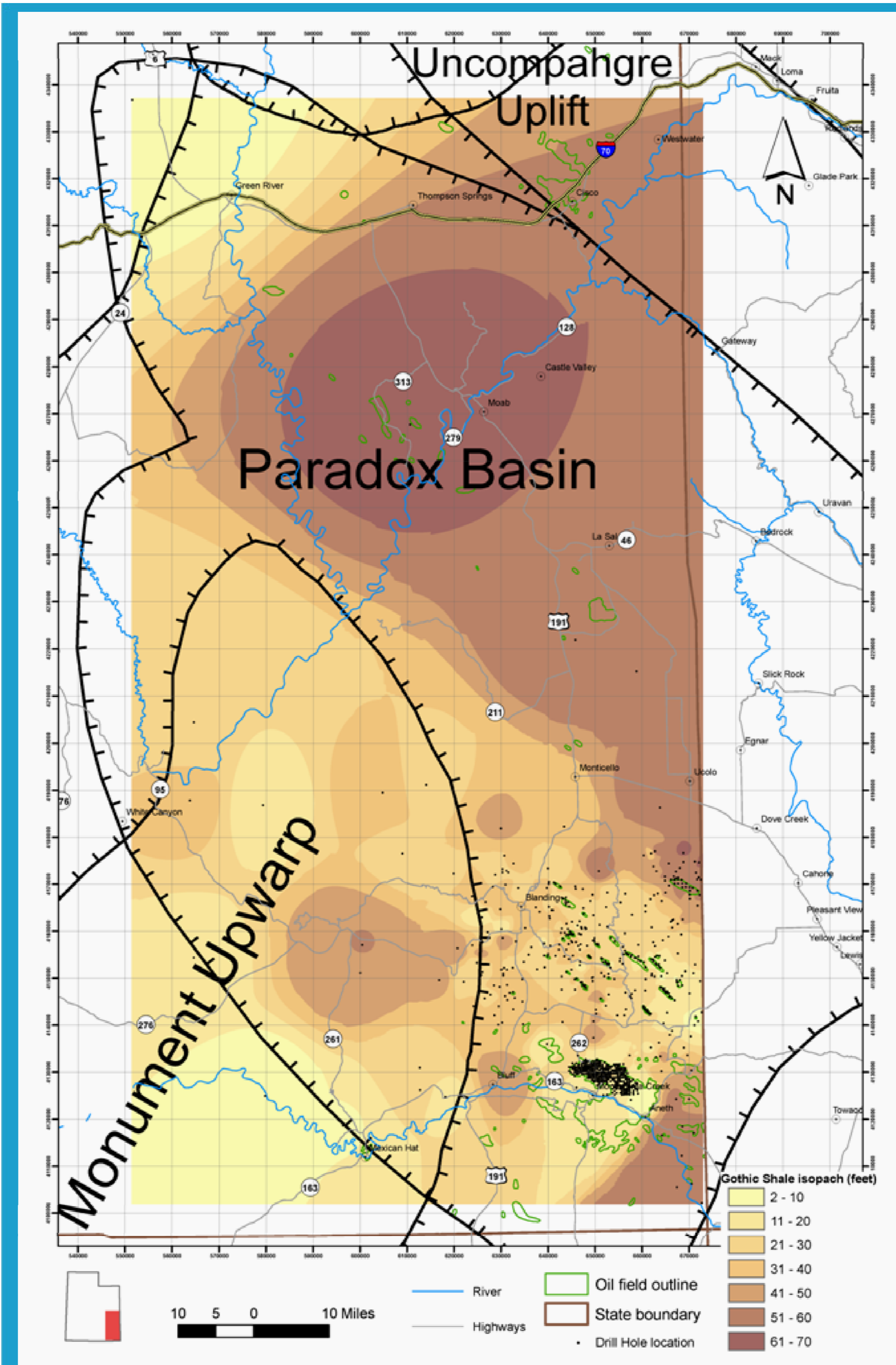
Modified from Hite and other, 1984



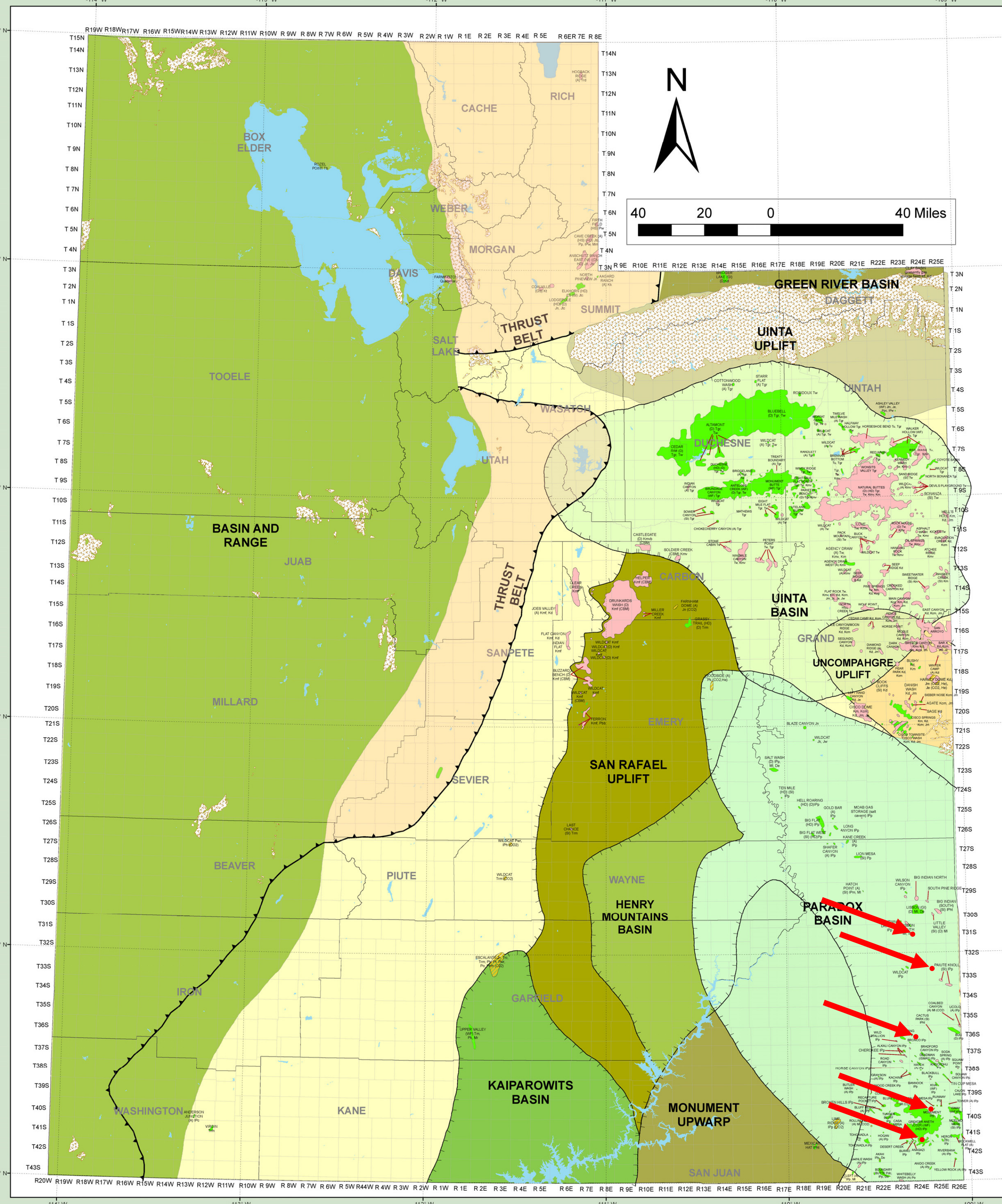
Pennsylvanian Stratigraphic Chart for the Paradox Basin



Hovenweep Isopach Map

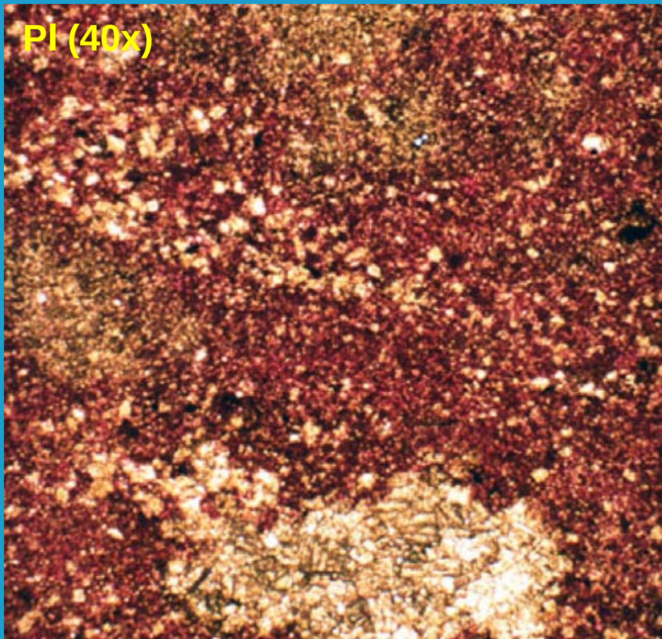


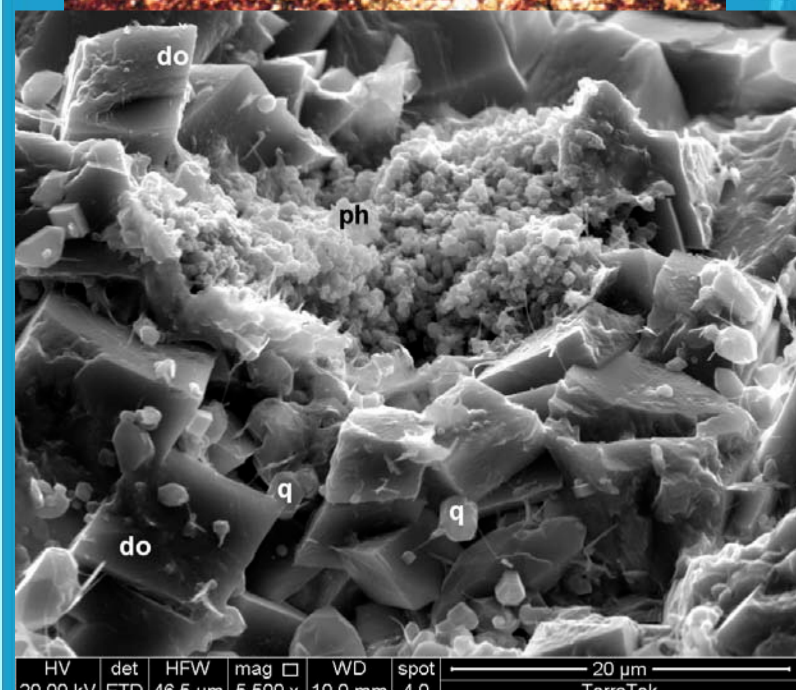
Gothic Shale Isopach Map



Hovenweep, Gothic, & Chimney Rock Shale Core at the Utah Core Research Center

UTAH DNR GEOLOGICAL SURVEY

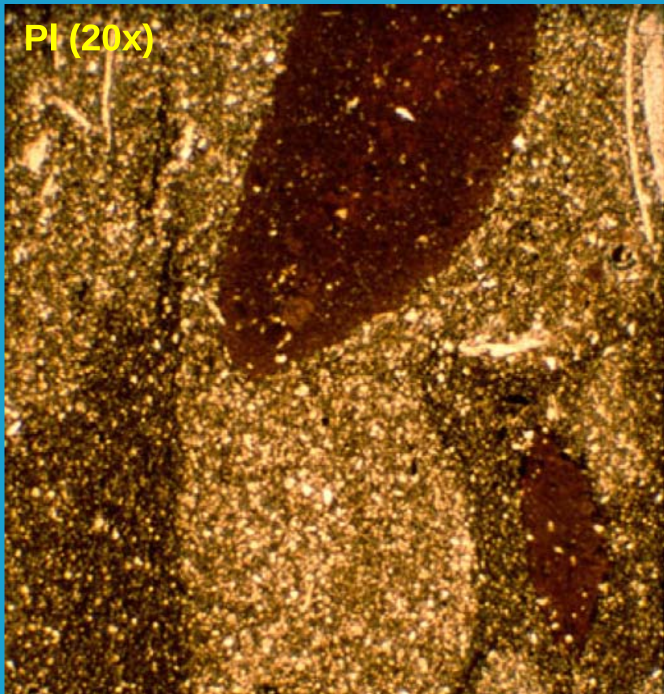


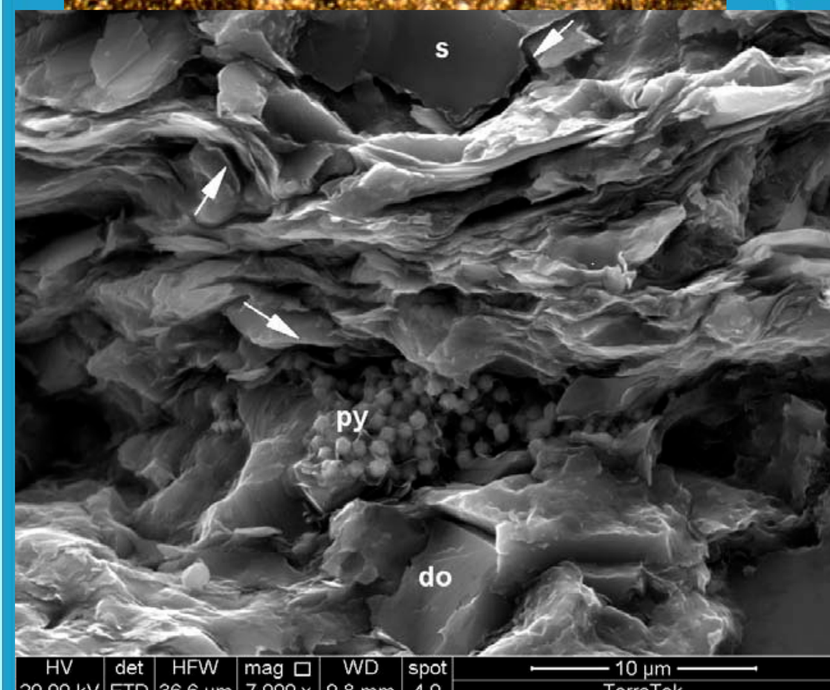


Porous Upper Ismay Dolomite Overlying Hovenweep Shale

- Bimodal distribution of dolomite
- Large crystals partially to completely replaced detrital terrigenous silt
- Cryptocrystalline dolomite was likely an alteration of original lime mud
- Phosphatic pellets
- Larger nodule is anhydrite, common to this portion of the core
- Interval is porous, and any stimulation of the underlying mudstone could access additional zones of conventional porosity

Marie Ogden 1, 5185.6 ft.





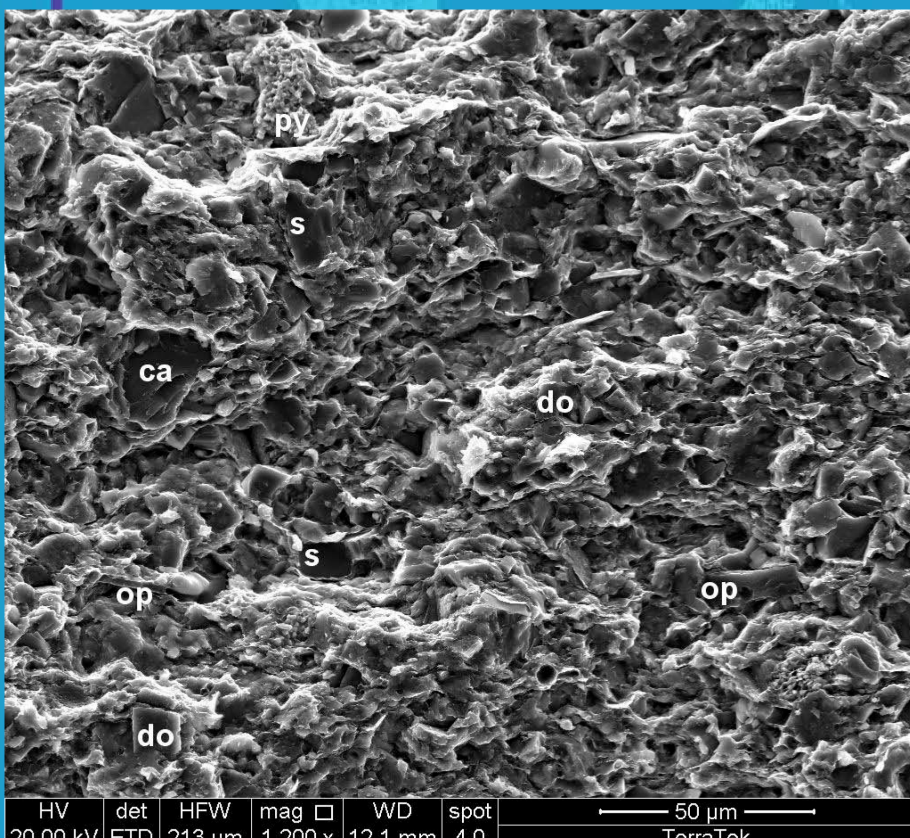
Hovenweep Shale

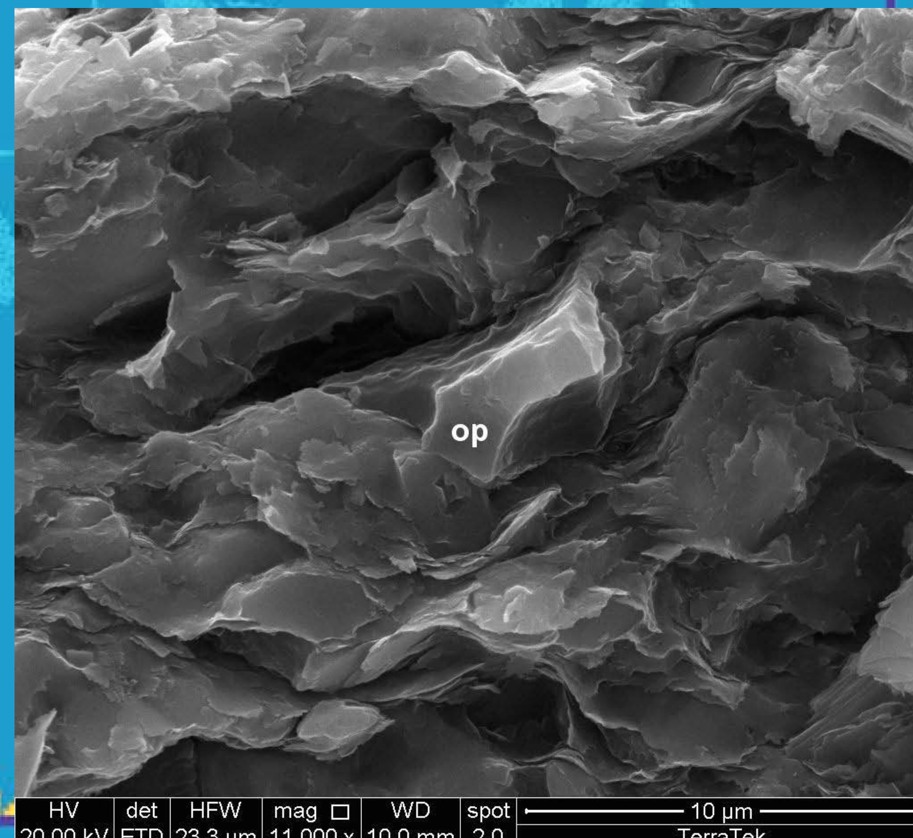
- Muddy dolomite near base of Upper Ismay cycle
- Phosphate clasts
- Bioturbation features
- Terrigenous quartz
- Skeletal debris
- The most common pore type is intercrystalline pores found between clays, authigenic dolomite, pyrite
- Demarcation between dysaerobic deeper conditions below and an aerobic shallower setting in the superjacent strata

Marie Ogden 1, 5190 ft.

Hovenweep Shale

- Dolomitic mudstone
- Silt (detrital quartz and feldspar)
- Dolomite rhombs
- Compacted clay minerals
- Pyrite
- Organic particles (spores?)
- Elongated pores in clay layers

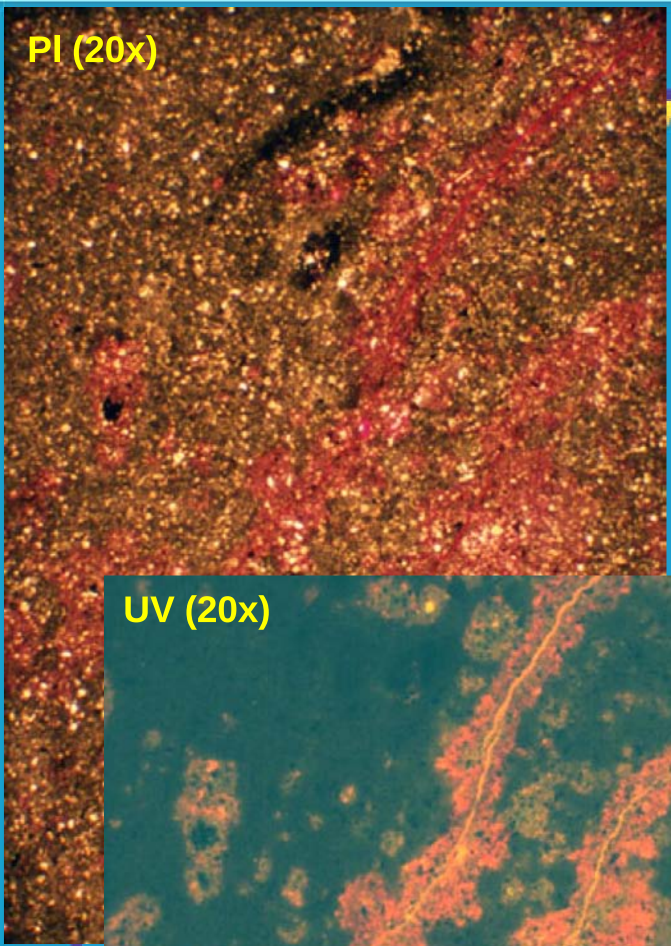


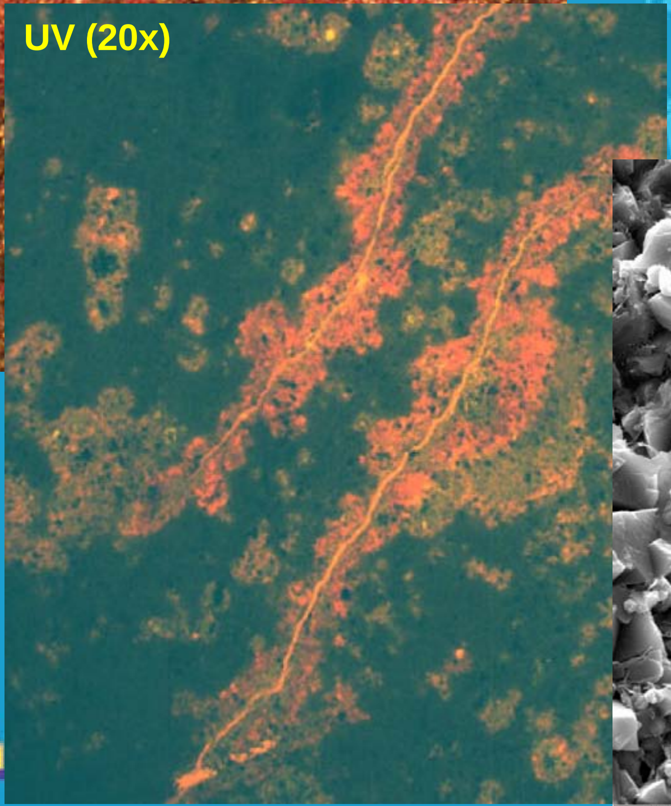


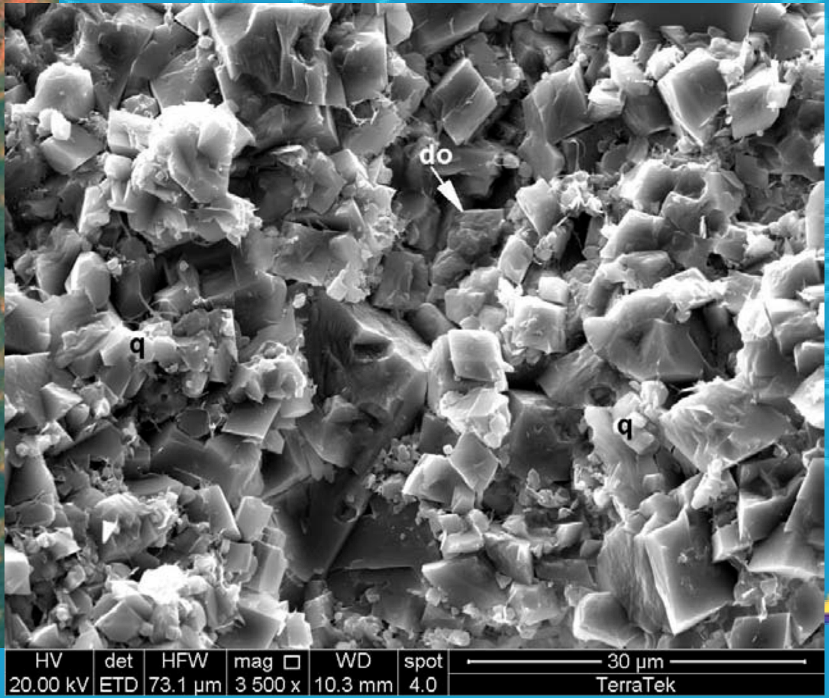
Marie Ogden 1, 5196.3

Lower Ismay Subjacent to the Gothic Shale

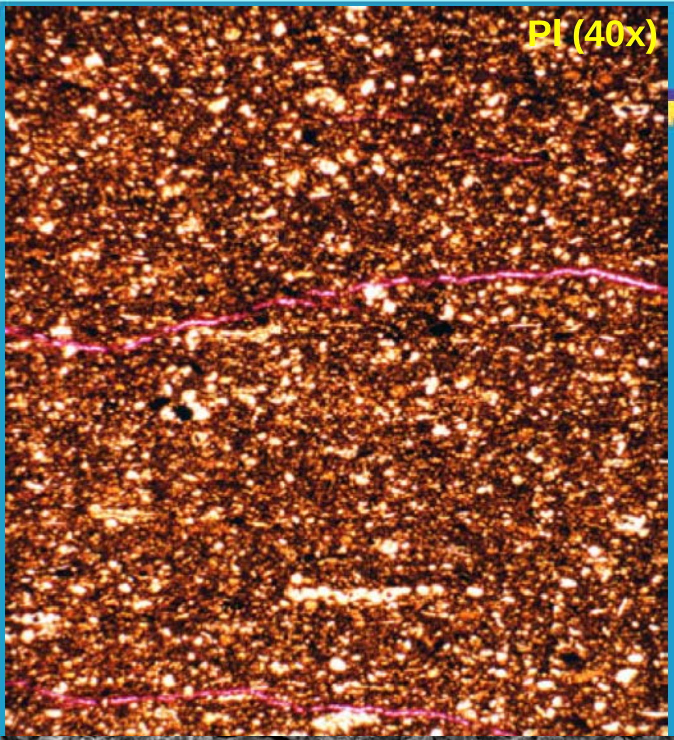
- Finely crystalline dolostone
- Intercrystalline pores
- Natural microfractures and stylolites
- Patches of magenta indicate additional amounts of matrix porosity
- Evidence for overall reservoir quality enhancement from the (mostly) carbonate strata bounding any stimulated black shales





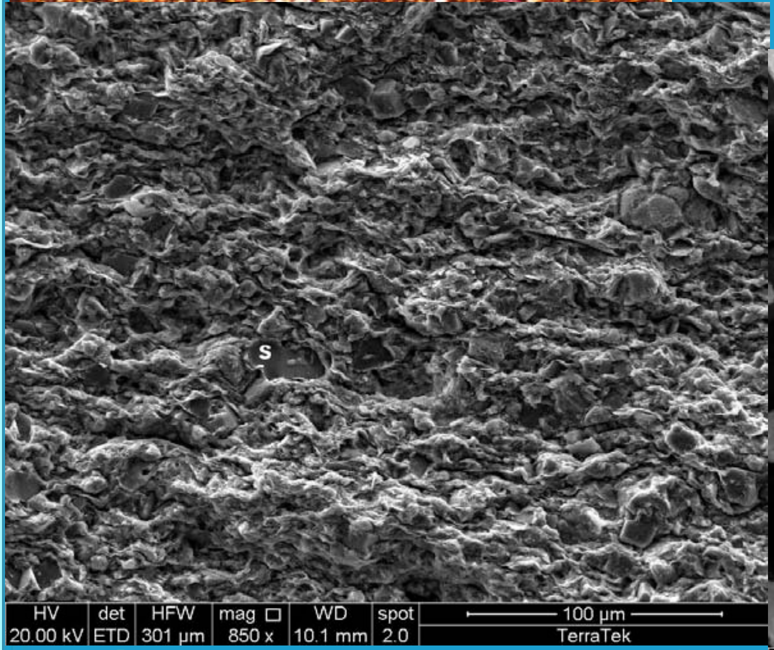


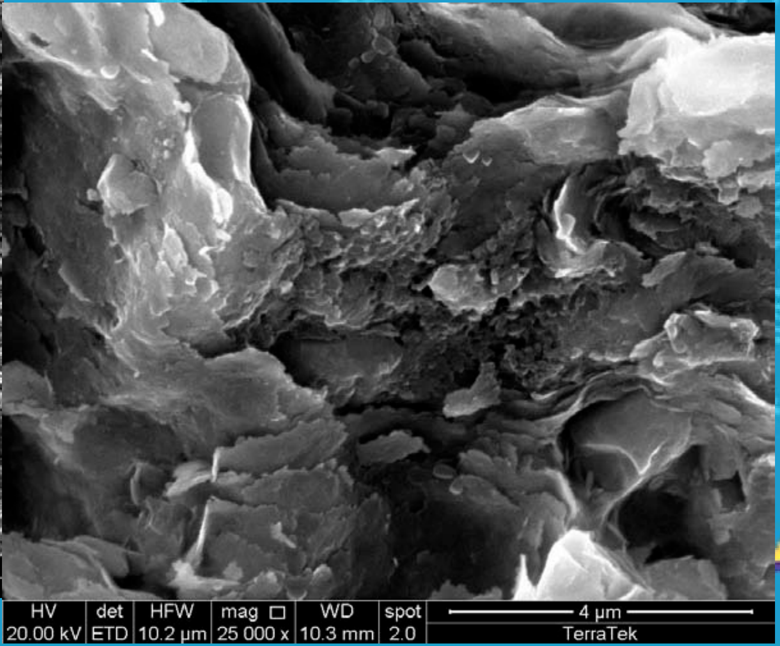
Marie Ogden 1, 5320.6 ft.



Gothic Shale

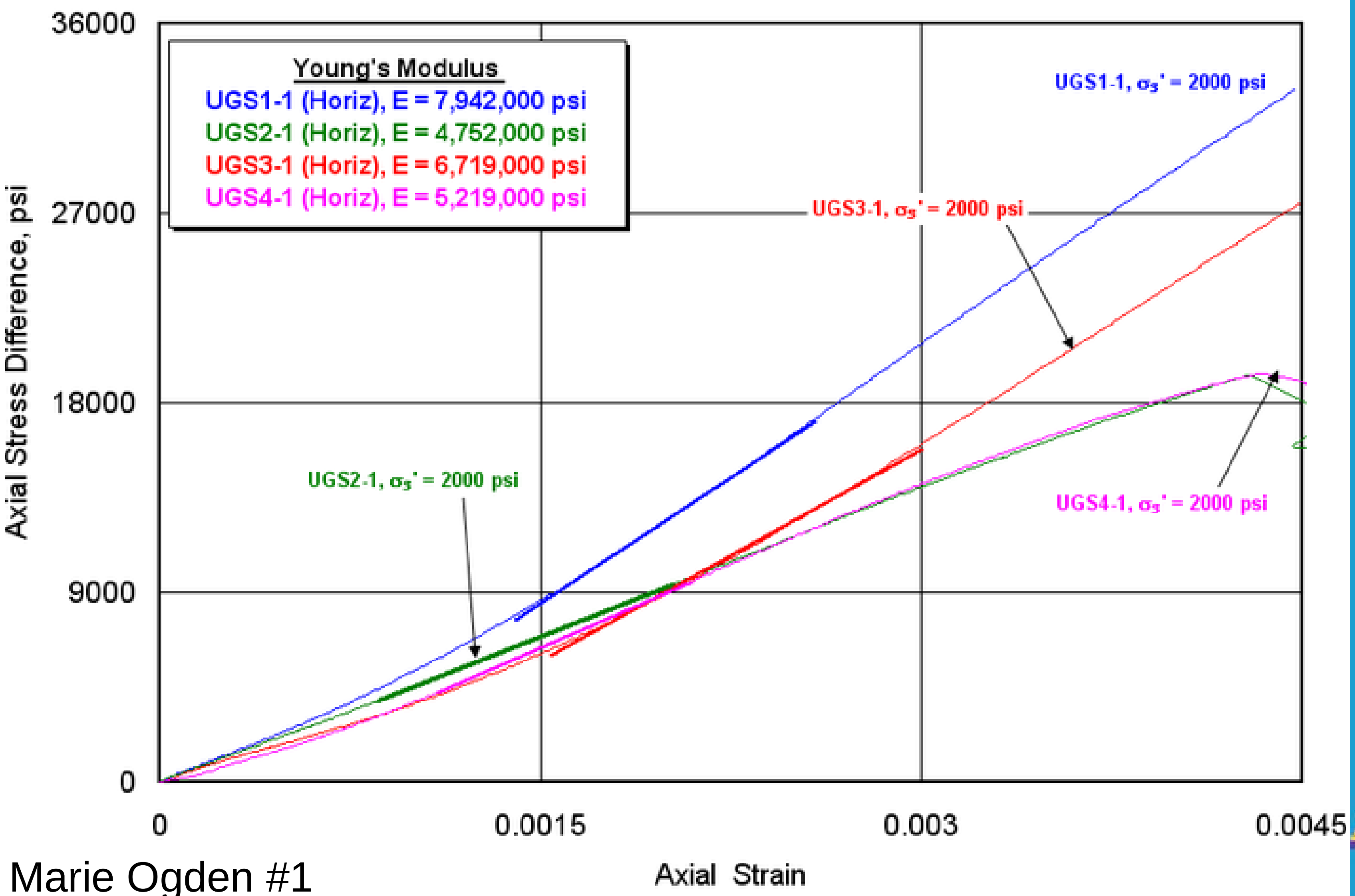
- Silty argillaceous mudstone
- Calcareous skeletal material and compacted agglutinated foraminifera
- Disseminated pyrite & authigenic minerals
- Very poorly laminated (microlamination defined by wavy clay flakes)
- Nanoporous kerogen contains numerous gas adsorption sites
- Intercrystalline pores between clay flakes are well connected





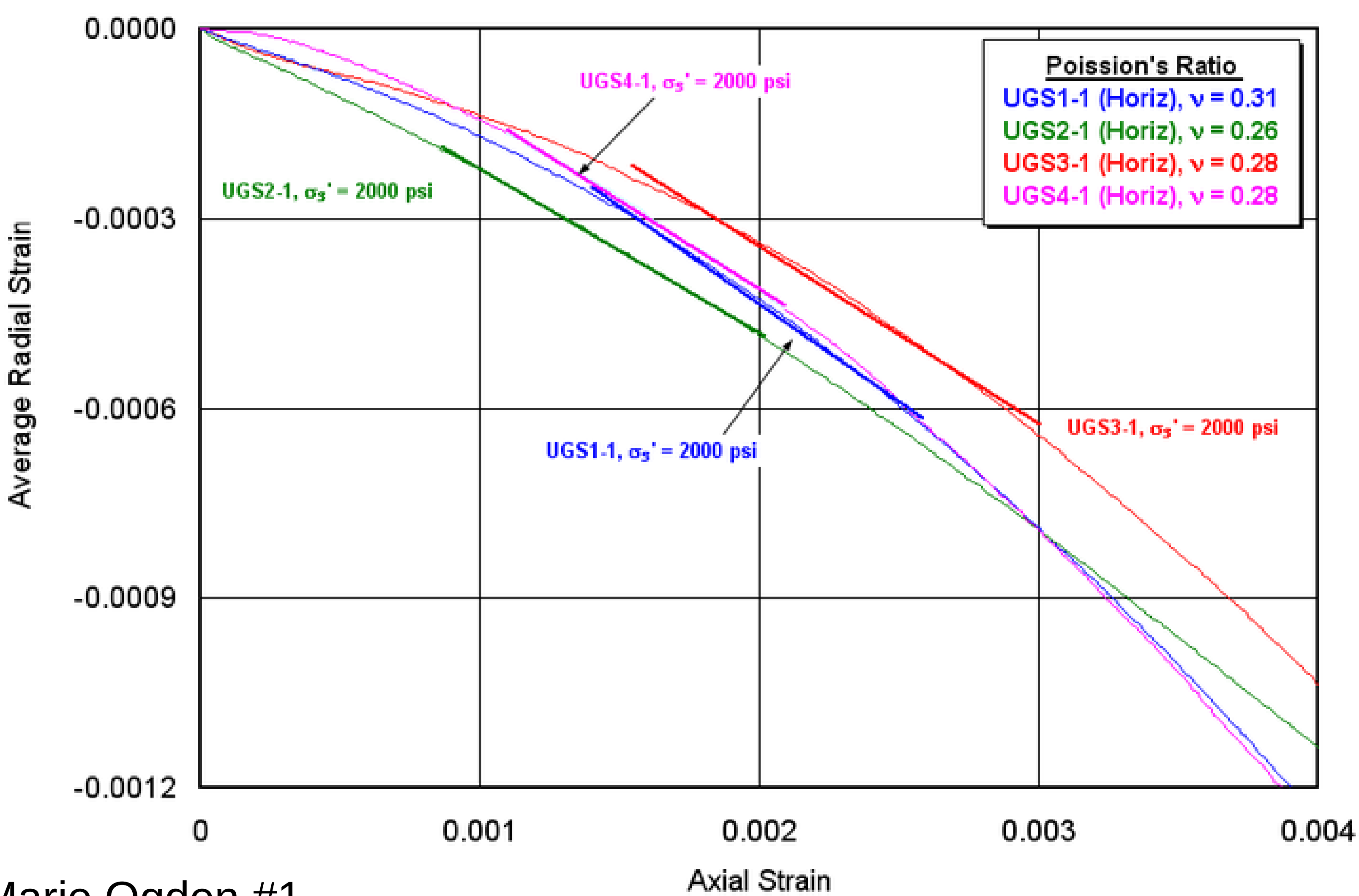
Lake Canyon 1-27, 5774 ft.

Young’s Modulus for U. Ismay, Hovenweep, L. Ismay, and Gothic

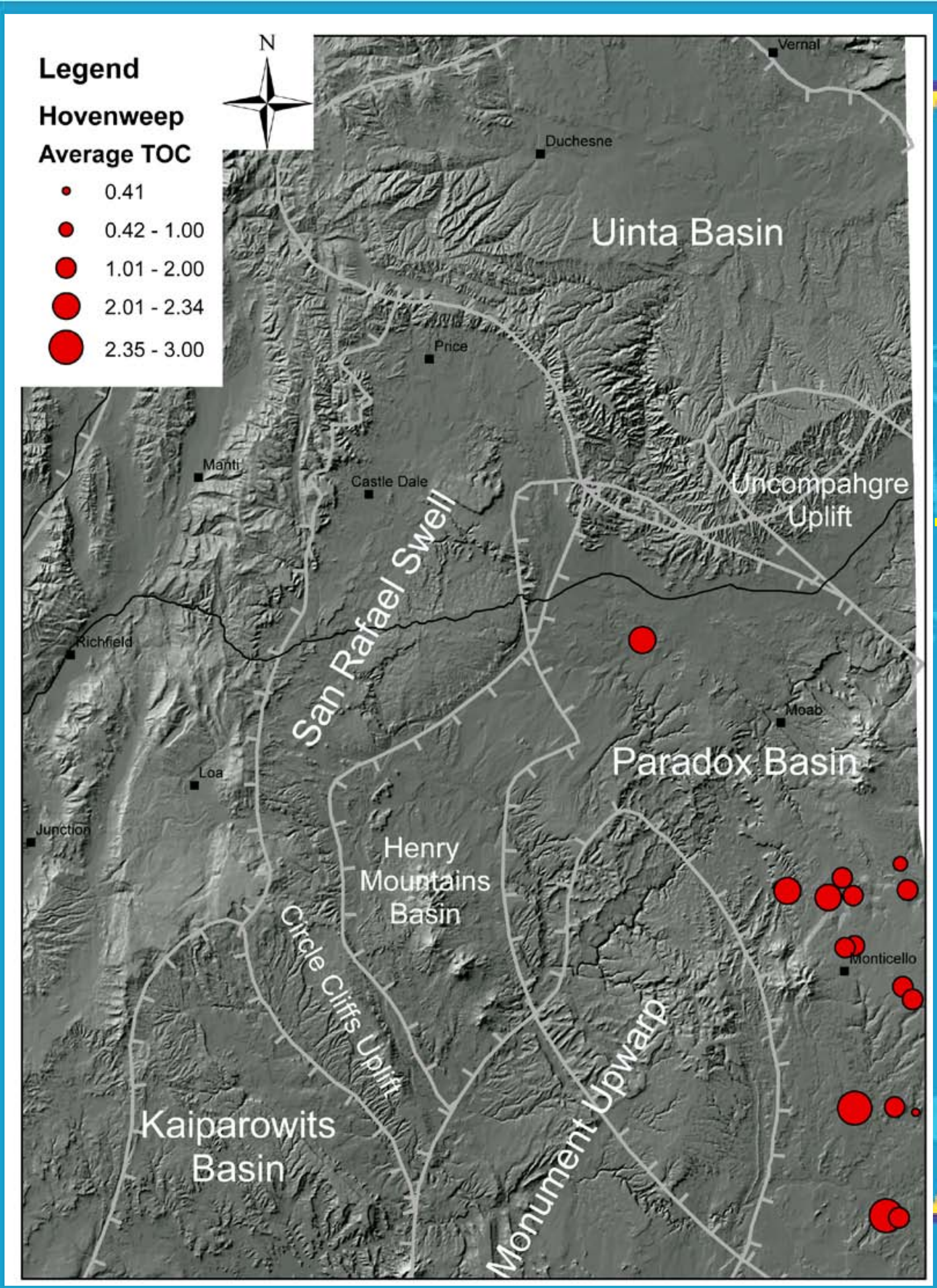


Marie Ogden #1

Poisson's Ratio for U. Ismay, Hovenweep, L. Ismay, and Gothic

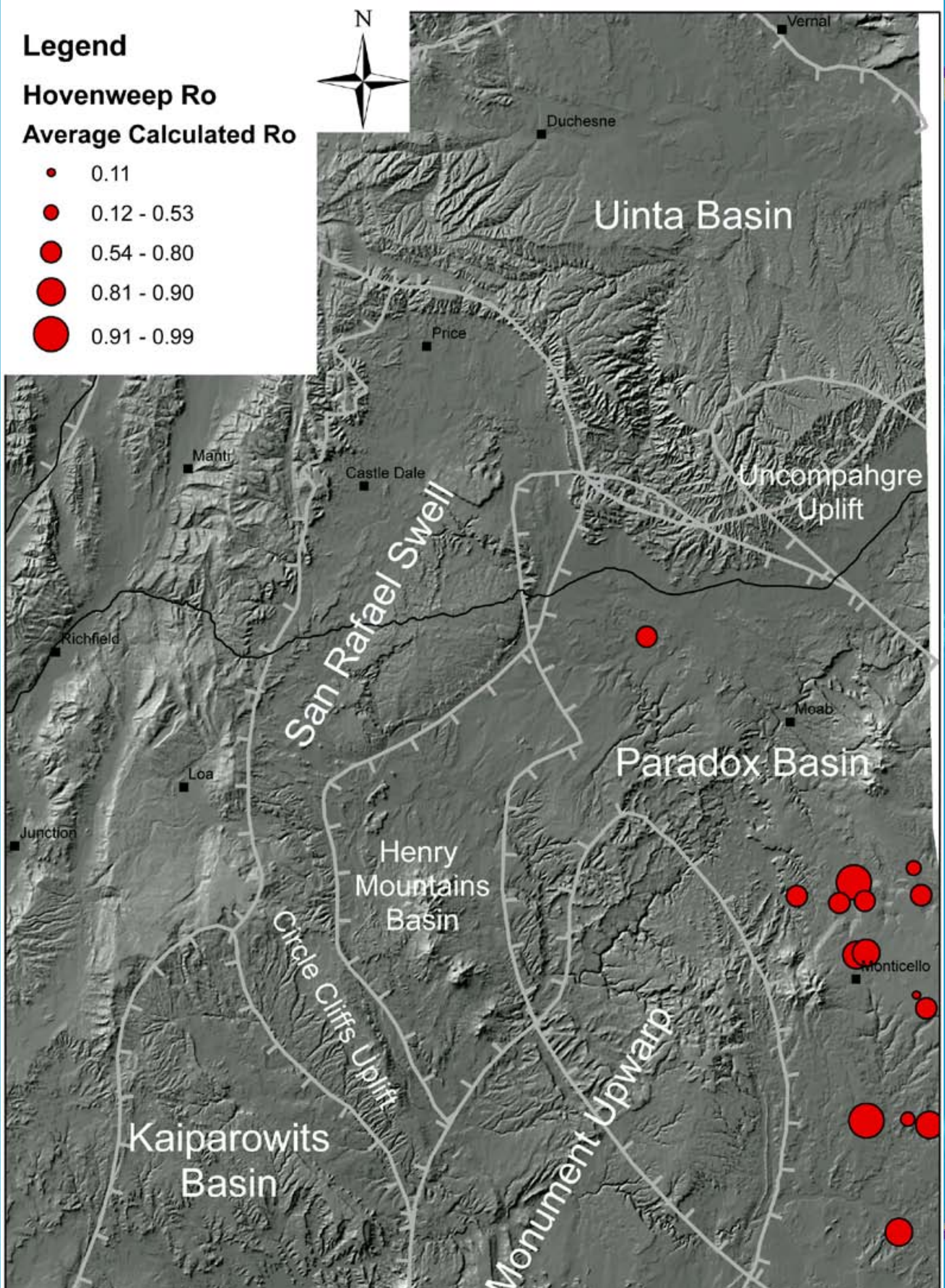


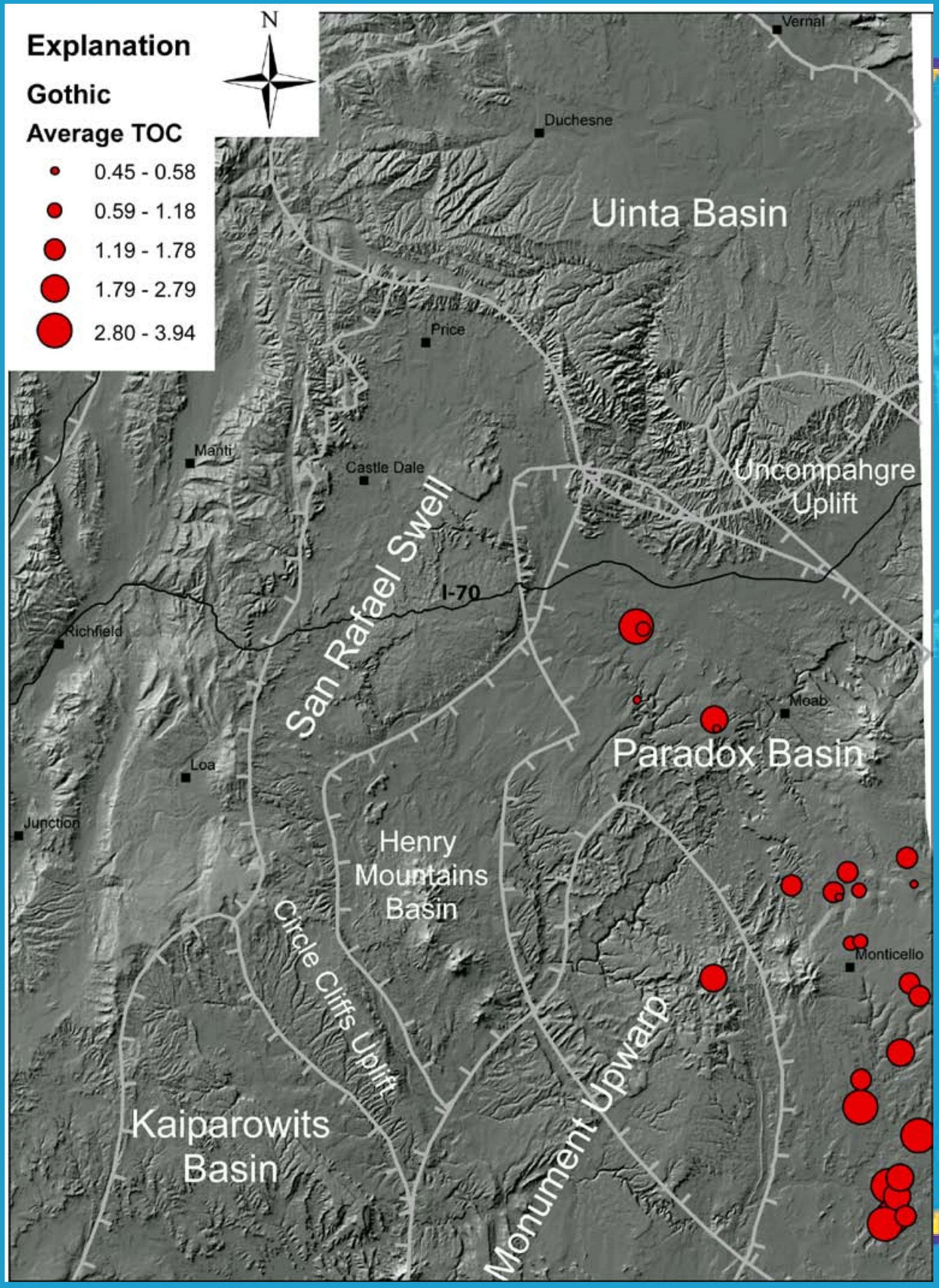
Marie Ogden #1



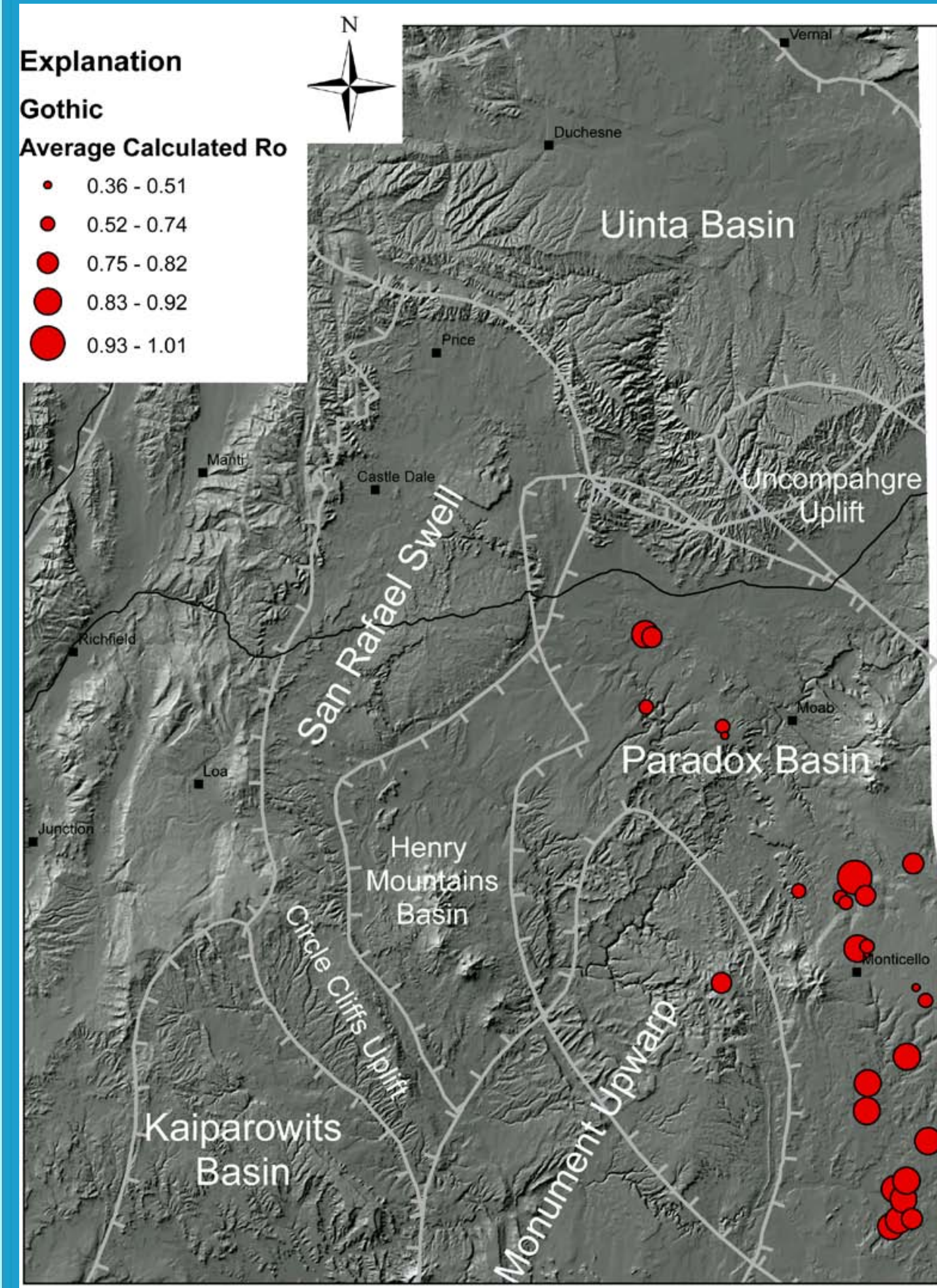
Total Organic Carbon: Hovenweep

Vitrinite Reflectance: Hovenweep



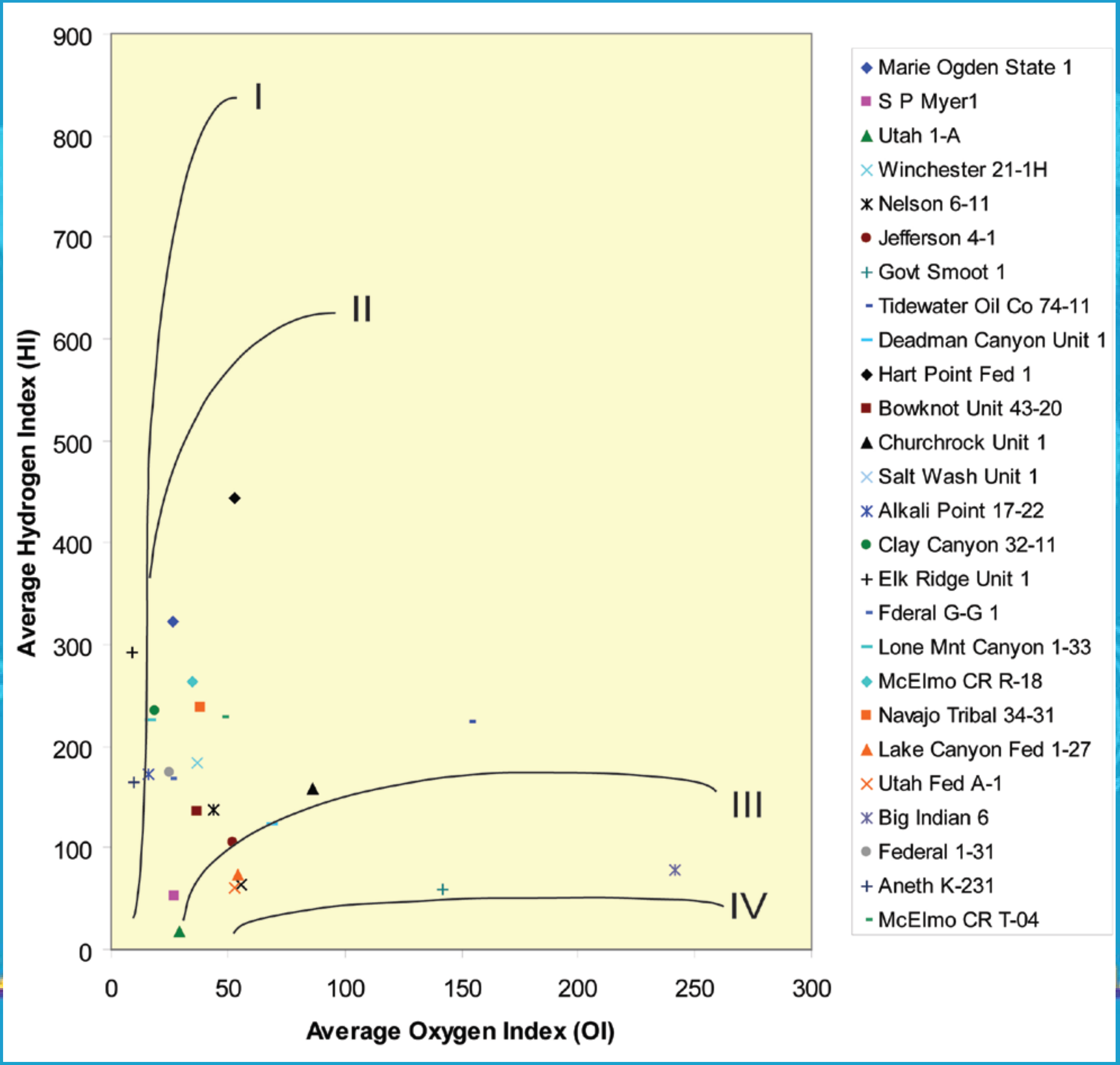


Total Organic Carbon: Gothic Shale



Vitrinite Reflectance: Gothic Shale

Pseudo van Krevelen: Gothic Shale



Pennsylvanian Paradox Shales: Conclusions

- The three shale intervals are gas productive in Hovenweep, Gothic, Chimney Rock mudstones.
- Most contain illitic clays, terrigenous silt, organic matter, dolomite, pyrite, and a variety of reworked and/or fossil fragments.
- Rock-eval pyrolysis clearly points to rocks in the oil window; gas production is therefore anomalous in terms of simple geochemical analysis—at least in Utah portions of the Paradox.
- Gas might be the product of solution gas drive or of a more complicated PVT relationship.

Pennsylvanian Paradox Shales: Conclusions Continued

- The porosity and permeability of all mudstone reservoirs are modest – porosity between 2 and 5%; permeability approaches 200 nanodarcies.
- Permeability appears directly related to intercrystalline porosity from dolomite crystal aggregates.
- The interbedded silty dolomites within and bounding the mudstone sections may be the most permeable conduit and most critical key for sustained hydrocarbon production when successfully accessed by the stimulation protocol.
- Natural fractures could assist in providing a respectable IP especially when hydraulic fracturing is applied.