Overview of Organic-Rich Facies of the Permian Phosphoria Formation, USA*

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Abstract

The Permian Phosphoria Formation of the U.S. Northern Rocky Mountain region is a major petroleum system that includes thermally mature world-class petroleum source rock facies, in addition to high quality conventional reservoir facies and a regionally extensive overlying seal. Middle Permian organic-rich mudstone facies of the Phosphoria Formation occur in two separate depocenters, each named an organic-rich member of the Phosphoria. The Retort depocenter of southwestern Montana contains a phosphatic mudstone facies with up to 25% measured TOC. Retort mudstone decreases in %TOC and increases in %P away from the depocenter. At the depositional margins of the Retort depocenter, very well-sorted ore grade peloidal phosphorite is present. The Meade Peak depocenter in southeastern Idaho into northern Utah and parts of northeastern Nevada. In the Oquirrh basin of northwestern Utah Carboniferous and Permian strata are ~7.5 kilometers thick, and the Meade Peak Member is ~150 meters thick. The thick accumulations of Middle Permian organic-rich source rocks in northwestern Utah effectively expands the size of the 'classic Phosphoria basin' as described by the USGS and other publications, and it also greatly expands the size of the Phosphoria Total Petroleum System. For example, DeMaison (1977) suggested that Phosphoria mudrocks provided the source for the ~16 billion Bbl 'Tar Sands Triangle' of southeastern Utah. Most paleogeographic reconstructions interpret the Phosphoria Formation to have been separated from the open Panthalassa Ocean by an archipelago of islands and larger landmasses that included the Golconda Allochthon, the Sonoma Arc, and possibly a second more outboard arc. Southwesterly connection of the Phosphoria basin to Panthallasa is consistent with regional stratigraphic information and would have introduced more nutrient-rich waters from the north equatorial gyre than a south-flowing current that entered the Phosphoria basin from the northwest.

Selected References

DeMaison, G.J., 1977, Tar sands and supergiant oil fields: AAPG Bulletin, v. 61, p. 1950-1961.

Hiatt, E., and D. Budd, 2003, Extreme paleoceanographic conditions in a Paleozoic oceanic upwelling system: Organic productivity and widespread phosphogenesis in the Permian Phosphoria Sea: Geological Society of America, Special Paper 370, DOI: https://doi.org/10.1130/0-8137-2370-1.245

Maughan, E.K., 1975, Preliminary unevaluated map showing distribution of organic carbon in Meade Peak and Retort members of the Phosphoria Formation (Permian) in parts of Utah, Idaho, Wyoming, and Montana: USGS Open-File Report 75-101, https://doi.org/10.3133/ofr75101

McKelvey, V.E., T.M. Cheney, E.R. Cressman, R.P. Sheldon, R.W. Swanson, and J.S. Williams, 1959, The Phosphoria, Park City, and Shedhorn Formations in the Western Phosphate Field: U.S. Geological Survey Professional Paper 313-A, p. A1-A47.

Overview of organic-rich facies of the Permian Phosphoria Formation, USA

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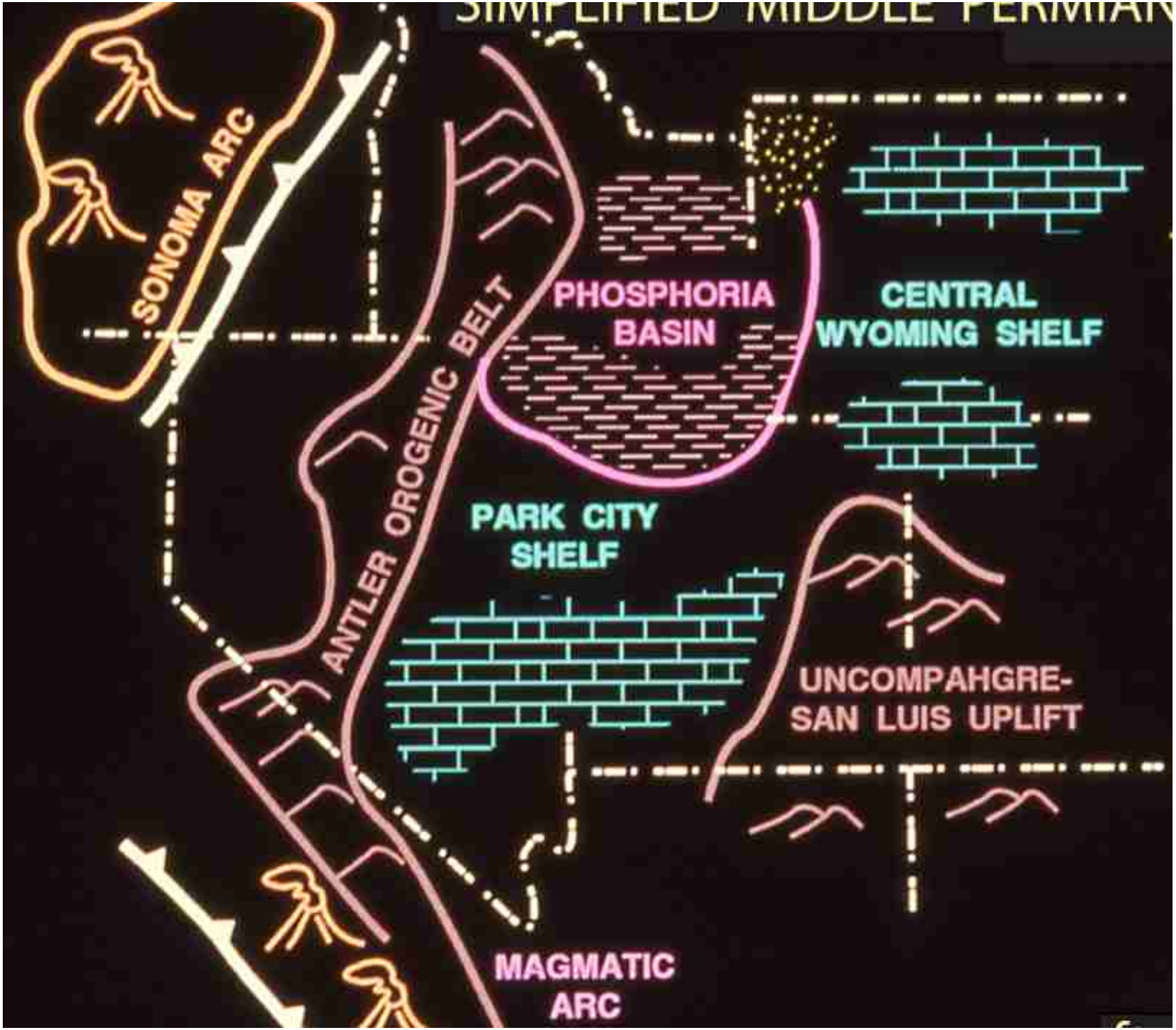
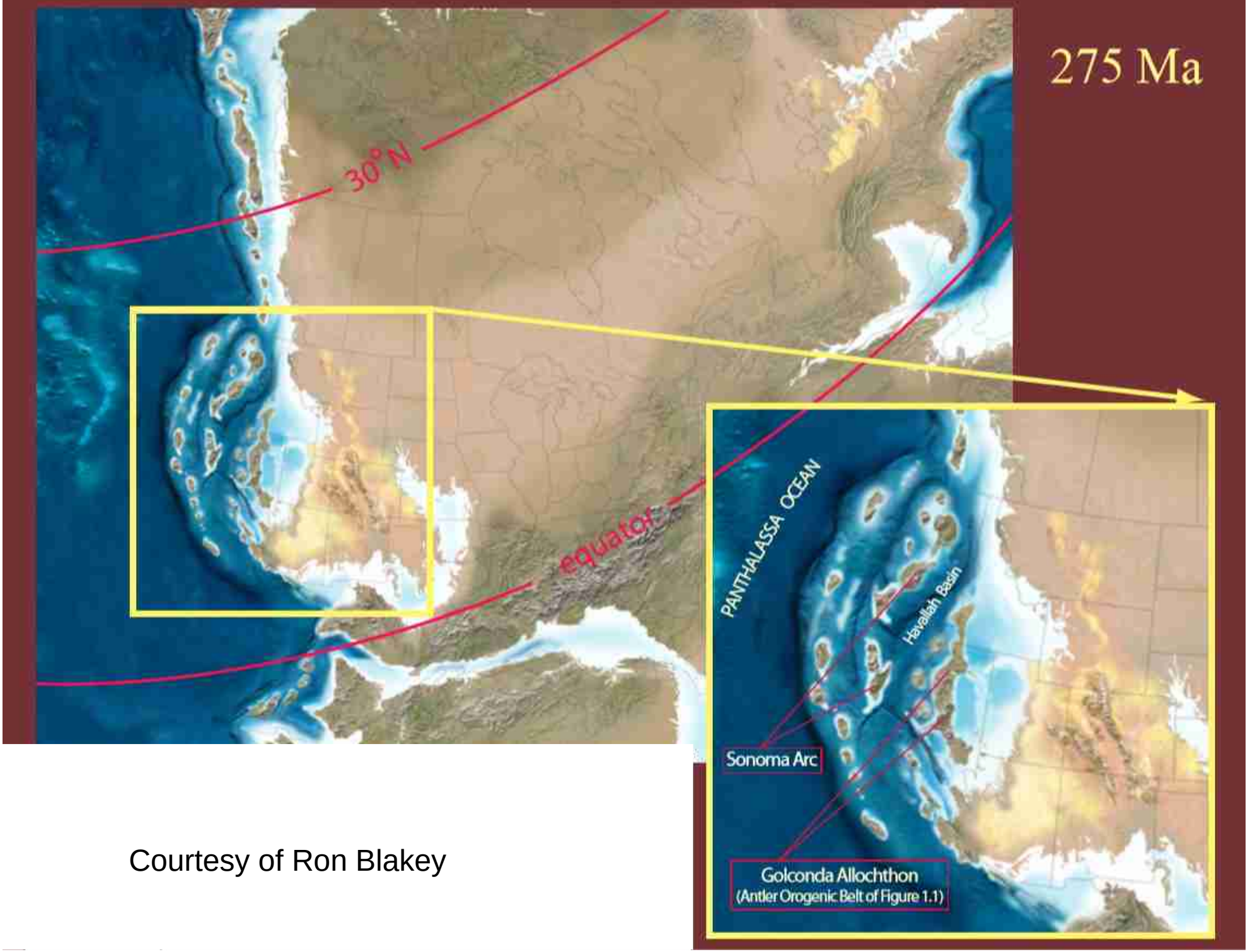
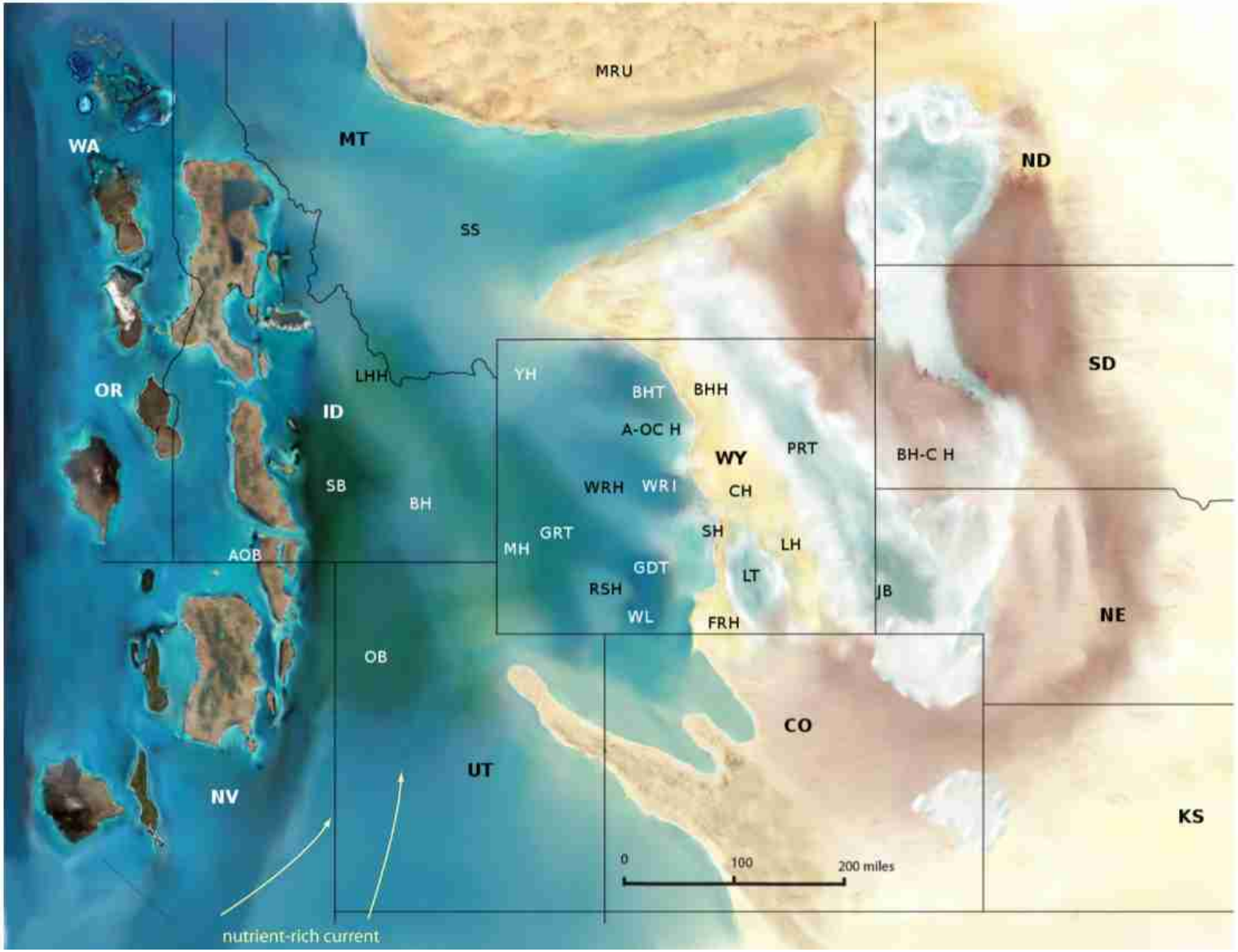
UNIVERSITY OF MONTANA

AIM GeoAnalytics


SIMPLIFIED MIDDLE PERMIAN
SONOMA ARC
ANTLER OROGENIC BELT
PHOSPHORIA BASIN
CENTRAL WYOMING SHELF
PARK CITY SHELF
UNCOMPAHGRE-SAN LUIS UPLIFT
MAGMATIC ARC

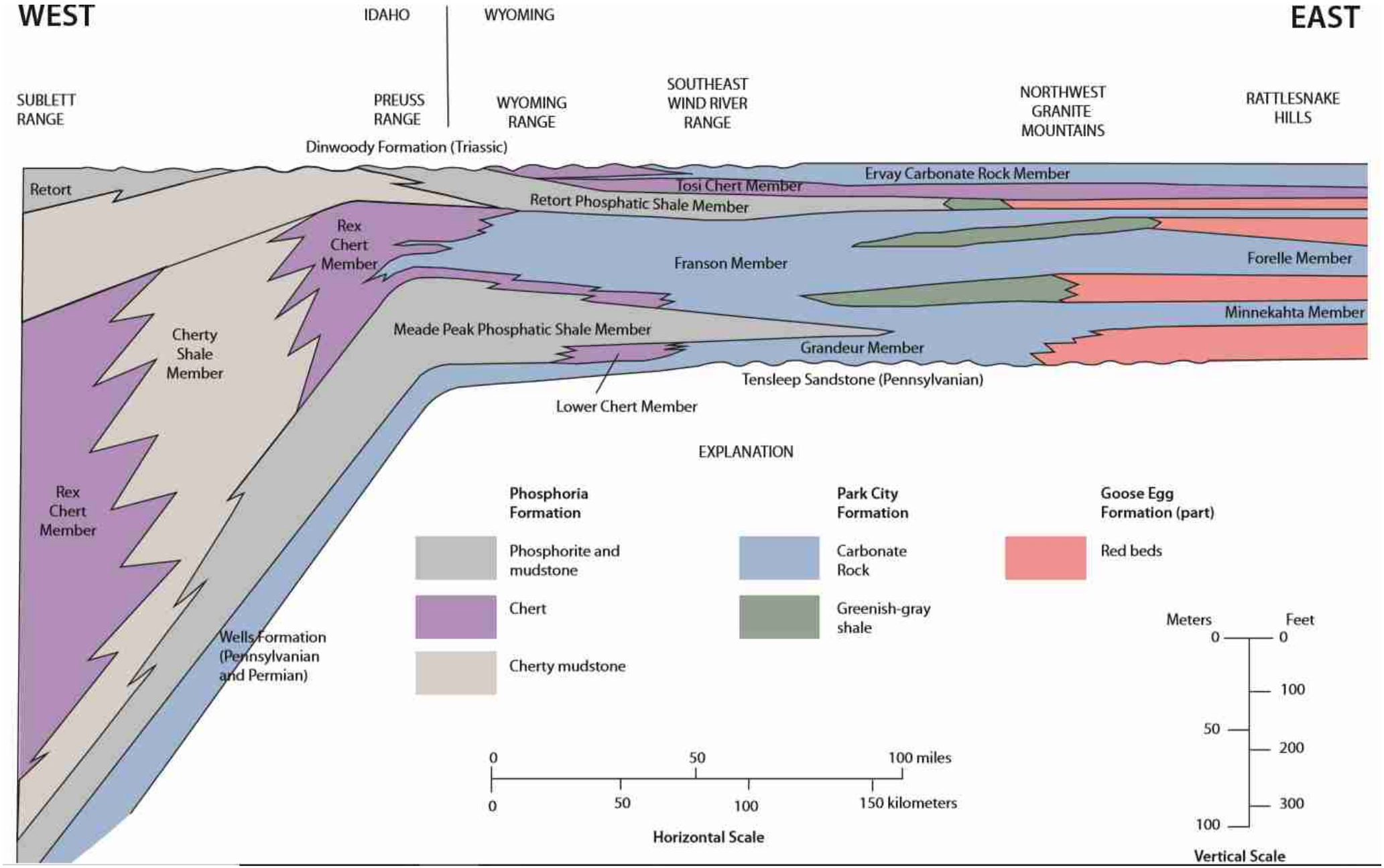


Courtesy of Ron Blakey

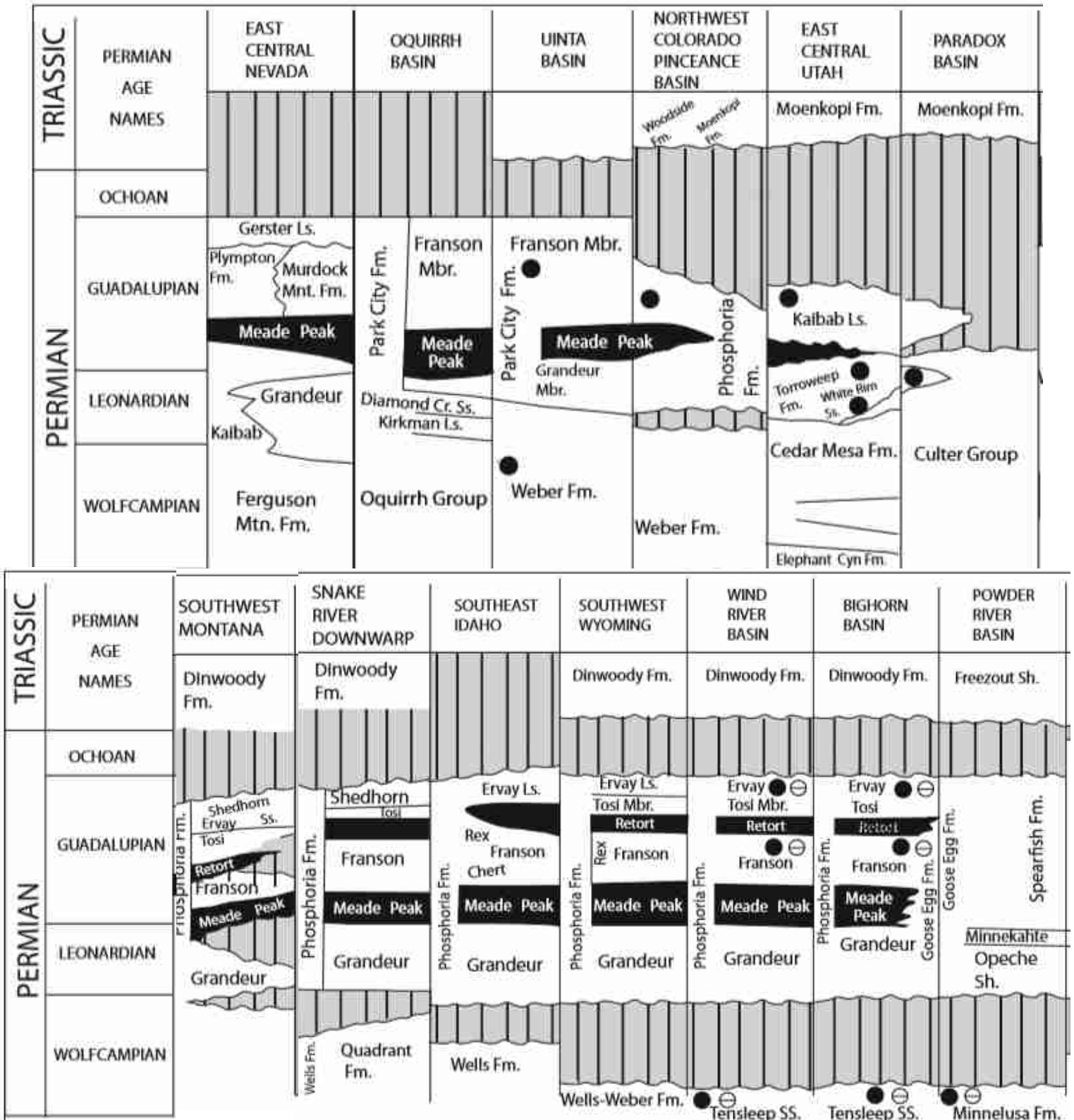


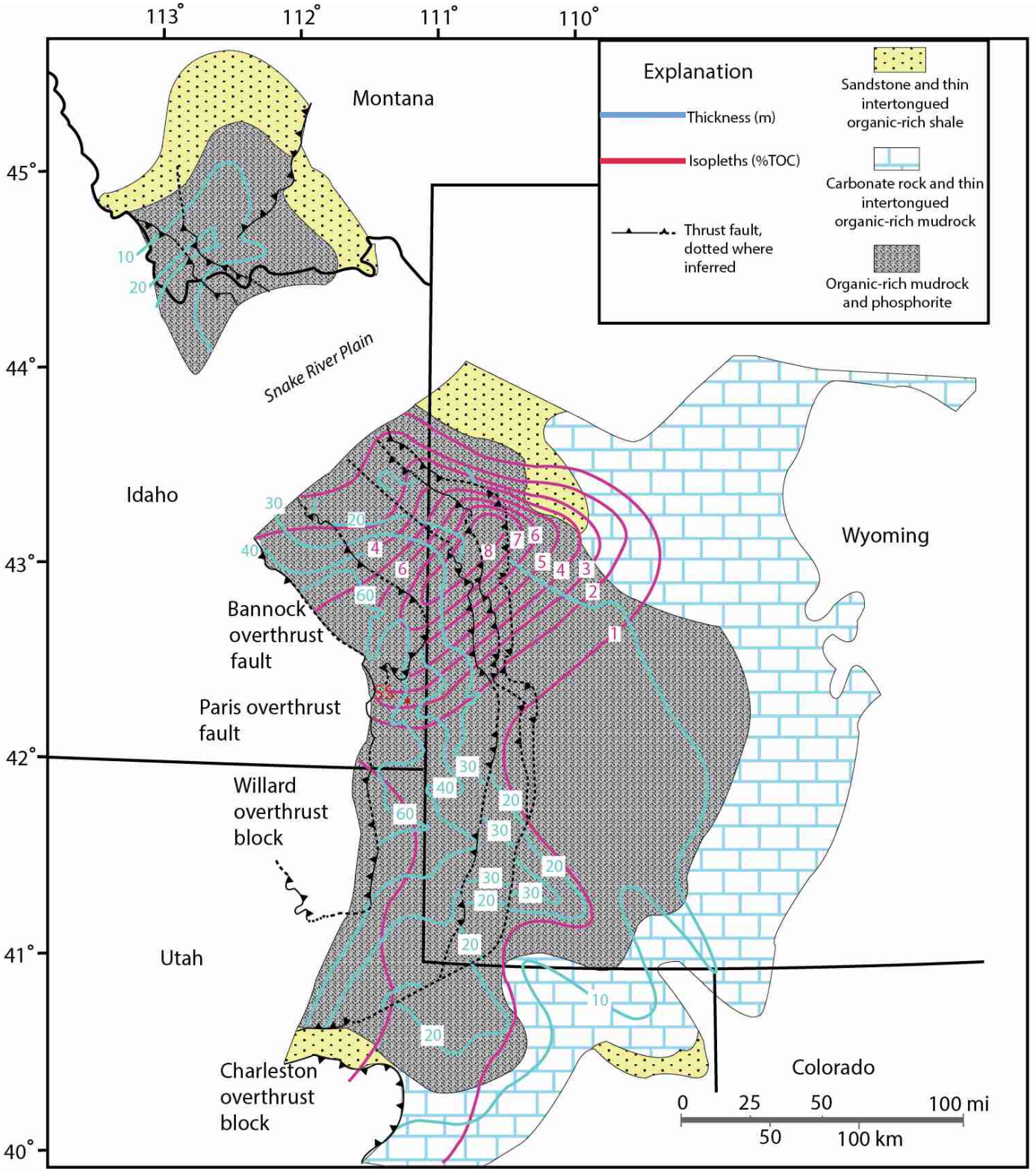
Key to Abbreviations
(paleotectonic elements)

AOB	Antler Orogenic Belt
A-OC H	Absaroka-Owl Creek High
BH	Bannock HIgh
BH-C H	Black Hills-Chadron High
BHH	Bighorn High
BHT	Bighorn Trough
CH	Casper High
FRH	Front Range High
GDT	Great Divide Trough
GRT	Green River Trough
JB	Julesburg Basin
LH	Laramie High
LT	Laramie Trough
LHH	Lemhi High
MH	Moxa High
MRU	Milk River Uplift
RSH	Rock Springs High
OB	Oquirrh Basin
PRT	Powder River Trough
SB	Sublett Basin
SH	Sweetwater High
SS	Shedhorn Shelf
UA	Uinta Axis
WL	Washakie Low
WRH	Wind River High
WRT	Wind River Trough
YH	Yellowstone High



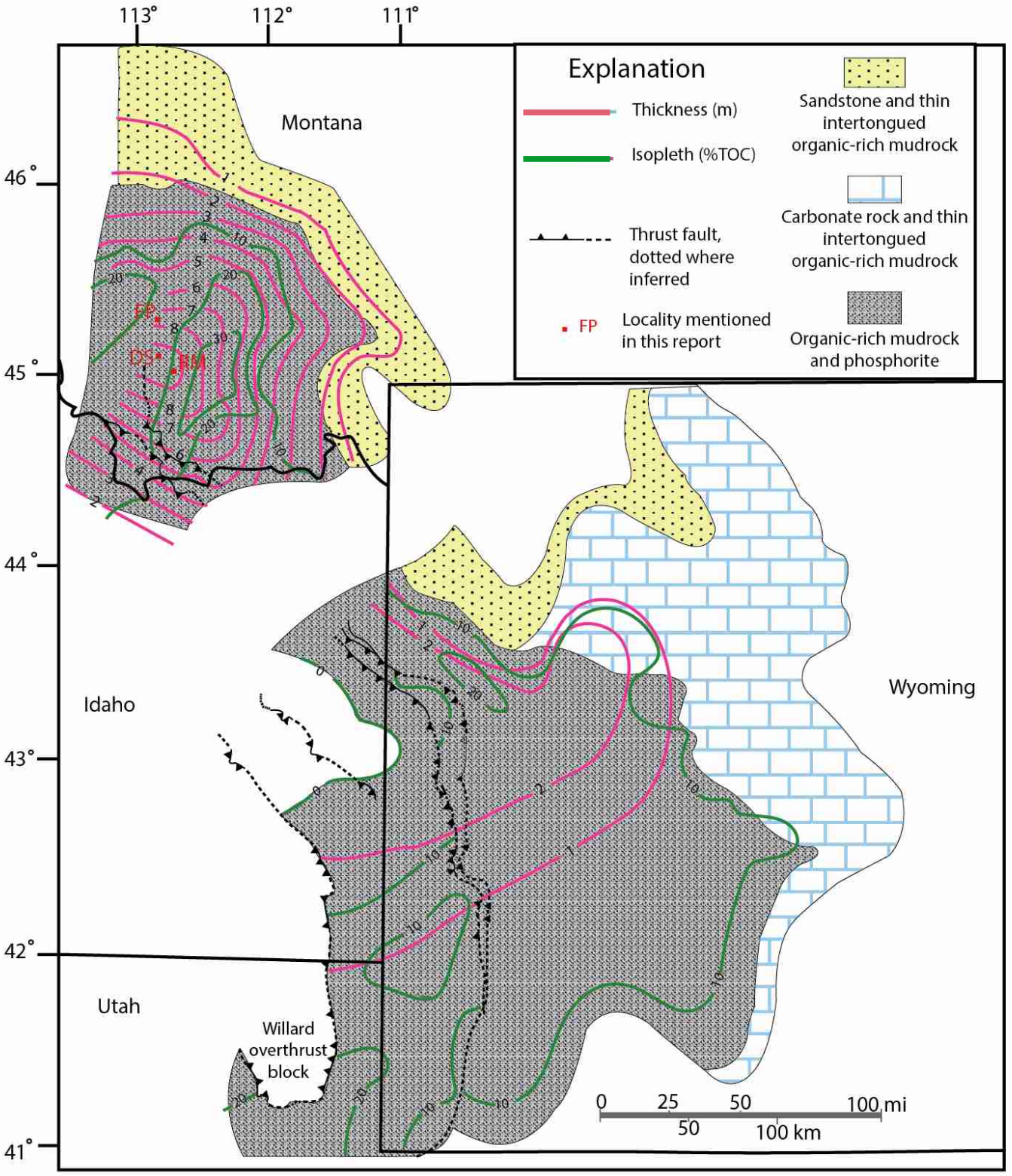
After McKelvey et al., 1959


TRIASSIC
PERMIAN
PERMIAN AGE NAMES
OCHOAN
GUADALUPIAN
LEONARDIAN
WOLFCAMPIAN
EAST CENTRAL NEVADA
OQUIRRH BASIN
UINTA BASIN
NORTHWEST COLORADO PINCEANCE BASIN
EAST CENTRAL UTAH
PARADOX BASIN
Gerster Ls.
Plympton Fm.
Murdock Mnt. Fm.
Meade Peak
Grandeur
Kaibab
Ferguson Mtn. Fm.
Park City Fm.
Franson Mbr.
Meade Peak
Diamond Cr. Ss.
Kirkman Ls.
Oquirrh Group
Park City Fm.
Franson Mbr.
Meade Peak
Grandeur Mbr.
Weber Fm.
Woodside Fm.
Moenkopi Fm.
Phosphoria Fm.
Weber Fm.
Moenkopi Fm.
Moenkopi Fm.
Kaibab Ls.
Torroweep Fm.
White Rim Ss.
Cedar Mesa Fm.
Culter Group
Elephant Cyn Fm.
SOUTHWEST MONTANA
SNAKE RIVER DOWNWARP
SOUTHEAST IDAHO
SOUTHWEST WYOMING
WIND RIVER BASIN
BIGHORN BASIN
POWDER RIVER BASIN
Dinwoody Fm.
Shedhorn
Ervay Ss.
Tosi
Retort
Franson
Meade Peak
Grandeur
Phosphoria Fm.
Dinwoody Fm.
Shedhorn
Tosi
Franson
Meade Peak
Grandeur
Phosphoria Fm.
Wells Fm.
Quadrant Fm.
Dinwoody Fm.
Ervay Ls.
Rex
Franson
Chert
Meade Peak
Grandeur
Phosphoria Fm.
Wells Fm.
Dinwoody Fm.
Ervay Ls.
Tosi Mbr.
Retort
Rex
Franson
Meade Peak
Grandeur
Phosphoria Fm.
Wells-Weber Fm.
Tensleep SS.
Dinwoody Fm.
Ervay
Tosi Mbr.
Retort
Franson
Meade Peak
Grandeur
Phosphoria Fm.
Tensleep SS.
Dinwoody Fm.
Ervay
Tosi
Retort
Franson
Meade Peak
Grandeur
Phosphoria Fm.
Goose Egg Fm.
Minnelusa Fm.
Freezout Sh.
Goose Egg Fm.
Spearfish Fm.
Minnekahta
Opeche Sh.



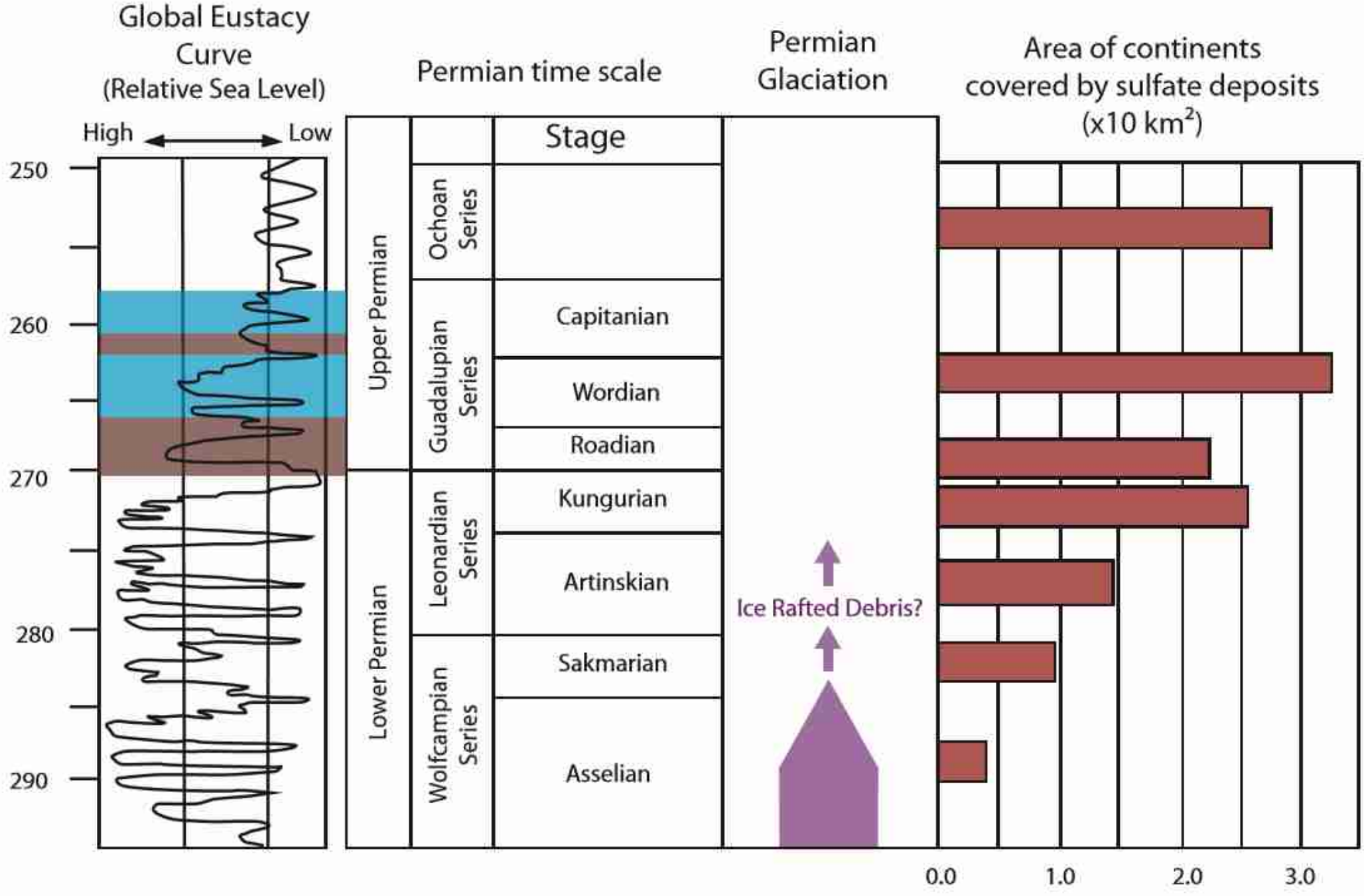
Meade Peak Distribution, Thickness, TOC%

Modified from Maughan, 1975

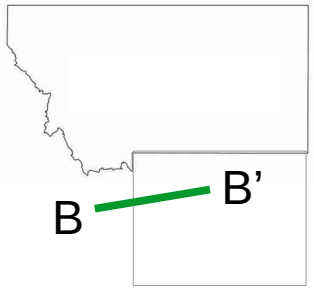


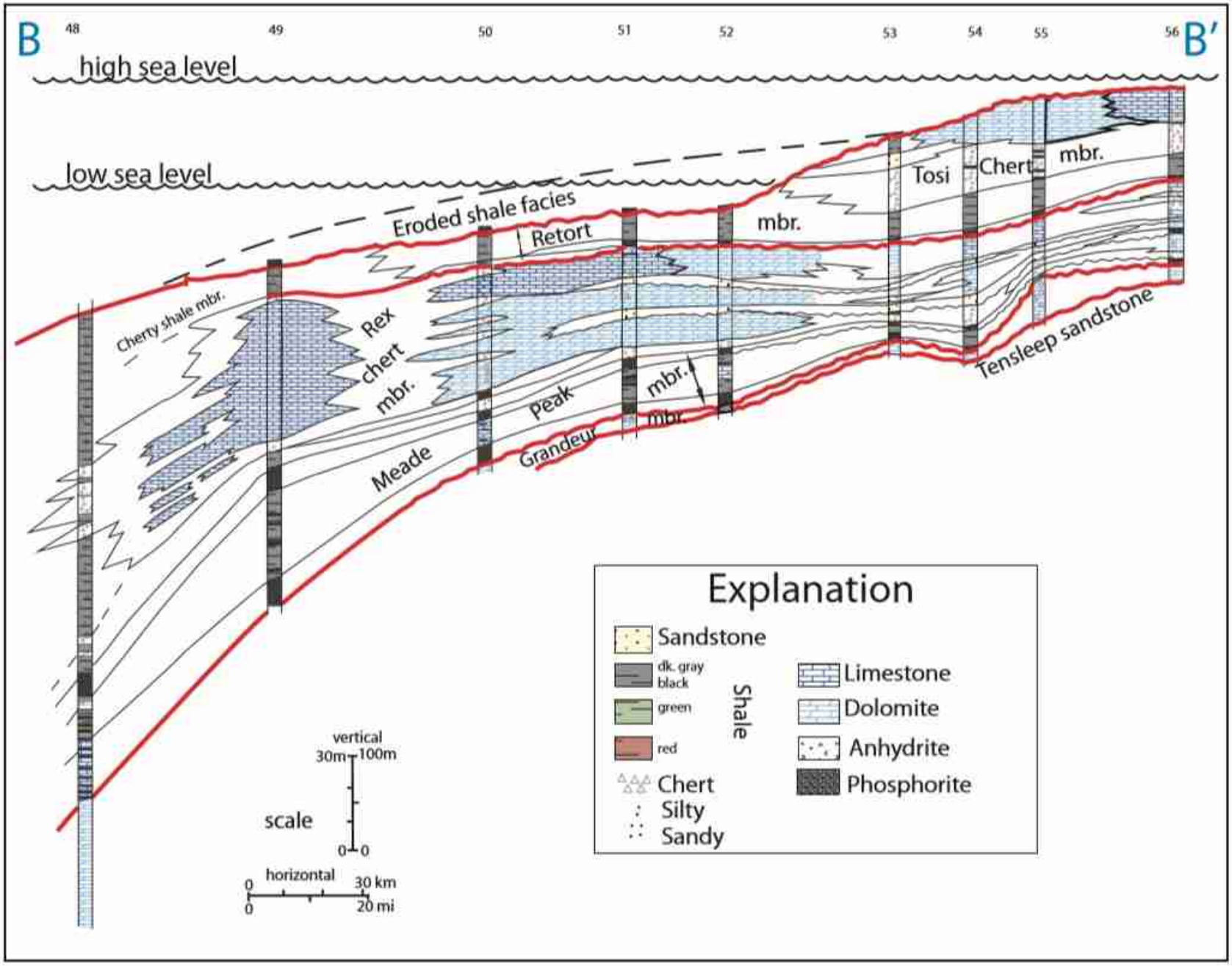
Retort Distribution, Thickness, TOC%

Modified from Maughan, 1975

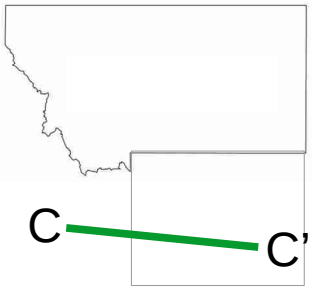


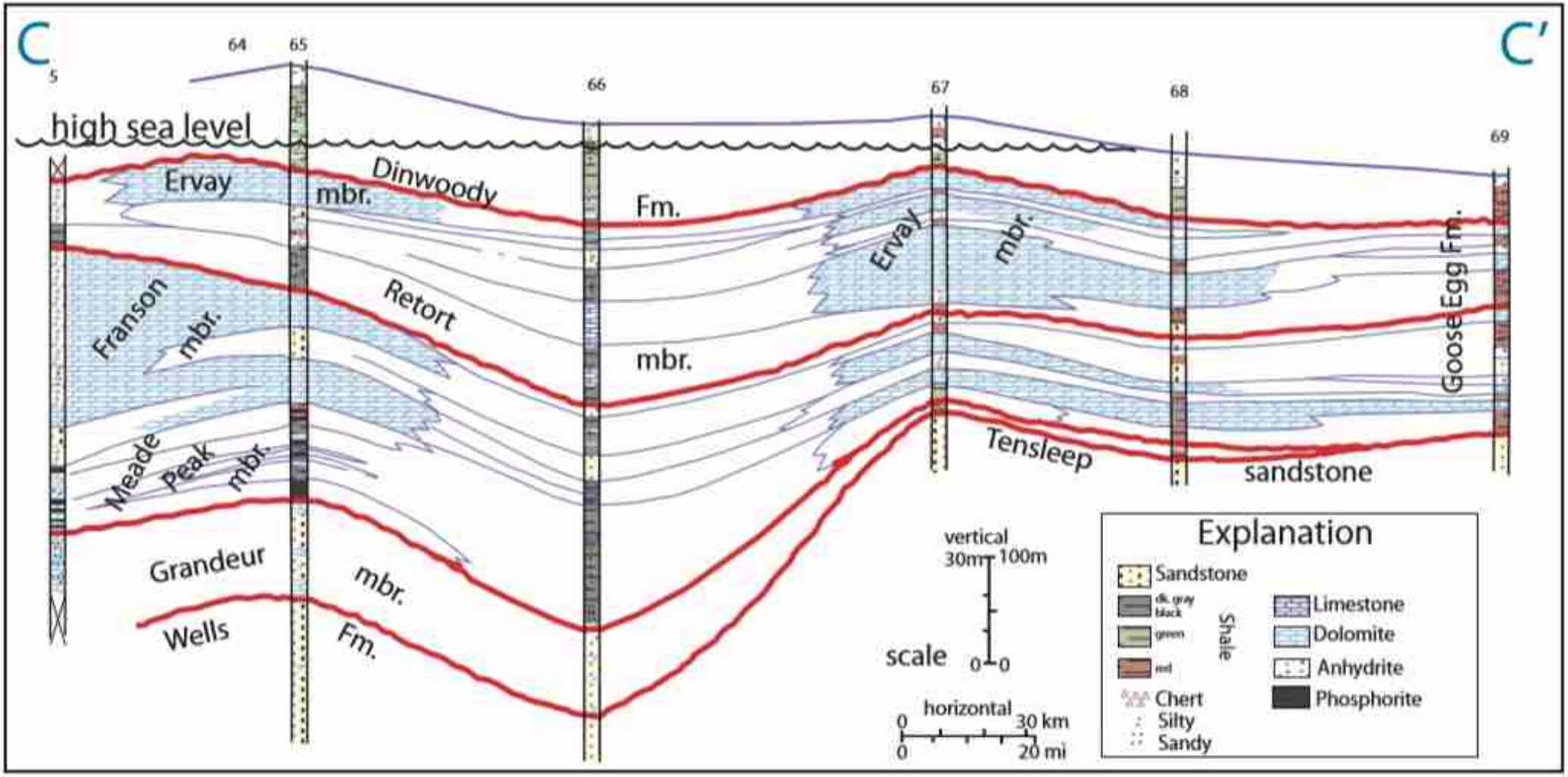
SL curve from Ross and Ross, 1994
Modified from Hiatt and Budd, 2003





Modified from Peterson, 1980

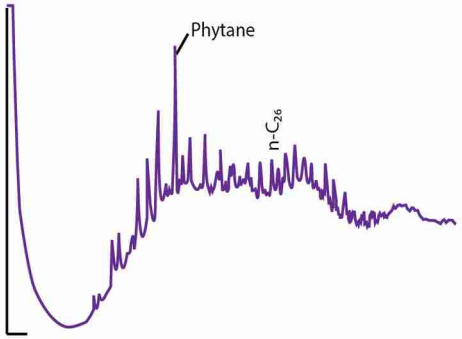




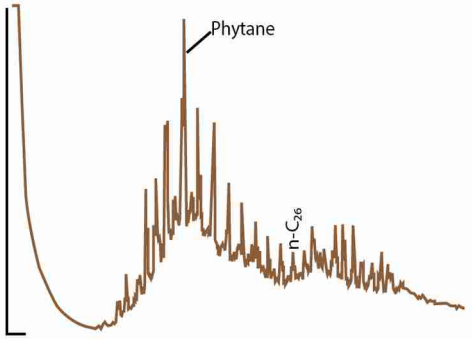
Modified from
Peterson, 1980

Low maturity

RETORT MEMBER
Blacktail Deer Range, SW Montana



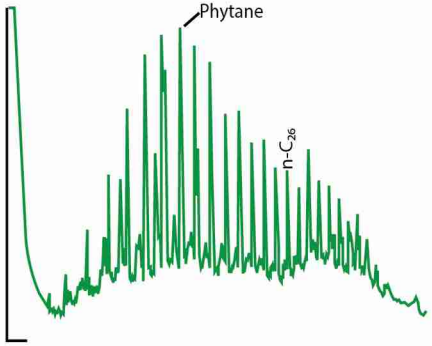
RETORT MEMBER
Little Sheep Creek, Tendoy Mtns., SW Montana



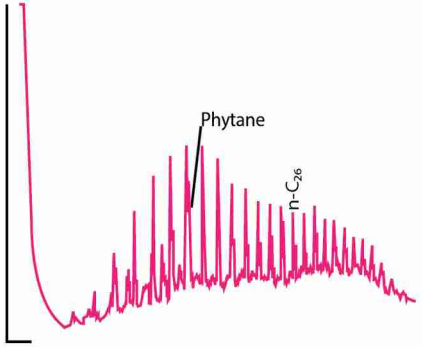
Mature

DETECTOR RESPONSE

RETORT MEMBER
Baldwin Creek, Wind River Range, western Wyoming

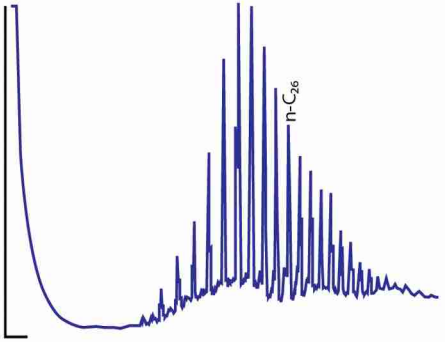


MEADE PEAK MEMBER
West Fork Duschesne R., southern Uinta Mtns., NE Utah

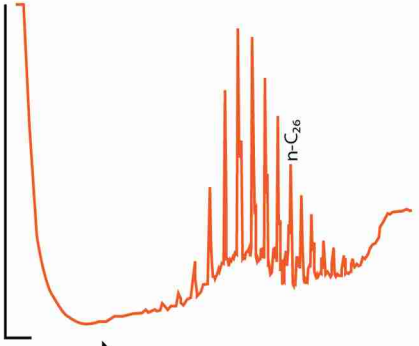


High Maturity

RETORT MEMBER
Gros Ventre Slide, Gros Ventre Mtns. western Wyoming

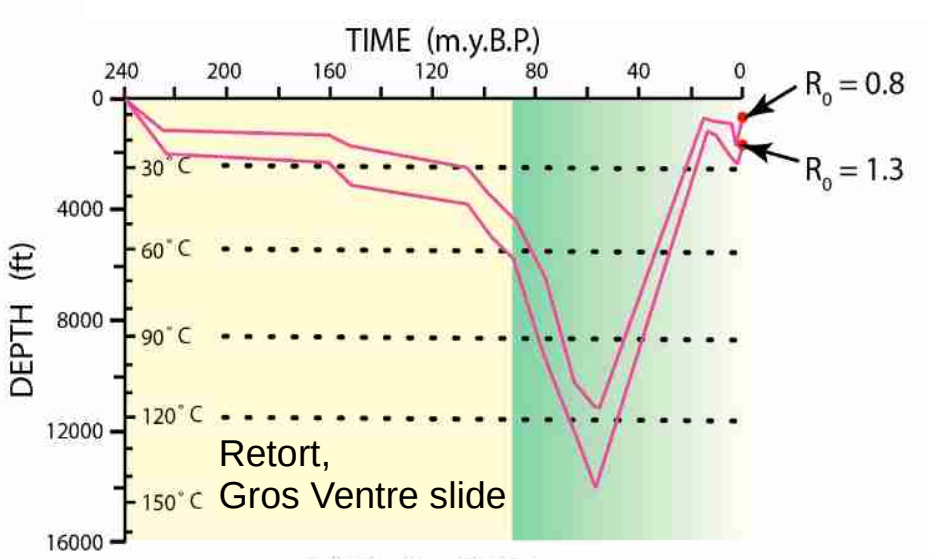


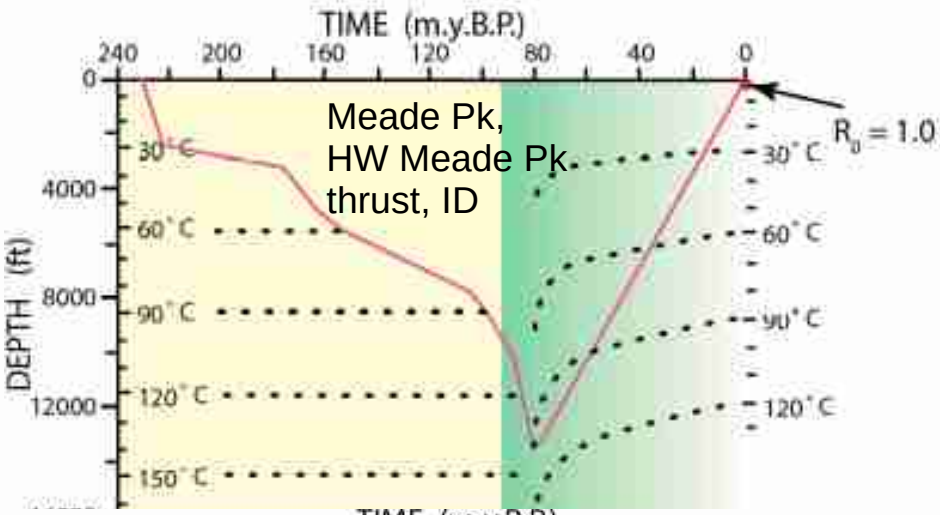
MEADE PEAK MEMBER
Benjamin Mine, Crawford Mtns., NE Utah

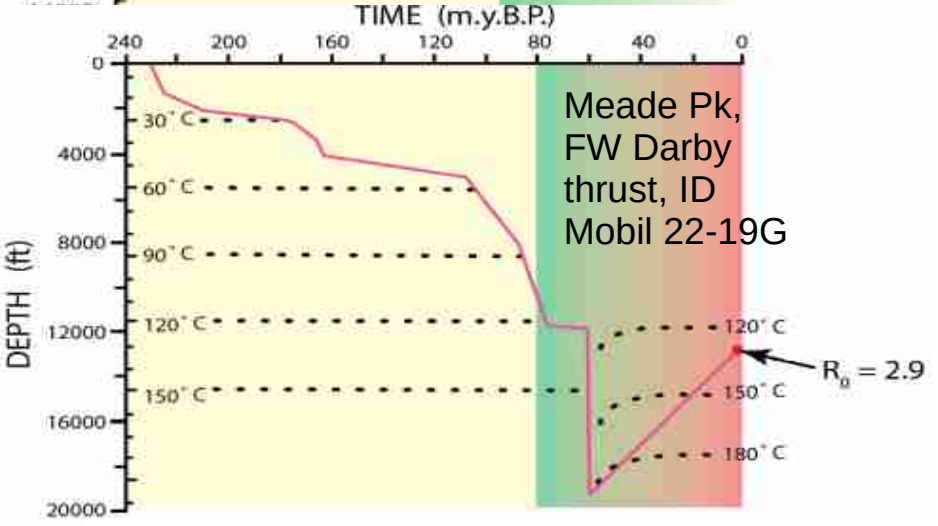


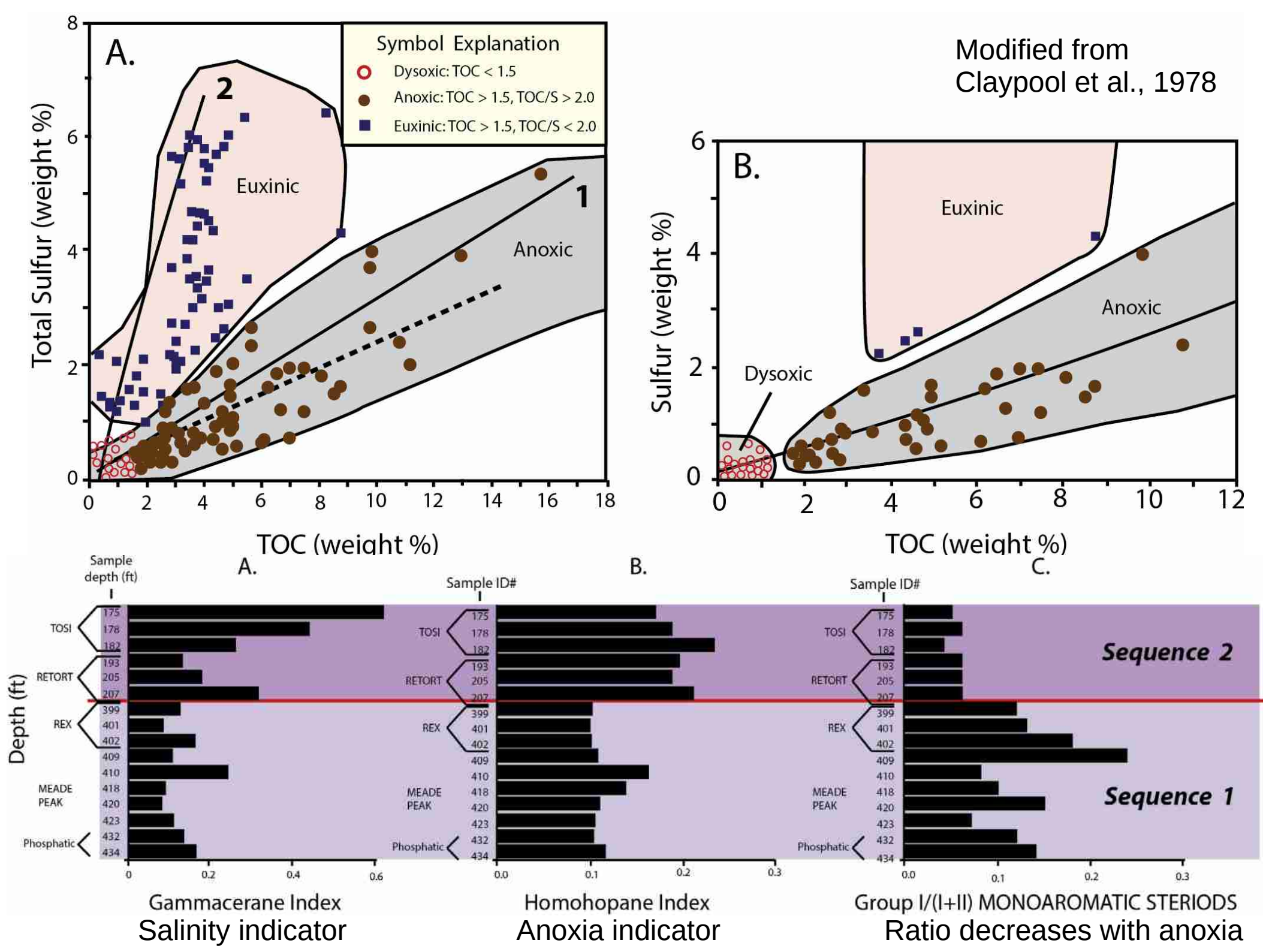
TEMPERATURE

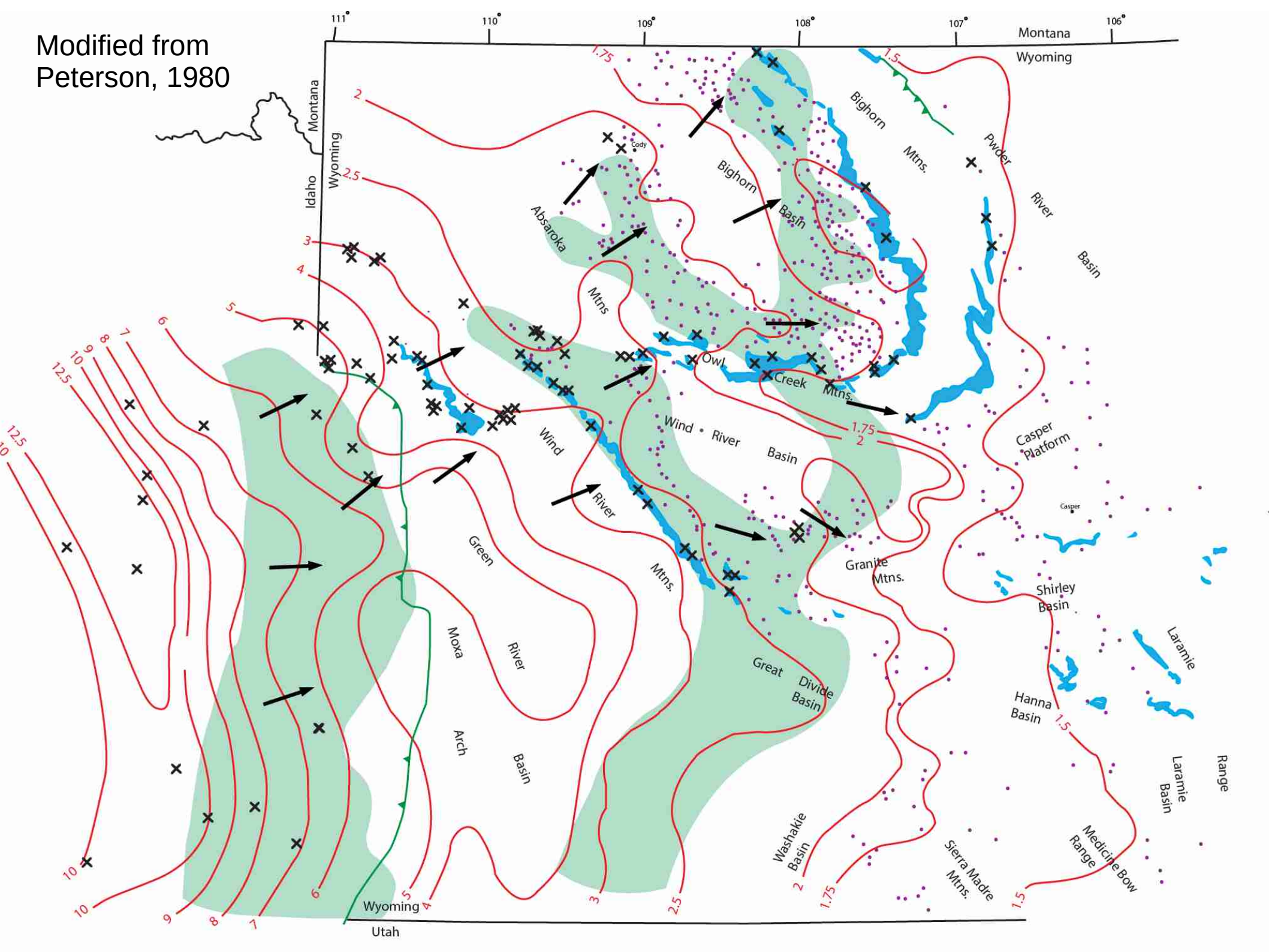
Dahl et al., 1993







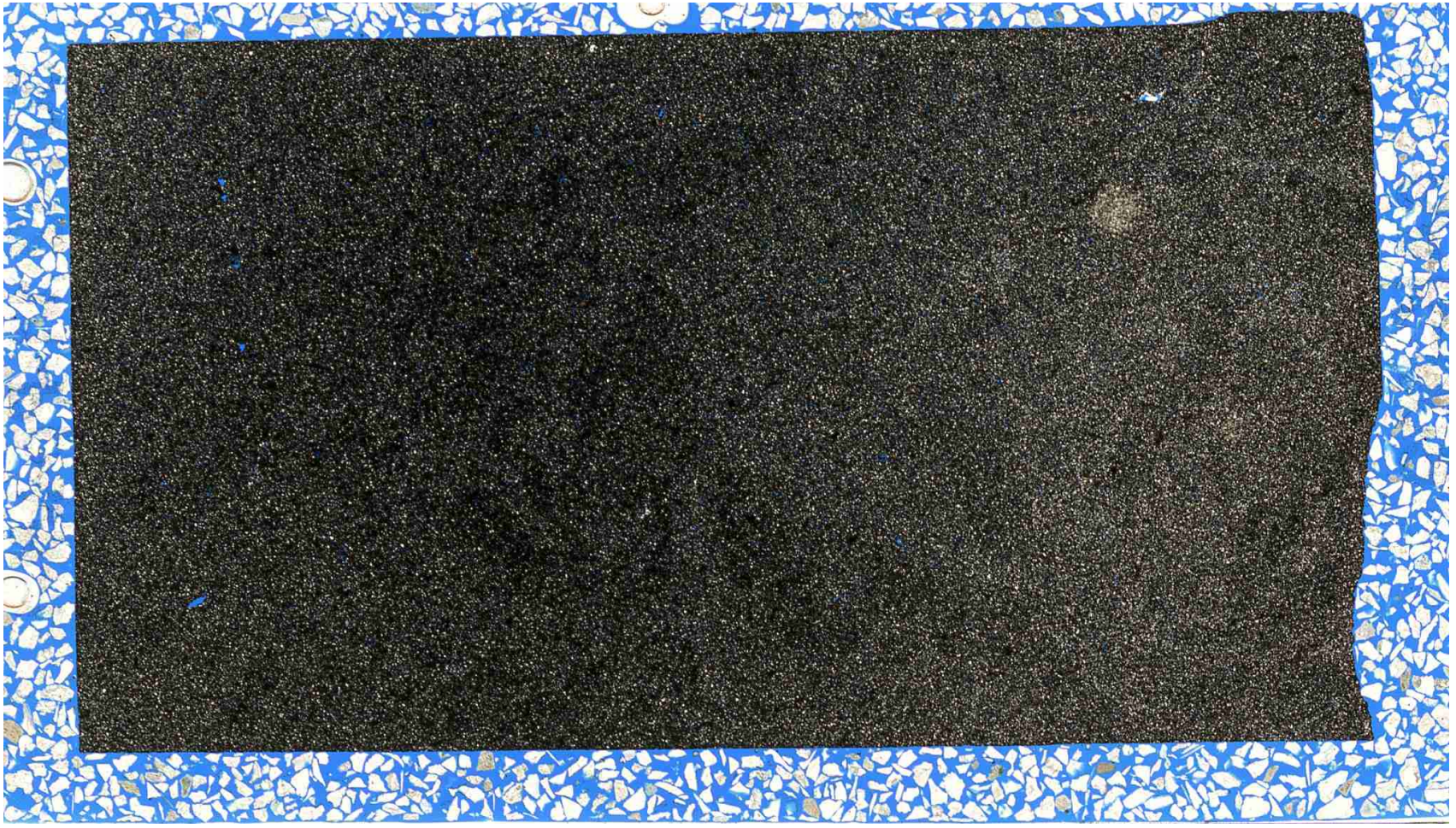

A.
Symbol Explanation
Dysoxic: TOC < 1.5
Anoxic: TOC > 1.5, TOC/S > 2.0
Euxinic: TOC > 1.5, TOC/S < 2.0
Euxinic
Anoxic
1
2
Total Sulfur (weight %)
TOC (weight %)
Modified from
Claypool et al., 1978
B.
Euxinic
Anoxic
Dysoxic
Sulfur (weight %)
TOC (weight %)
Sample depth (ft)
A.
Sample ID#
B.
Sample ID#
C.
TOSI
RETORT
REX
MEADE PEAK
Phosphatic
Depth (ft)
Sequence 2
Sequence 1
Gammacerane Index
Salinity indicator
Homohopane Index
Anoxia indicator
Group I/(I+II) MONOAROMATIC STERIODS
Ratio decreases with anoxia


Modified from
Peterson, 1980
111°
110°
109°
108°
107°
106°
Montana
Wyoming
Idaho
Cody
Bighorn
Mtns.
Pwder
River
Basin
Absaroka
Mtns
Owl
Creek
Mtns.
Wind
River
Basin
Casper
Platform
Casper
Granite
Mtns.
Shirley
Basin
Laramie
Hanna
Basin
Laramie
Basin
Range
Green
River
Basin
Moxa
Arch
Great
Divide
Basin
Washakie
Basin
Sierra Madre
Mtns.
Medicine Bow
Range
Utah
1.75
1.5
2
2.5
3
4
5
6
7
8
9
10
12.5

Sample 11-Pp-MF-01

Example of Facies 1: *Massive to thinly-Bedded organic-rich silty dolomudstone*

Sample: 11-Pp-MF-01
Meade Peak Member
42°38'41.69"N, 111°17'15.19"W
Montana Fuel Mine (inactive)
Southeastern Idaho

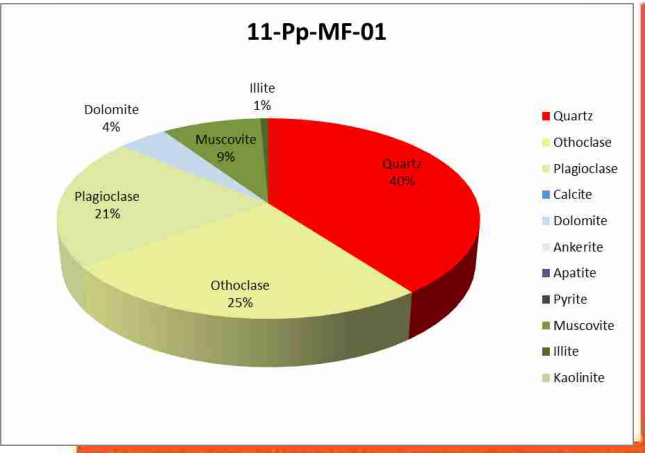


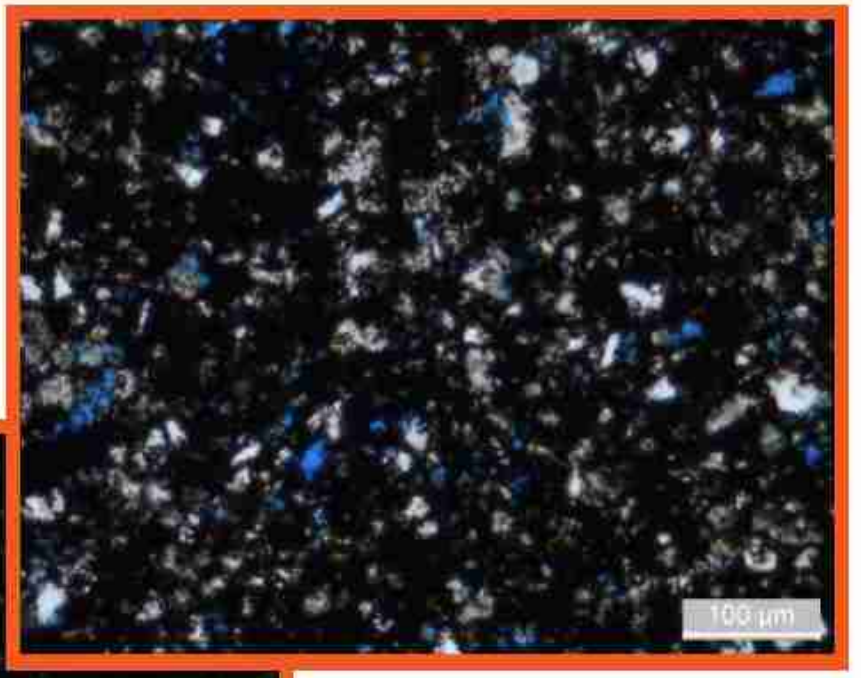
11-Pp-MF-01 thin-section

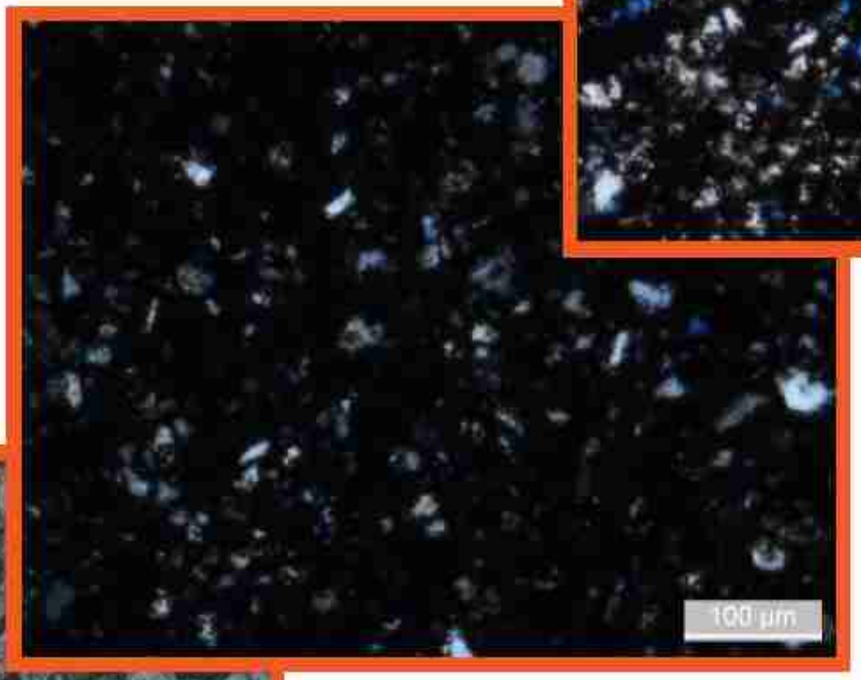
TOC = 5.87%

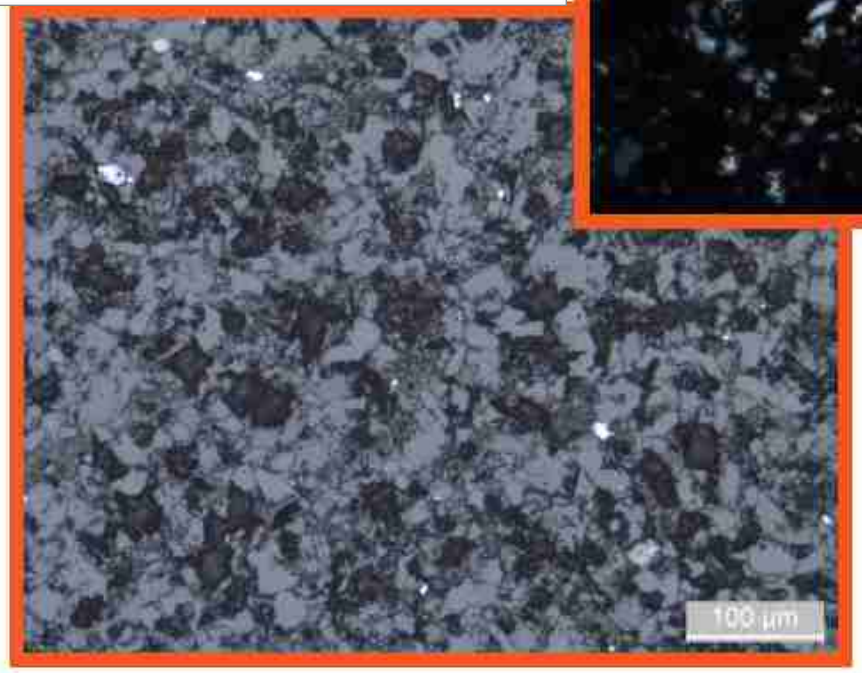
Sample: 11-Pp-MF-01
Meade Peak Member
43° 38'41.69"N, 111° 17'15.19"W
Montana Fuel Mine (inactive)
Southeastern Idaho

TOC = 5.87%
Nitrogen = 0.57%





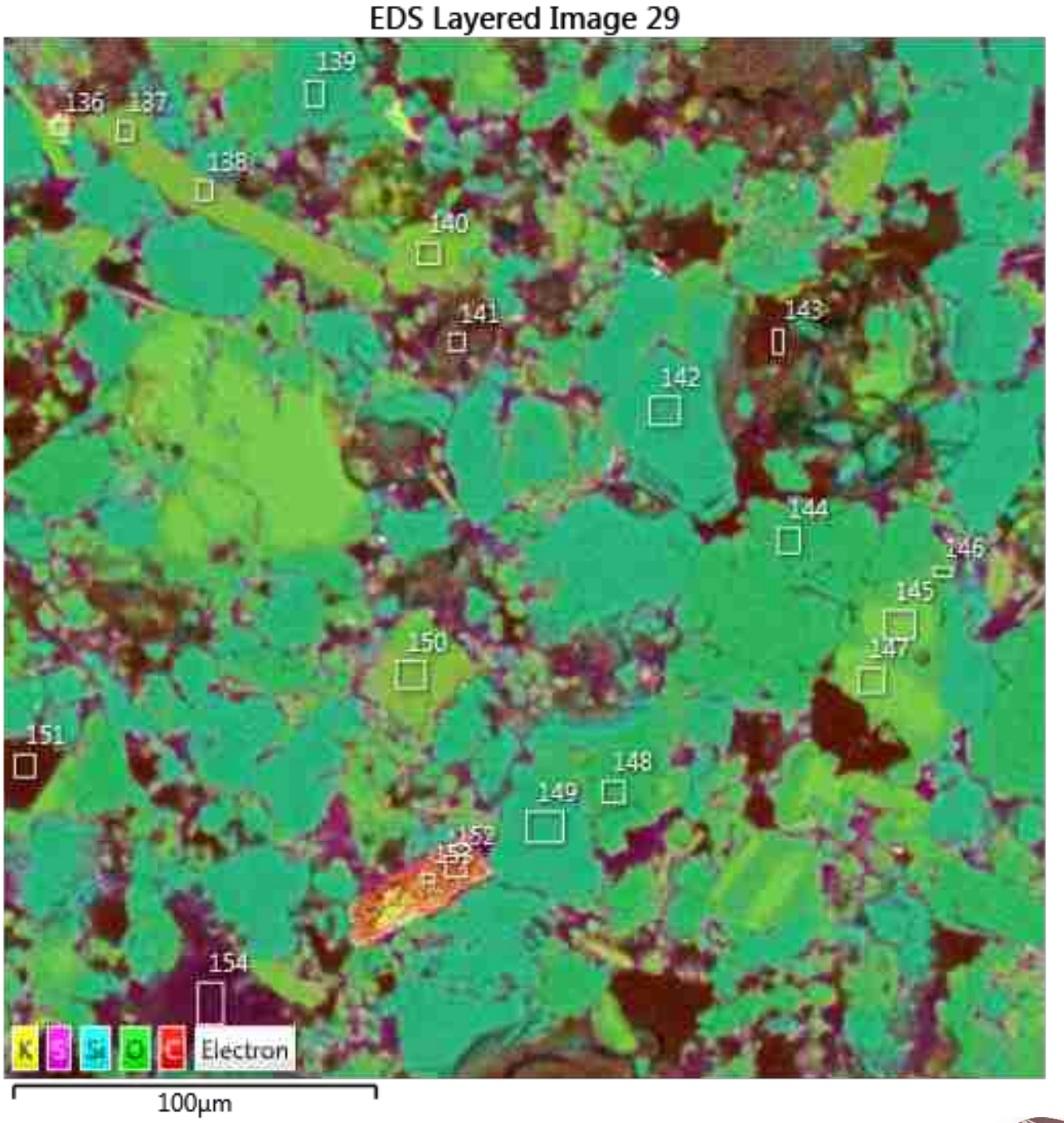




11-Pp-MF-01 thin-section

Preliminary Mineralogy
Based on Elemental Spectra

136 = Rutile
137 = Muscovite
138 = Muscovite
139 = Quartz
140 = Potassium Feldspar
141 = Glauconite
142 = Quartz
143 = Open pore
144 = Albite
145 = Potassium Feldspar
146 = Potassium Feldspar (partially converted to Kaolinite)
147 = Potassium Feldspar
148 = Albite
149 = Quartz
150 = Muscovite
151 = Open pore
152 = Rutile
153 = Rutile
154 = Bitumen-filled pore

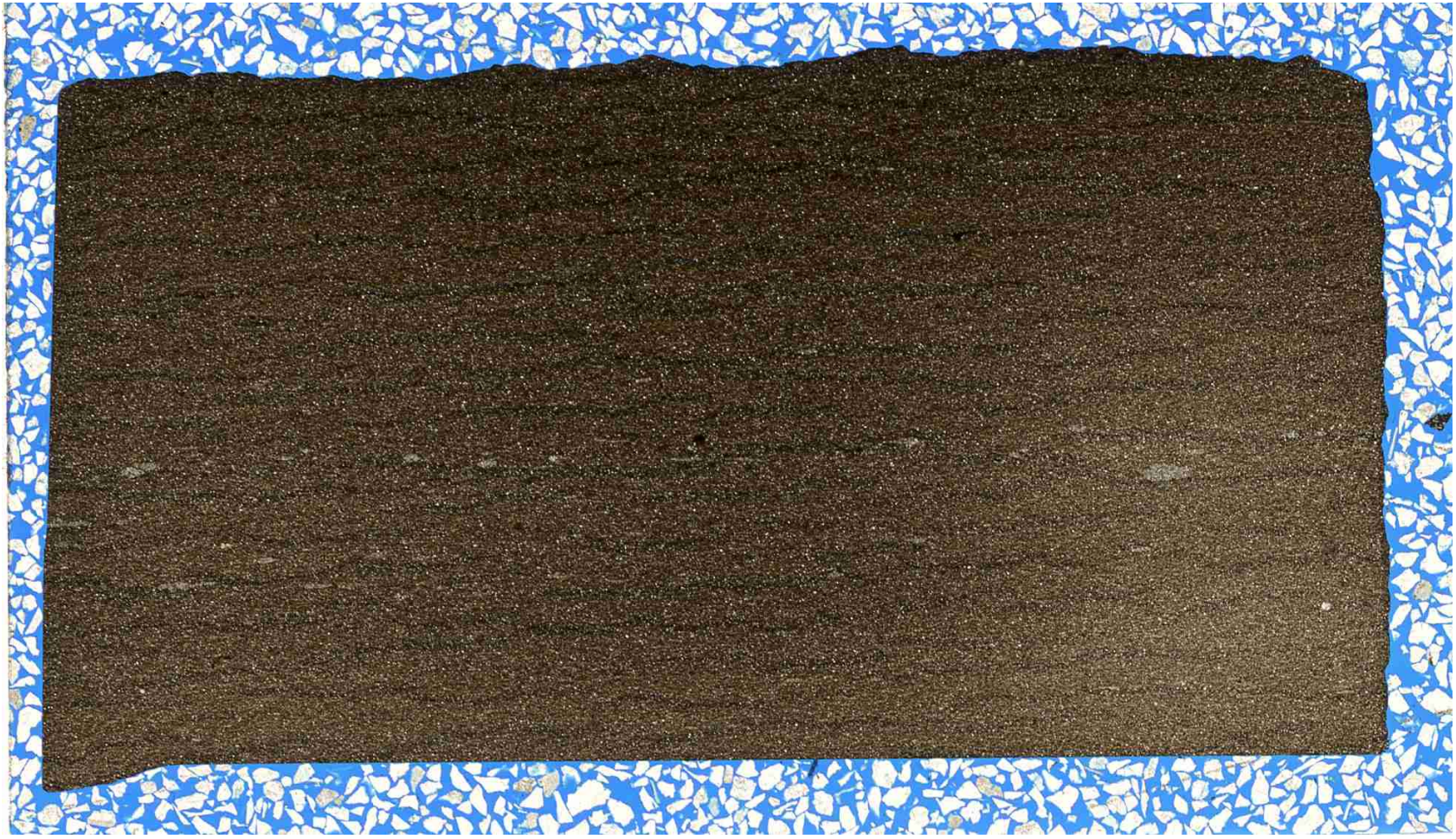


Composite elemental map of site 34, 11-Pp-MF-01

Sample 11-Paris-01

Example of Facies 2: Bioturbated
organic-rich silty dolomudstone

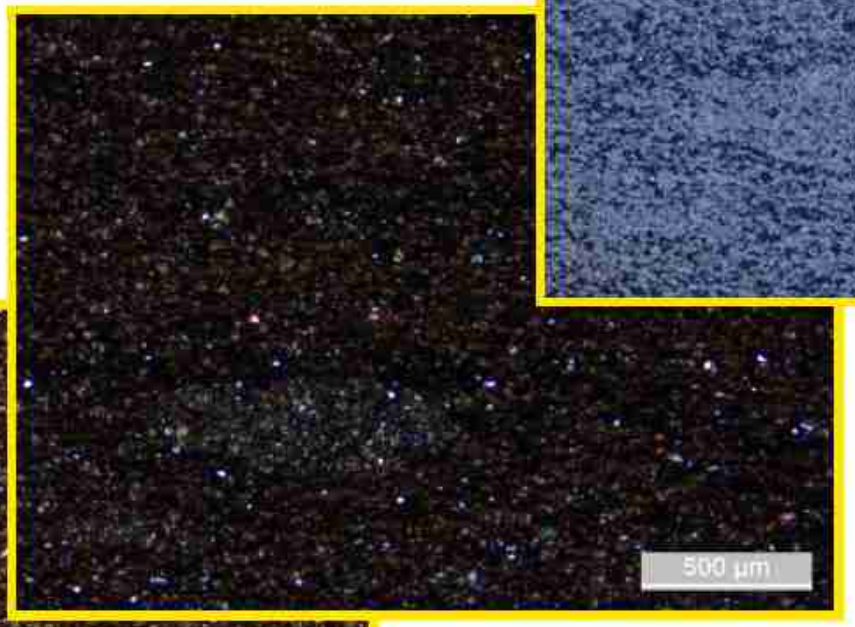
Sample: 11-Paris-01
Meade Peak Member
42°12'54.18"N, 111°26'55.20"
Paris Canyon, Idaho

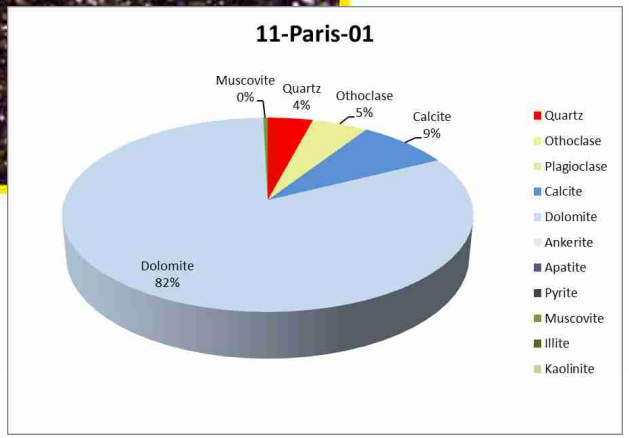


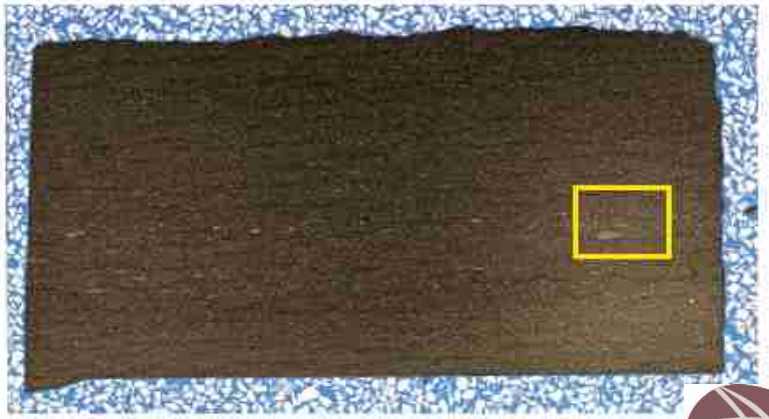
11-Paris-01 thin-section

Sample: 11-Paris-01
Meade Peak Member
42°12'54.18"N, 111°26'55.20"W
Paris Canyon, Idaho

TOC = 5.46%
Nitrogen = 0.0%







Preliminary Mineralogy
Based on elemental spectra

50 = Quartz
51 = Dolomite
52 = Calcite
53 = Calcite
54 = Dolomite
55 = Bitumen
56 = Bitumen
57 = Pyrite
58 = Sphalerite?
59 = Quartz
60 = Bitumen
61 = Calcite
62 = Calcite

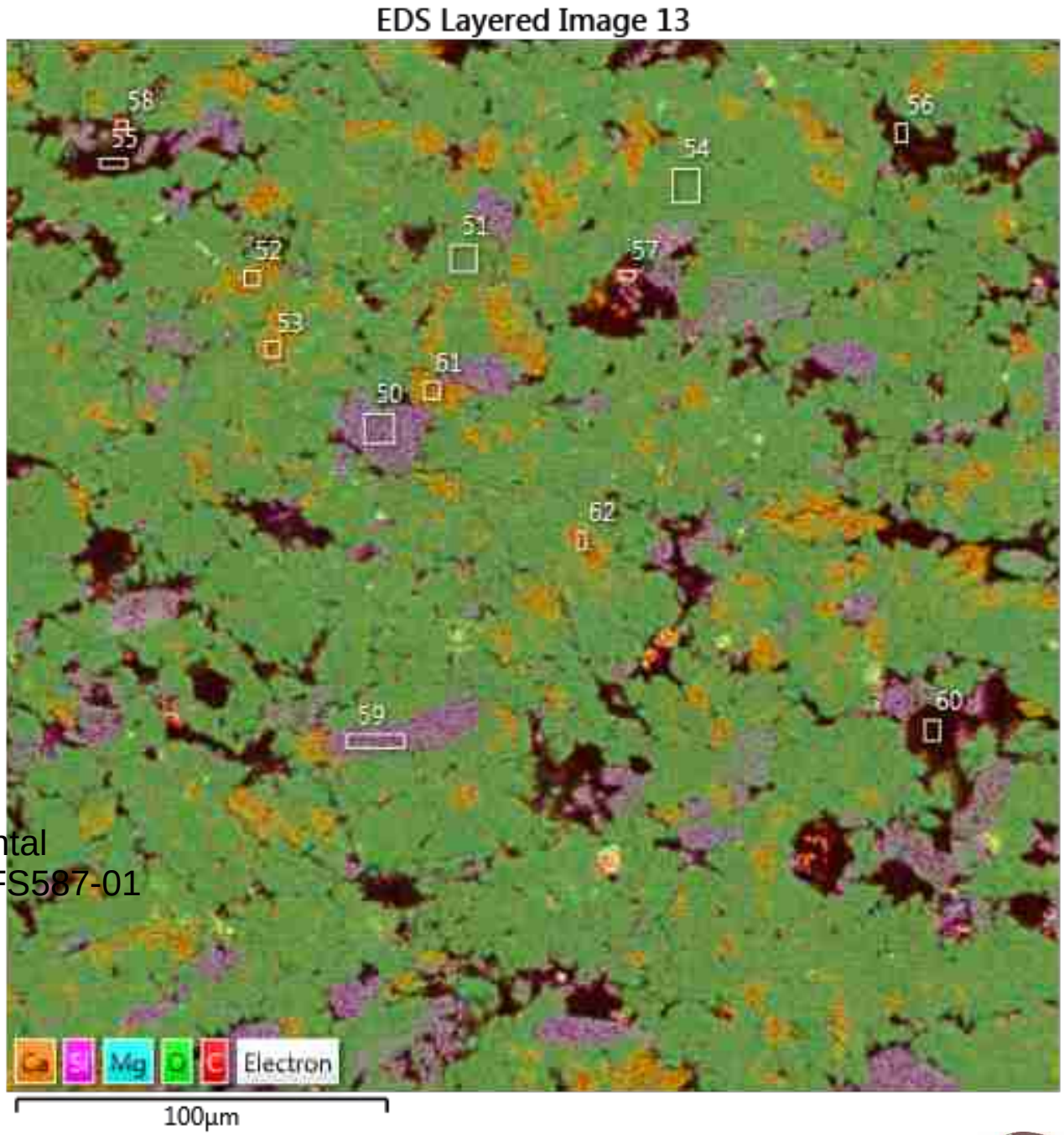


Figure 3.7
Composite elemental
map of site 2, 11-FS587-01

Composite elemental
map of site 12, 11-Paris-01

Preliminary Mineralogy
Based on elemental spectra

63 = Dolomite
64 = Calcite
65 = Quartz
66 = Orthoclase
67 = Bitumen
68 = Bitumen
69 = Bitumen
70 = Calcite
71 = Pyrite

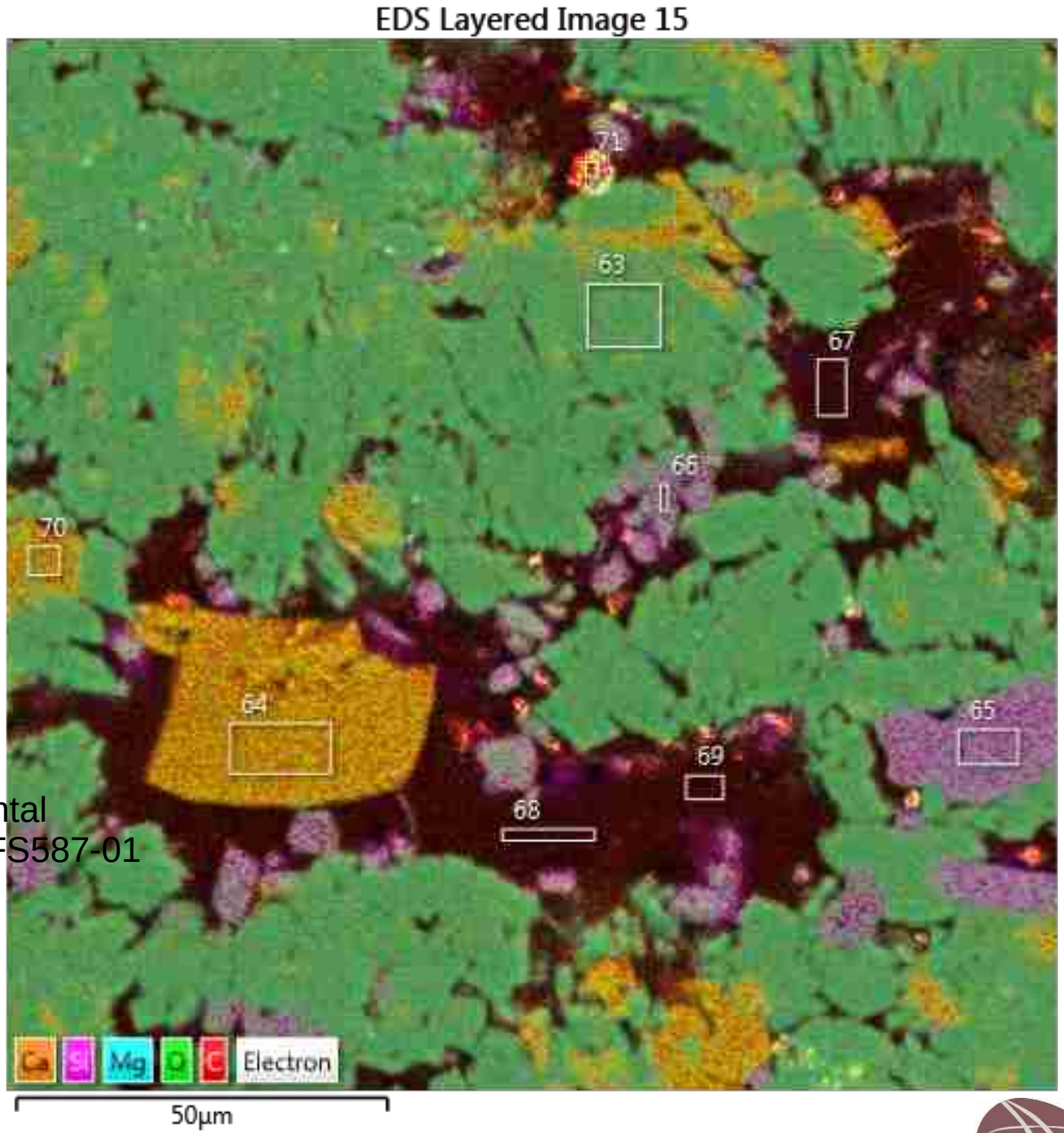


Figure 3.7
Composite elemental
map of site 2, 11-FS587-01

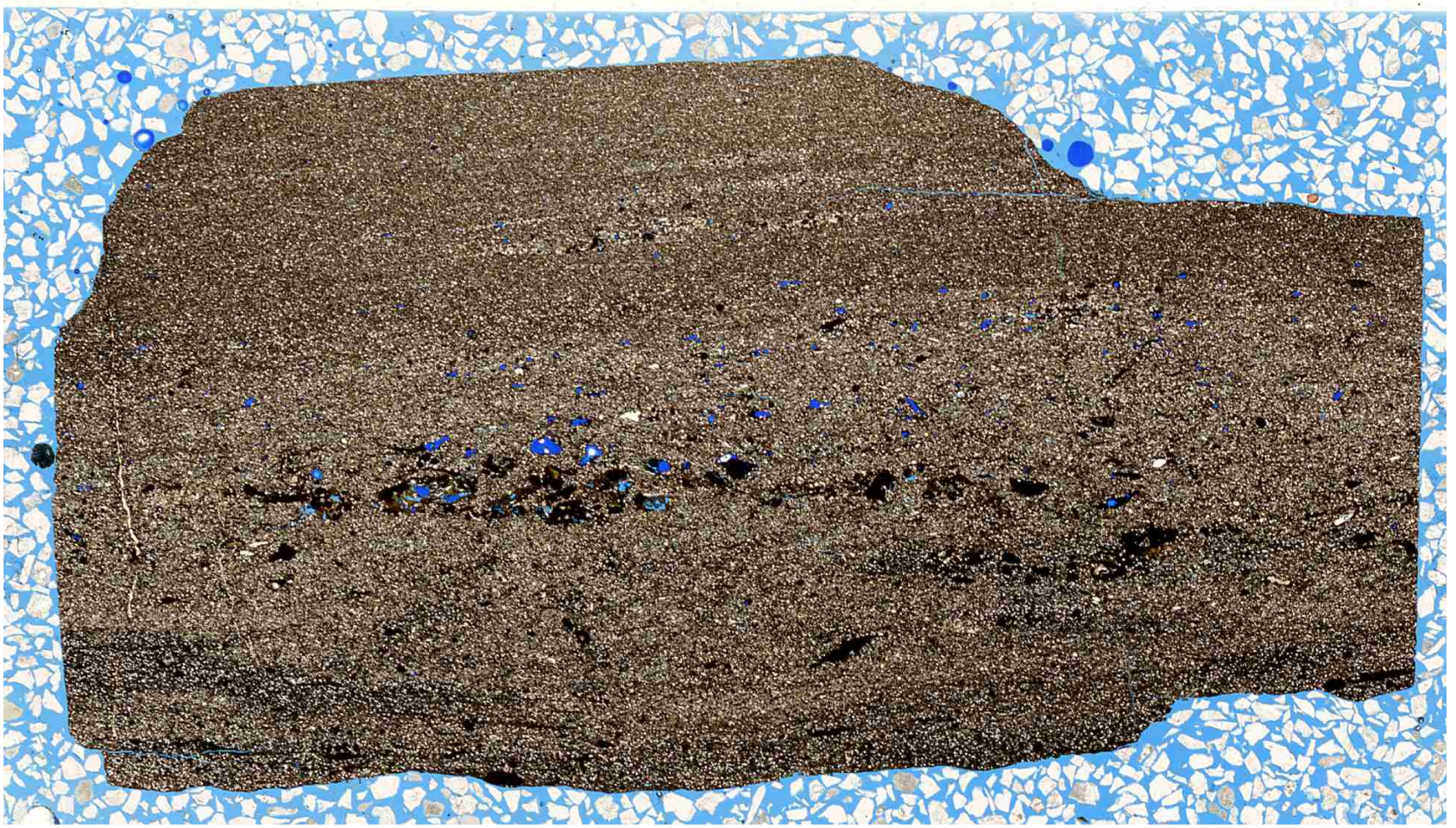
Composite elemental
map of site 15, 11-Paris-01

Sample 12-FP-25

Sample: 12-FP-25
Retort Member, Phosphoria Fm.
45°18'3.54"N, 112°48'23.99"W
Frying Pan Gulch measured section
~16km NW of Dillon, MT

Massive to thinly-bedded organic-rich silty mudstone

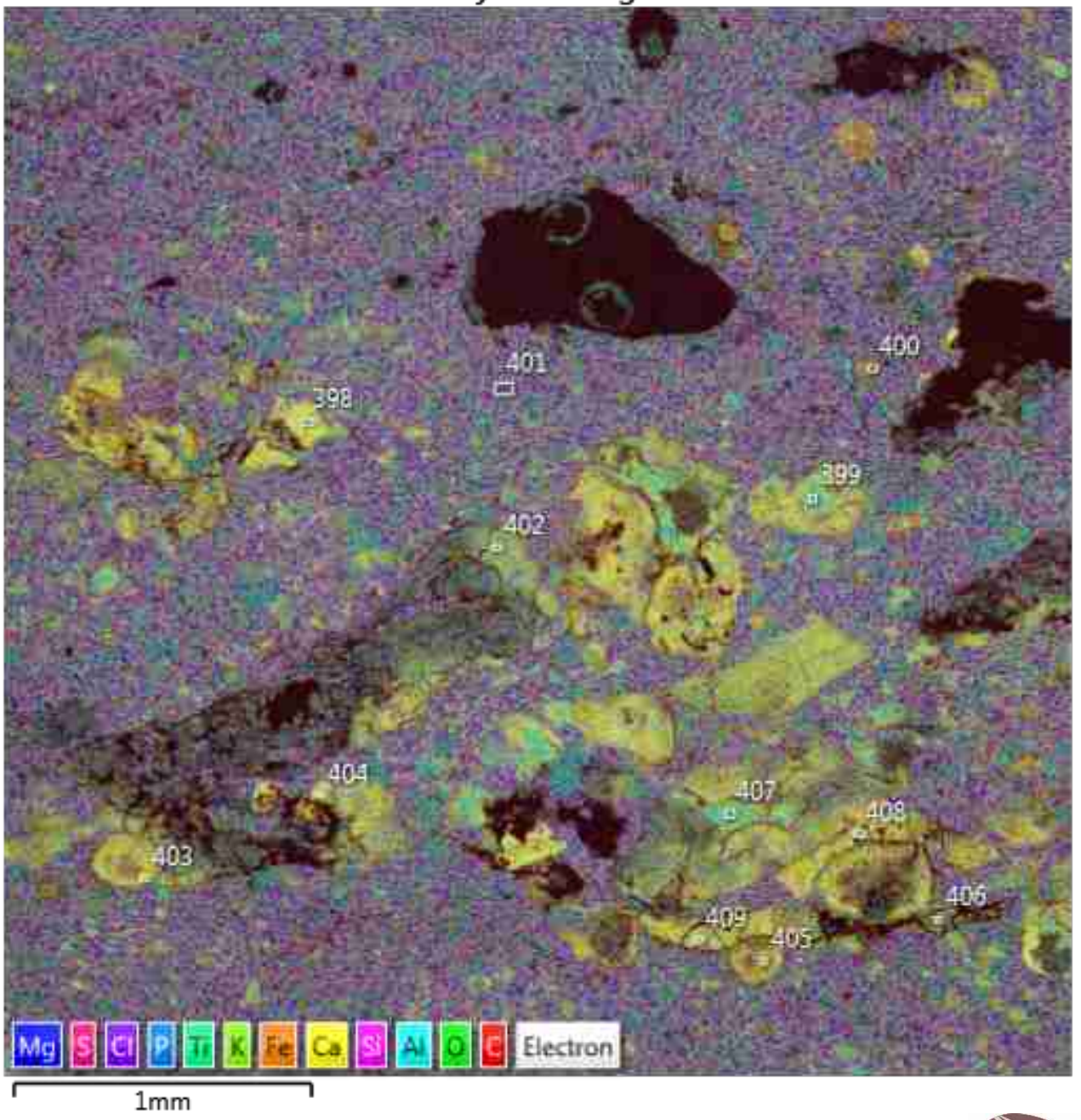
TOC = 9.25%

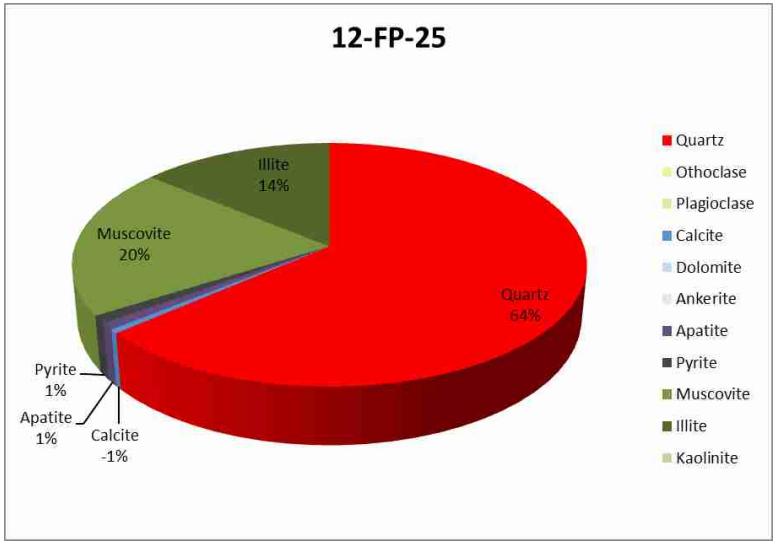


12-FP-25 thin-section

Preliminary mineralogy
based on elemental spectra

398 = glauconite
399 = iron phosphate
400 = glauconite
401 = quartz
403 = glauconite
404 = glauconite
405 = glauconite
406 = iron phosphate
407 = iron phosphate
408 = glauconite
409 = glauconite





Preliminary mineralogy
based on elemental spectra

410 = glauconite
411 = glauconite
412 = quartz
413 = glauconite
414 = glauconite
415 = illite
416 = glauconite
417 = glauconite
418 = glauconite
419 = glauconite
420 = glauconite
421 = quartz
422 = glauconite
423 = potassium feldspar
424 = potassium feldspar
425 = potassium feldspar
426 = glauconite + pyrite
427 = glauconite
428 = iron pyrite
429 = quartz
430 = quartz
431 = potassium feldspar
432 = open pore

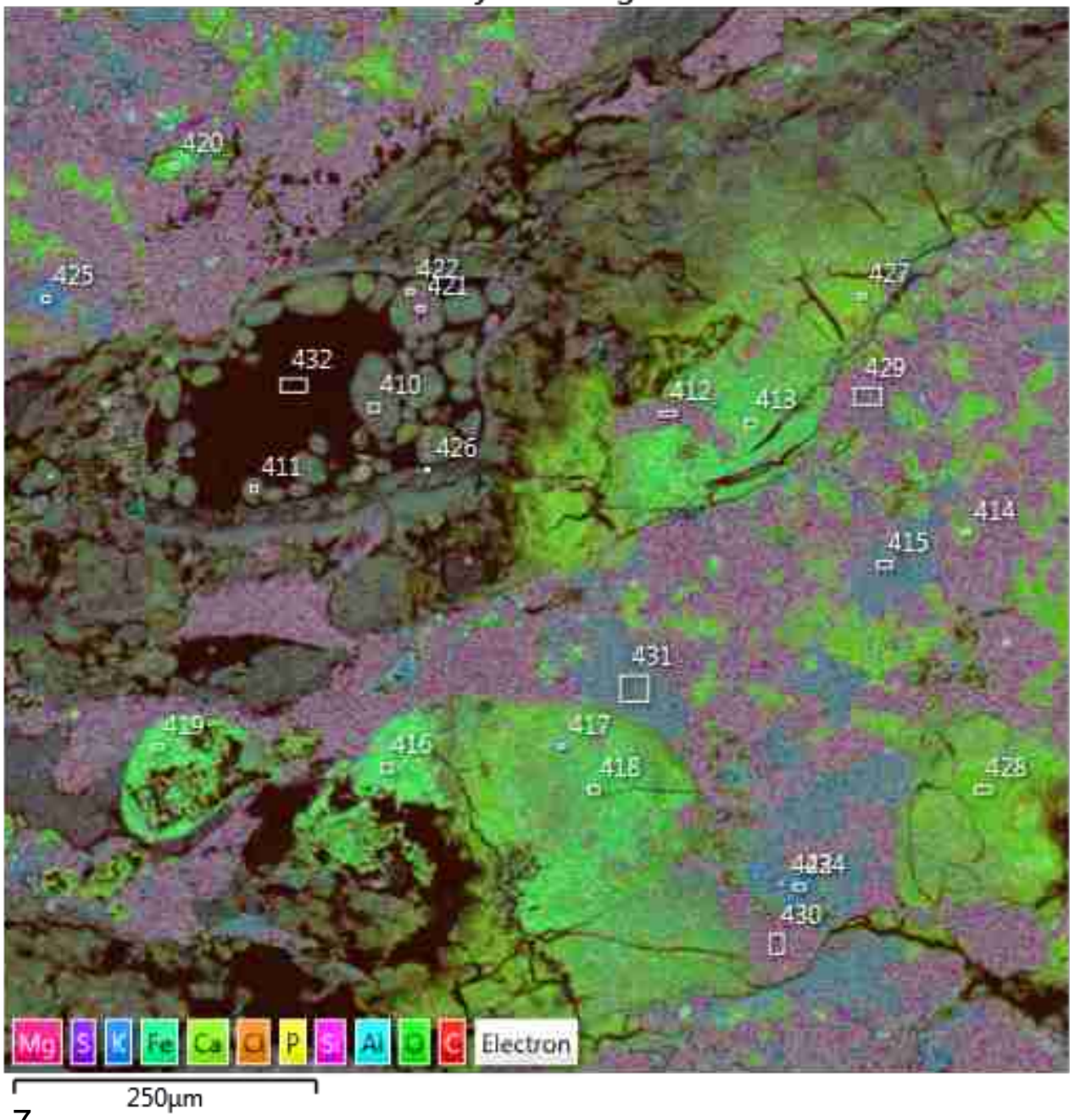


Figure 3.7
Composite elemental
map of site 2, 11-FS587-01

Conclusions:

1) The Permian Phosphoria Formation is a worldclass source rock.

2) Regionally extensive organic-rich mudstones deposited as part of fourth-order transgressions and are overlain by high-stand carbonates and siliceous mudstone (chert).

3) Penecontemporaneous Permian vertical tectonics across much of the Wyoming shelf is reflected by mapped thickness and facies trends.

4) Most sub-Cretaceous oils in Wyoming have a Phosphoria source, and it is likely that tar sands in SE Utah also were sourced by the Phosphoria.

5) Phosphoria mudrock facies are largely mature to overmature and are closely associated with dolomite and siliceous facies that will improve frac behavior.