Organic Matter Distributions in Oil Shales of the Green River Formation, Piceance Basin

By

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Critical elements of this talk:

- There was abundant clay (primarily illite) entering Lake Uinta throughout its history.
- We propose that most of the organic matter reached the bottom of the lake attached to fine-grained particles - mainly clay.
- Clay is largely missing from the hypersaline interval deposited in the central part of the lake today, due to disassociation to form authigenic feldspars and dawsonite.
- The clay probably sourced largely from Cretaceous marine rocks that were exposed on uplifts surrounding the lake.

Critical elements continued:

- This hypothesis may solve the problem of how lipid-rich Type 1 organic matter derived from algal material with a density of no greater than 1.05 could have settled through the hypersaline lower layer in Lake Uinta, which probably had a density of between 1.1 to 1.2.

For the mostly laminated Mahogany zone, there is a very strong linear correlation between thickness and total kerogen in place *as measured by barrels per acre*, with the majority of data points falling between the two black lines.

The data points to the right of the trend are near the basin margins and probably include coarser clastic sediments.

(Data from Piceance Oil Shale Database; see Johnson et al., 2010 for details)

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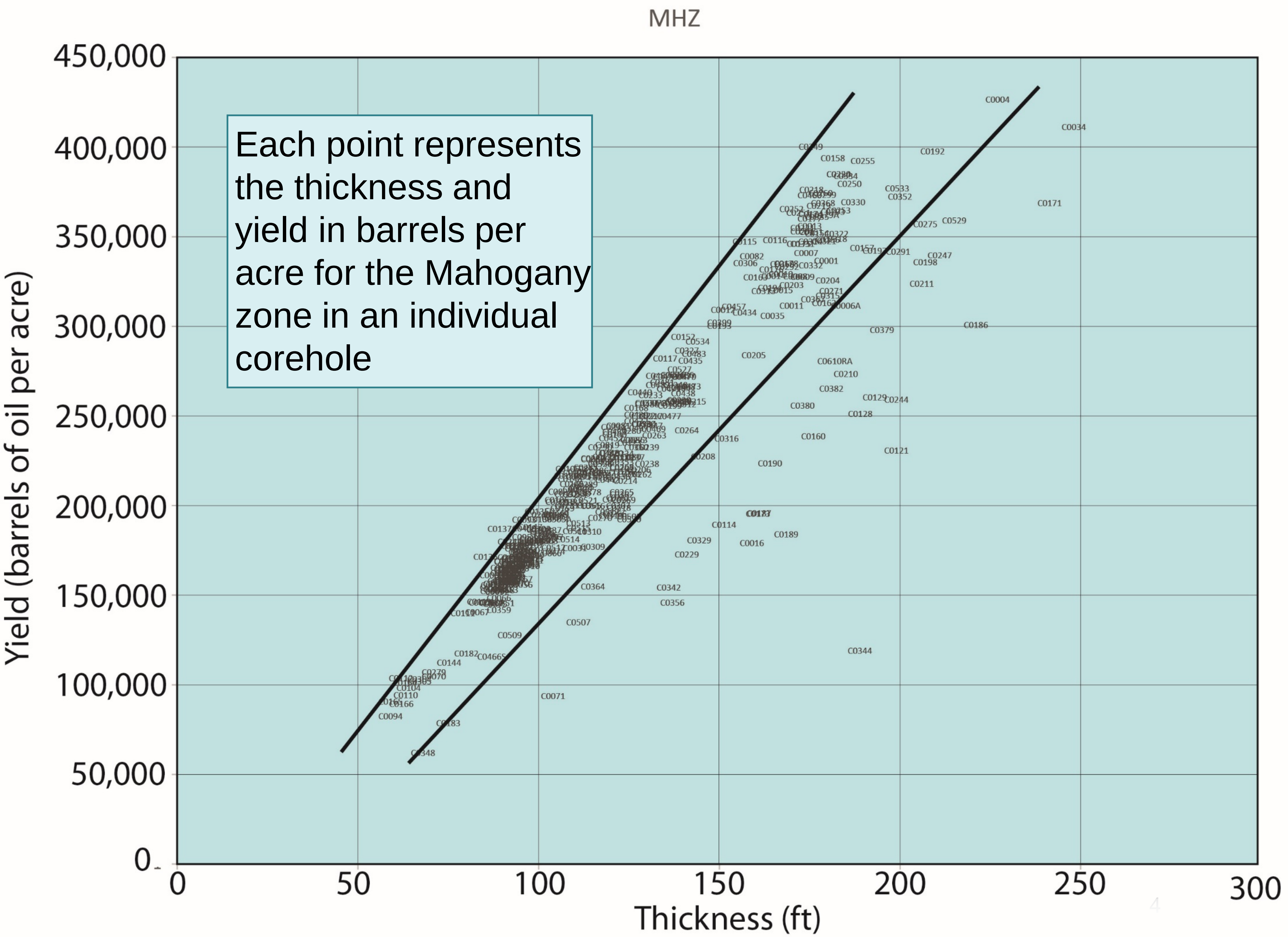

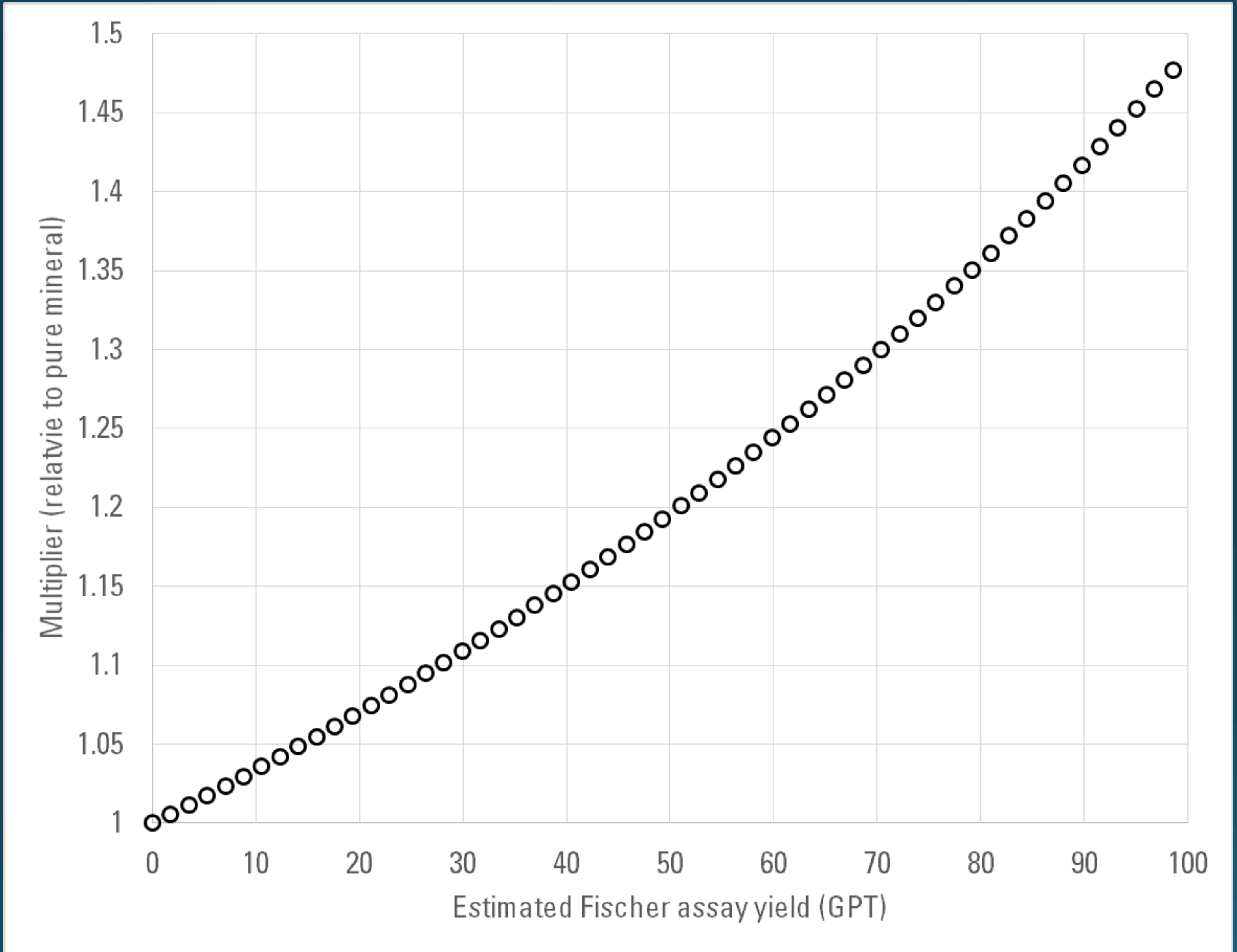

These values were calculated based on the following assumptions:

Mineral density (rho-M) = 2.6 g/cm^3
Kerogen density (rho-K) = 1.1 g/cm^3
Fischer assay yield (GPT), FA = 2 × TOC
Kerogen content (wt. %), K = TOC/0.8

Calculations
Oil shale density (rho-OS)
rho-OS = K × rho-K + (1-K) × rho-M

Thickness multiplier (relative to pure mineral)
TM = 1/(rho-OS/rho-M)

Note
TOC = total organic carbon, wt. %

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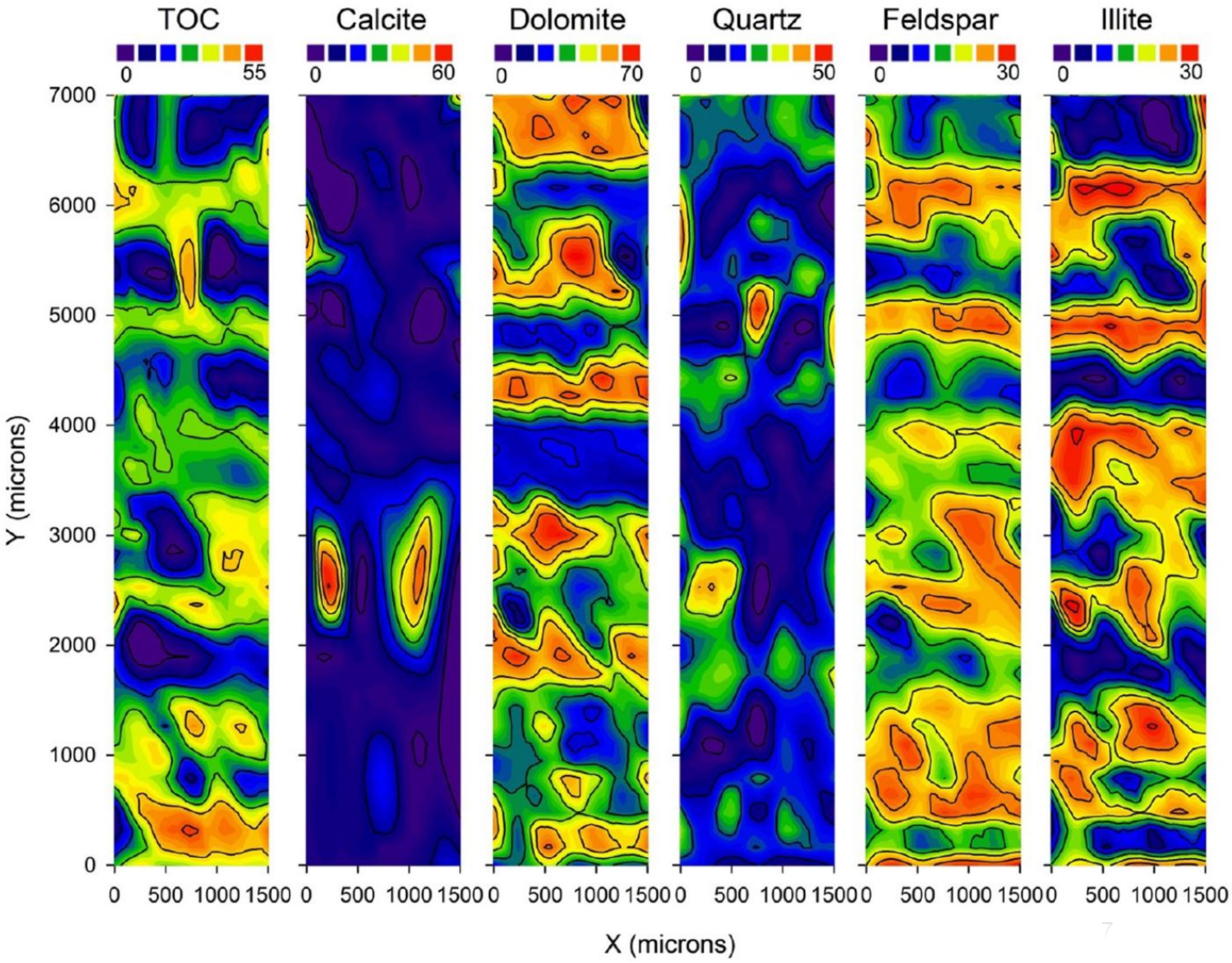
Only a small percentage of the increases in thickness are due to increases in kerogen. The rest are due to increases in mineral matter, including clay.

There is considerable research that shows that organic matter is attached to and protected by fine-grained mineral matter, mainly clay:

- Salmon et al. (2000, Organic Geochemistry 31, 463-474), Protection of organic matter by mineral matrix in a Cenomanian black shale.
- Kennedy et al. (2002, Science 25, 657-660), Mineral surface control of organic carbon in Black Shale.
- Hedges and Keil (1995, Marine Chemistry 49, 81-115) Sedimentary organic matter preservation: an assessment and speculative synthesis.
- Keil and Hedges (1993, Chemical Geology, 107, 385-388), Sorption of organic matter to mineral surfaces and the preservation of organic matter in coastal marine sediments.

Mineralogical study of a laminated interval in the Mahogany zone using Fourier transform infrared (FTIR) microscopy showing a strong correlation between total organic carbon (TOC) values and illite and feldspar and a negative correlation with dolomite (from Washburn et al., 2015). This is similar to many previous studies (see, for example, Bradley, 1929).



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Herein we use two publically available databases: (1) Piceance Basin oil shale database (for more information, see Johnson et al., 2010) and (2) Mineral Occurrence data for the Eocene Green River Formation in the Piceance and Uinta Basins (Johnson et al., 2017; DOI: 10.5066/F7XP7334) and a soon to be released database that compiled percentages of laminated and "blebby" oil shale for coreholes in the Piceance Basin to study the relationship between mineral matter and organic matter in the Green River Formation, Piceance Basin, Colorado.

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The Laramide orogeny in the Rocky Mountain region (Late Cretaceous through Eocene) created a number of basins that were occupied by large permanent lakes. Lake Uinta occupied the Uinta and Piceance Basins.

Lake Uinta had two deep depocenters with shallower water over the Douglas Creek arch. The lake was permanently stratified with a highly alkaline and saline lower layer and a fresher upper layer (Bradley, 1963; Bradley and Eugster, 1969).

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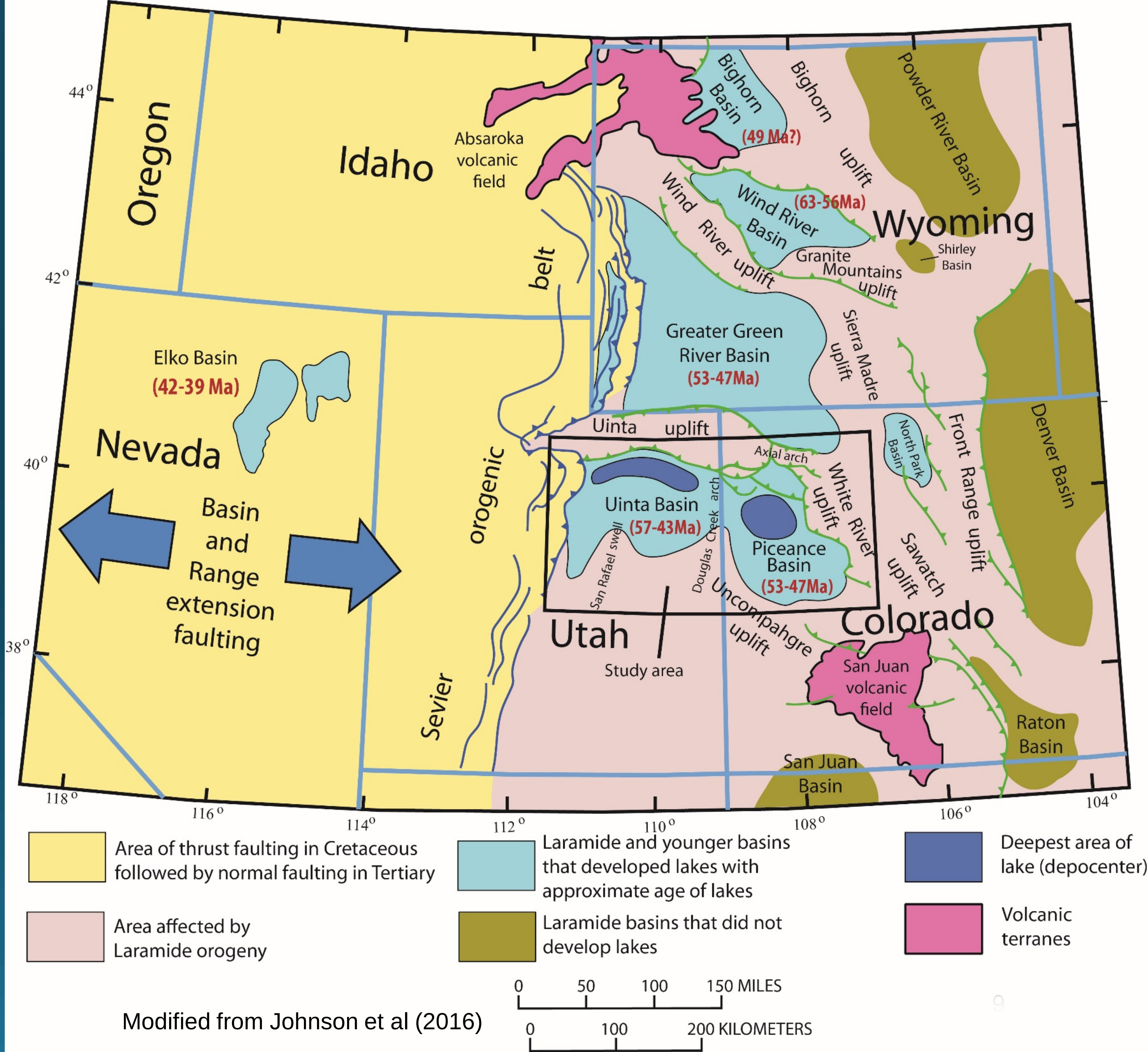
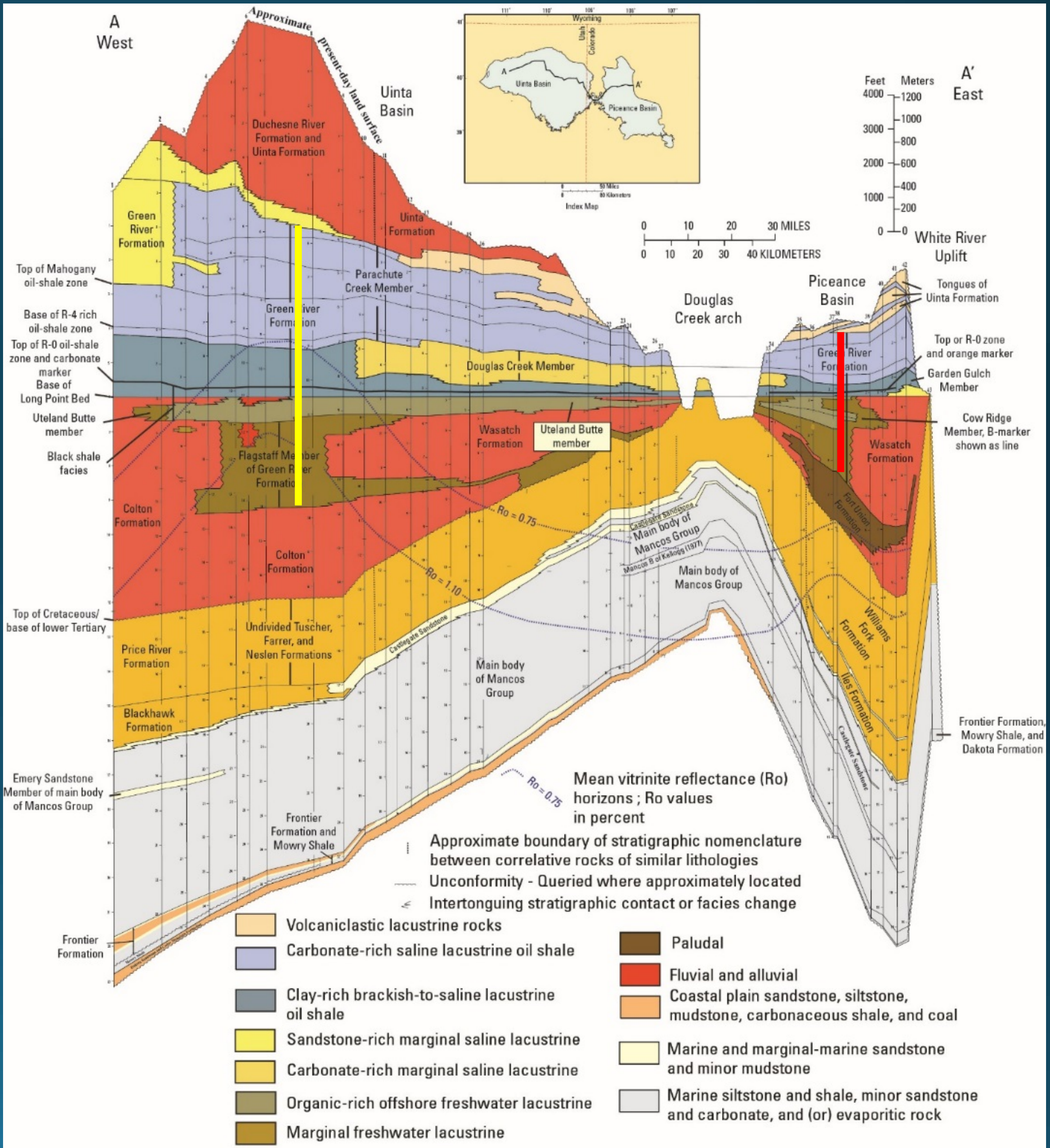


Modified from Johnson et al (2016)

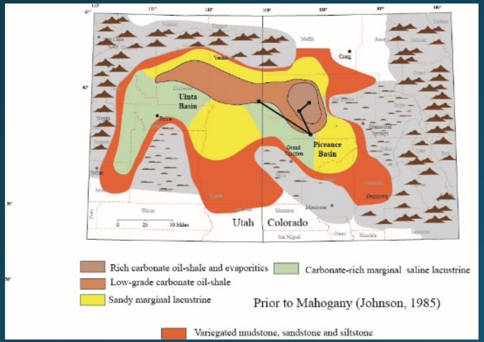
The two deep depocenters can be seen on this west to east cross section across the Uinta and Piceance Basins and the Douglas Creek arch that separates them. The Douglas Creek arch subdivided the lake into two during much of the early freshwater period, but a single lake extended across the arch during the saline period.

In the heart of the Uinta Basin depocenter there is more than 9,500 ft of continuous, mostly fine-grained offshore lacustrine rock (yellow line). Maximum thickness of offshore lacustrine rock in the Piceance depocenter is about 4,000 ft (red line).



Modified from Johnson (1989)

The oil shale interval in the Uinta and Piceance Basin has been traditionally subdivided into the lower, clay-rich Garden Gulch Member and upper carbonate-rich (mainly dolomite) Parachute Creek Member. Cashion and Donnell (1972) subsequently subdivided the two members into 18 laterally persistent, time stratigraphic rich and lean zones that can be found in both basins.



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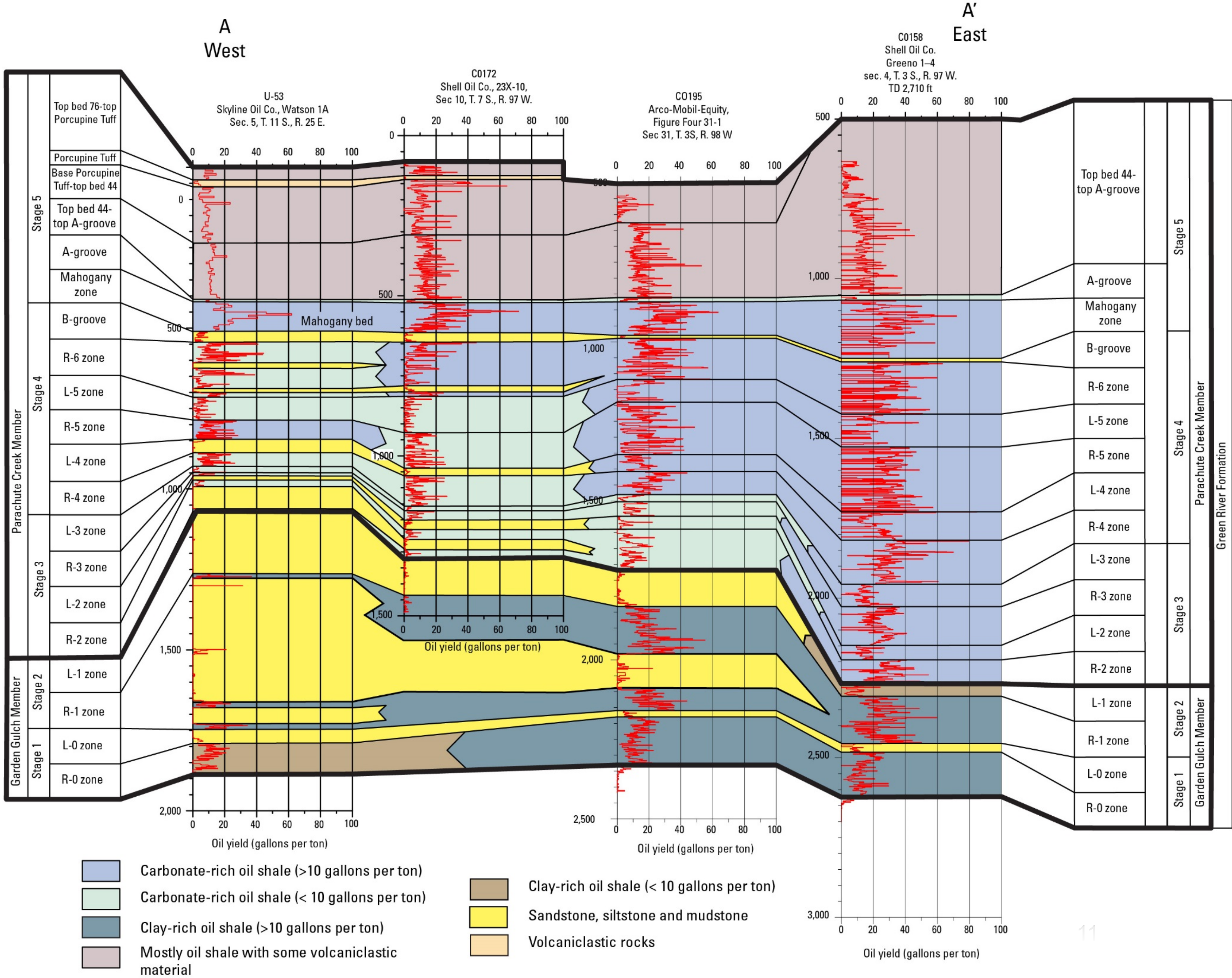
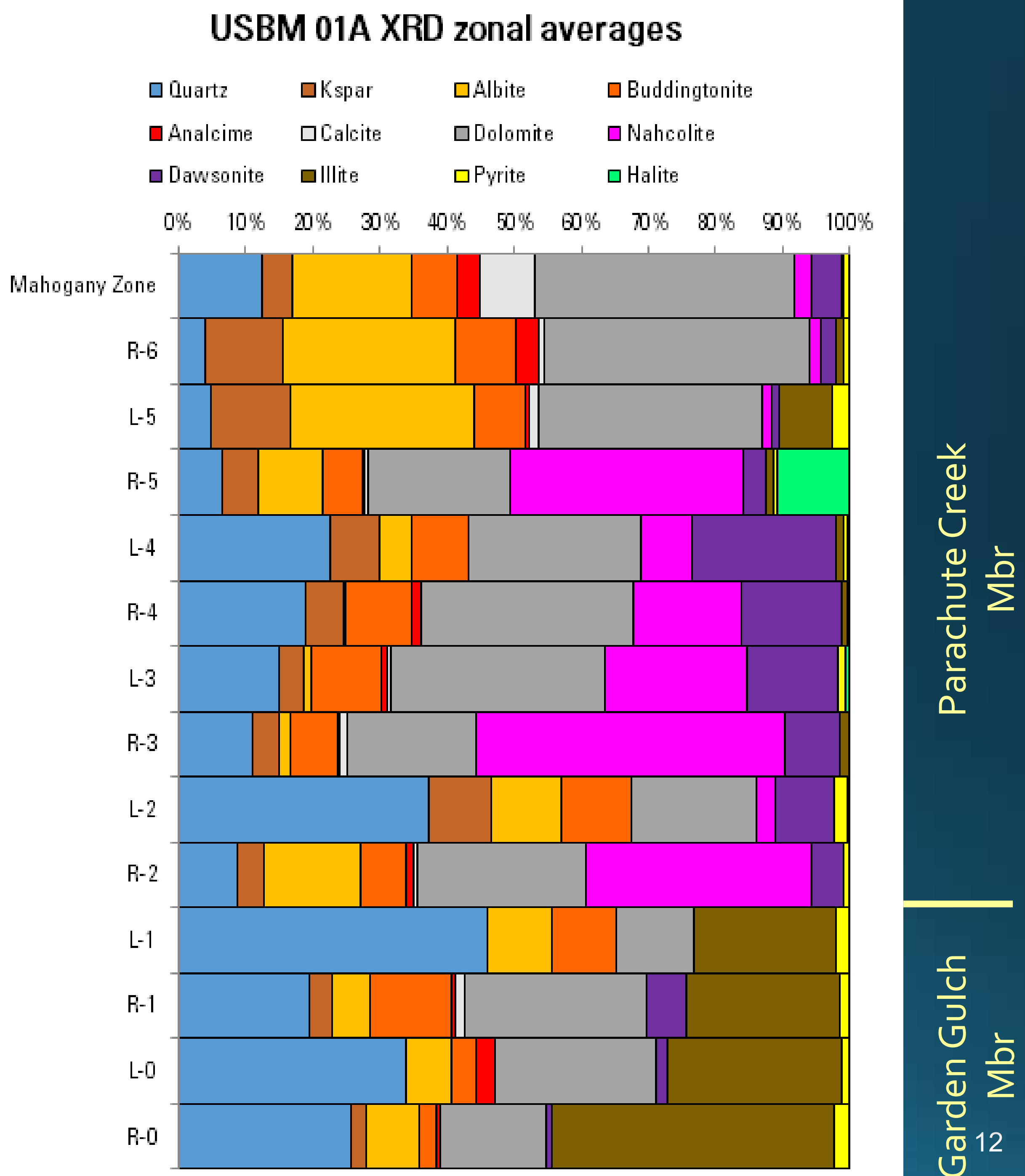


The Garden Gulch has been traditionally referred to as the illitic member as it contains about 20-40% illite. The Parachute Creek has been referred to as the dolomitic member, but both units have about the same amount of dolomite.

Note the increase in dawsonite [$NaAl(CO_3)(OH)_2$], nahcolite [$NaHCO_3$], and feldspar where illite disappears.



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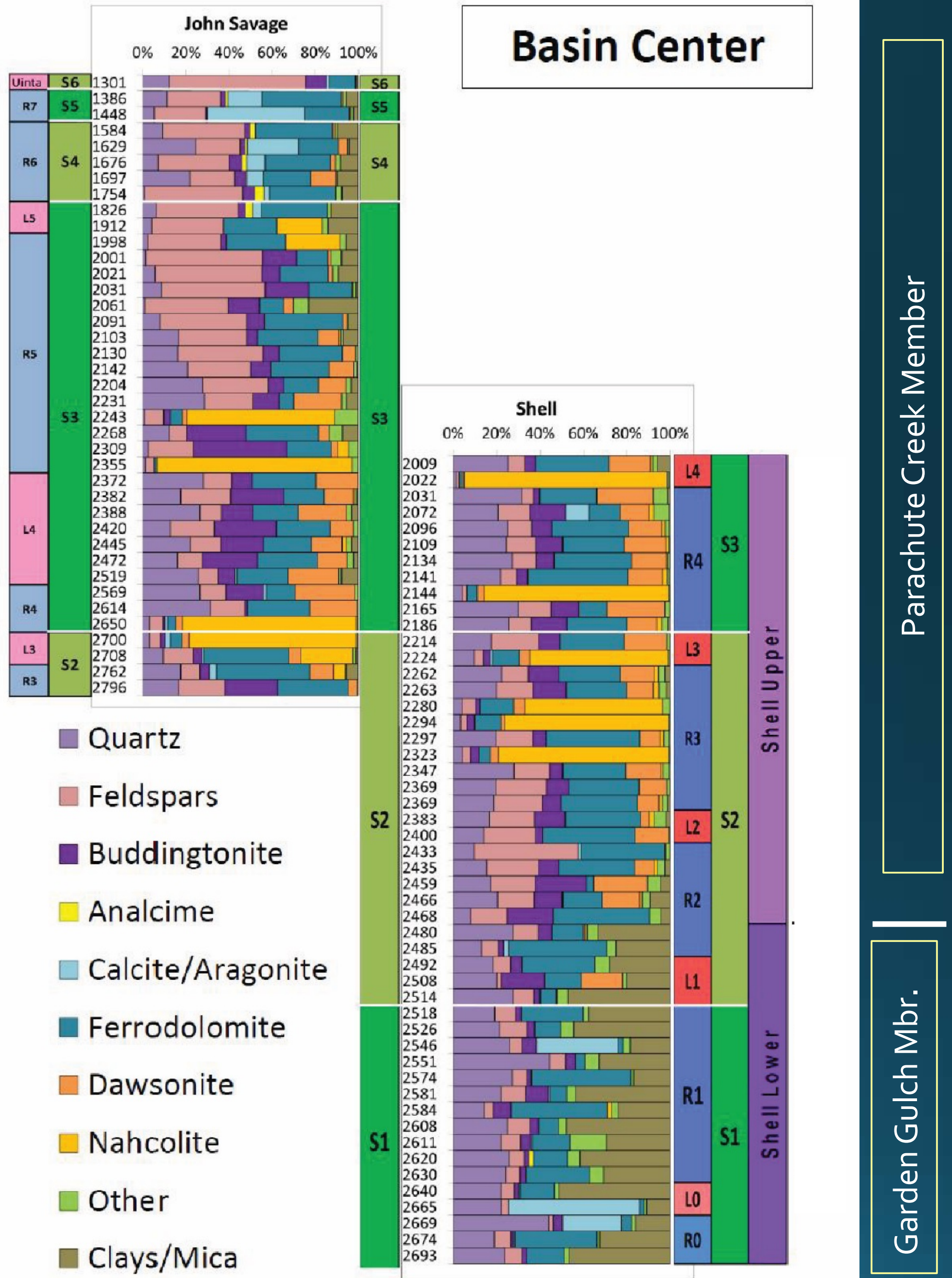
Based on recent work, the contact between the Garden Gulch and Parachute Creek Members appears to be largely if not totally diagenetic.

"The disappearance of clay minerals does not reflect a change in the sedimentary mixture, but rather the diagenetic alteration of the clay mineral component into authigenic feldspar (including a significant buddingtonite [$NH_4AlSi_3O_8$] component in the K-feldspar) and dawsonite [Na Al (CO_3) $(OH)_2$]." (Boak et al., 2016)



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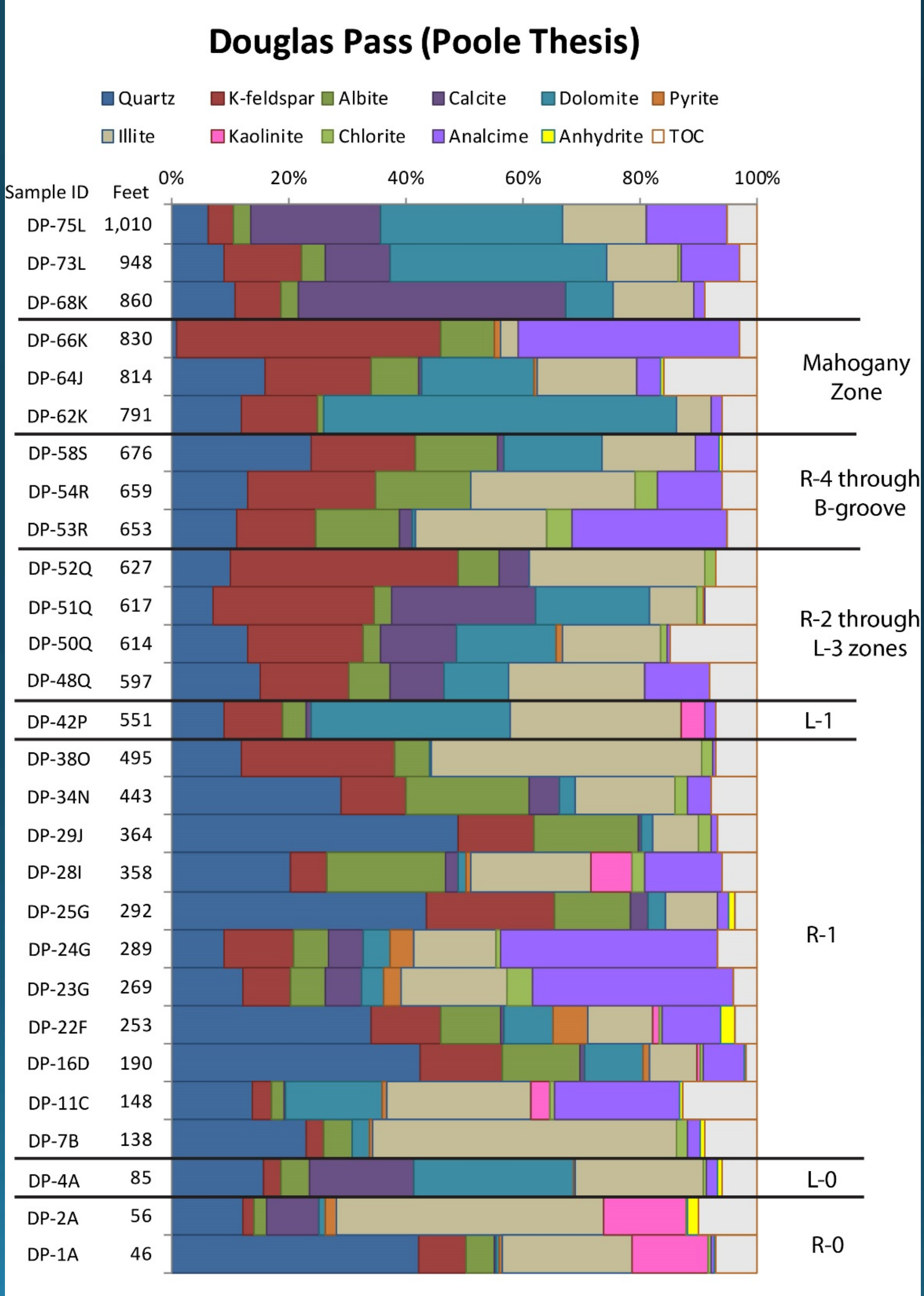
Quantitative X-ray mineralogy for the Green River Formation in a lake margin setting near Douglas Pass along the western margin of the Piceance Basin. (from Poole, 2014). Rich and lean zone picks are new to this report. Illite is present throughout the Green River Formation at this locality.



Modified from Poole (2014)

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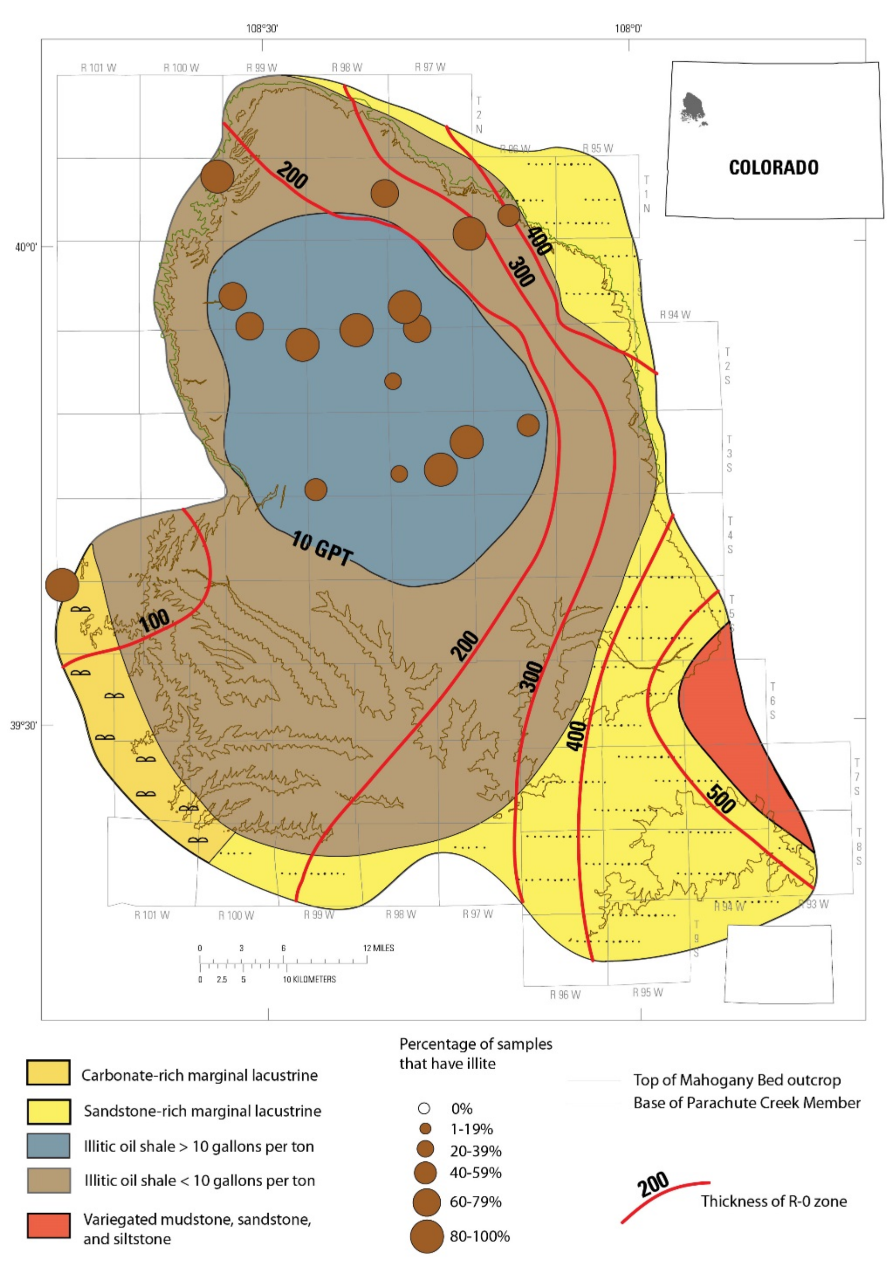
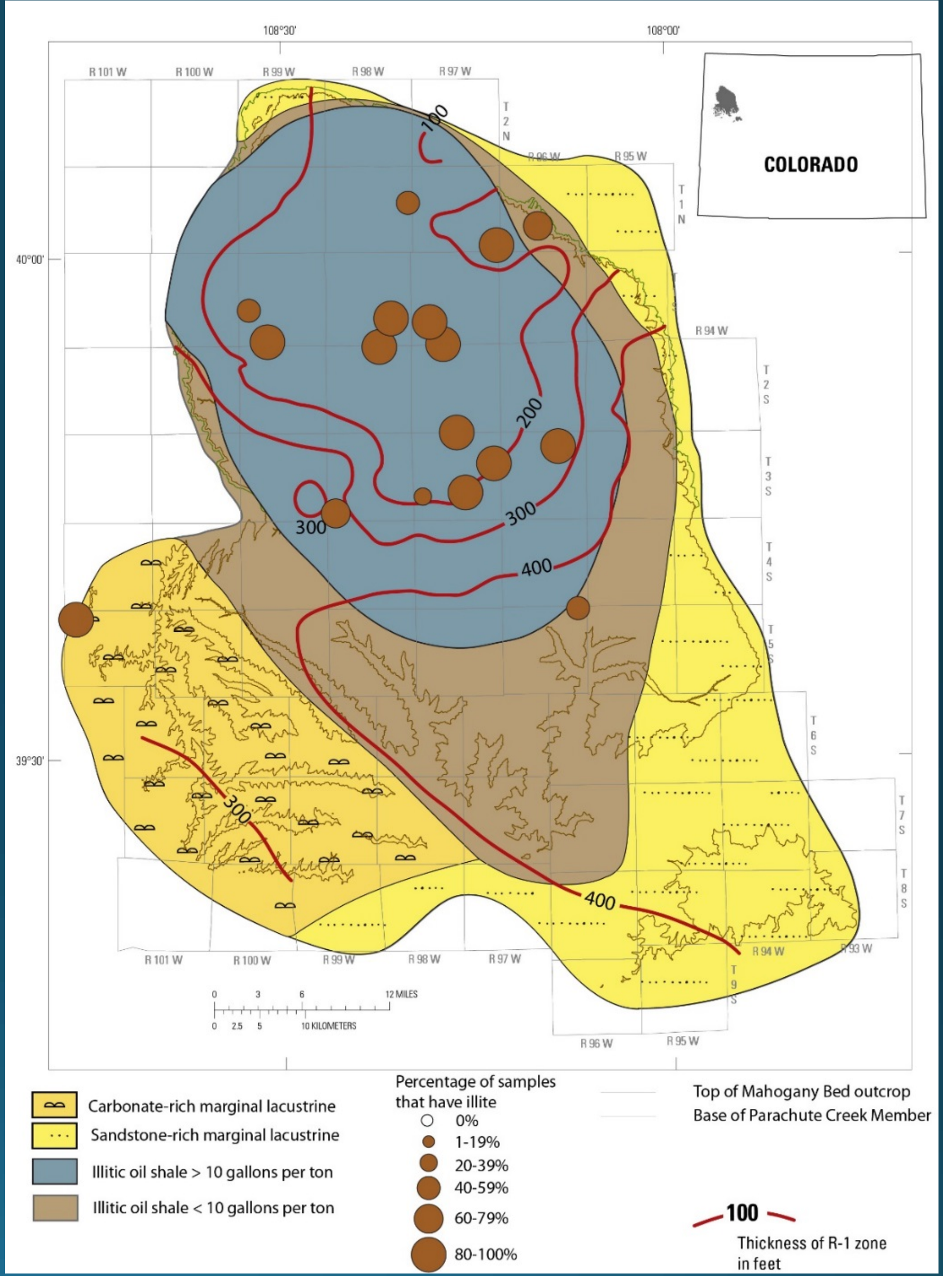
Map generated using "Mineral Occurrence data for the Eocene Green River Formation in the Piceance and Uinta Basins"

https://doi.org/10.5066/F7XP7334

The database contains 9443 analyses from 30 coreholes in the Piceance Basin





Illite is present in the R-0 and R-1 zones throughout their extent.

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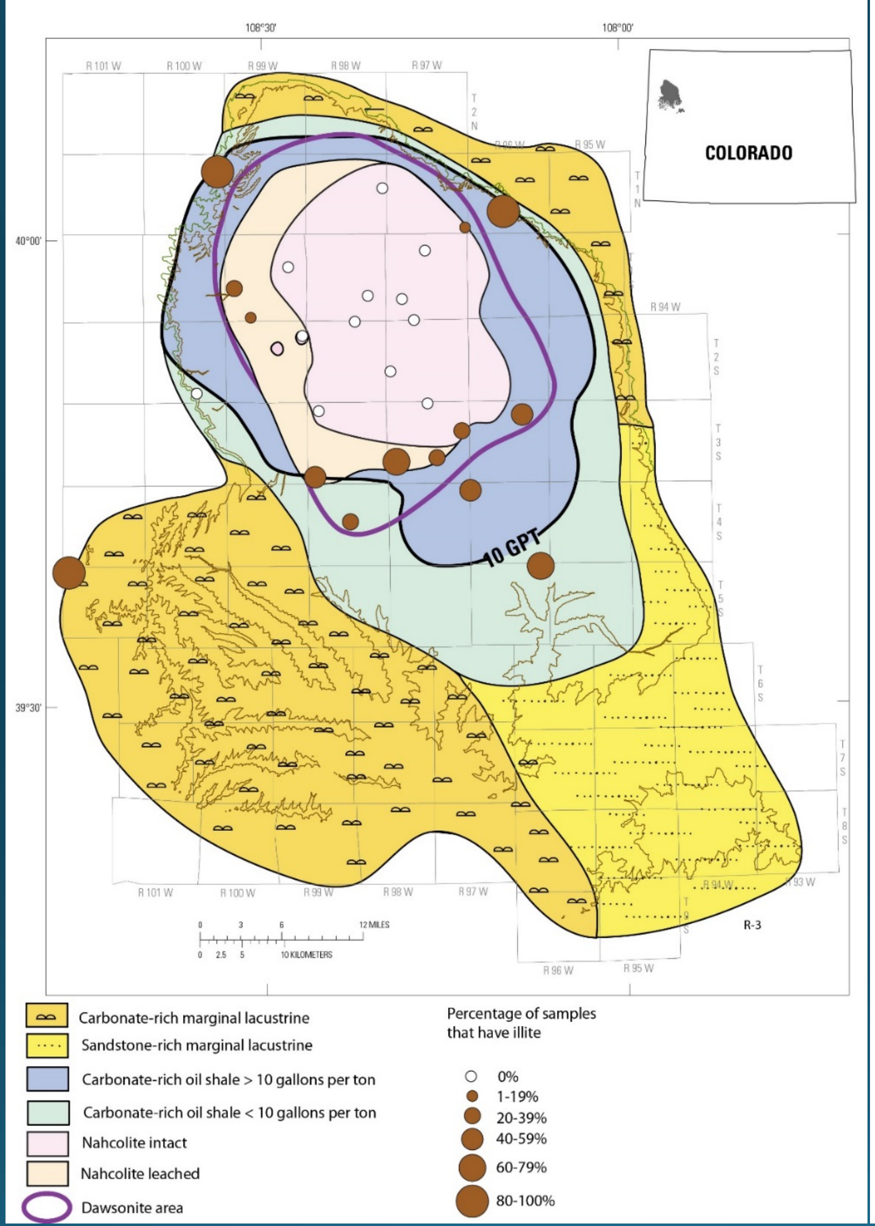
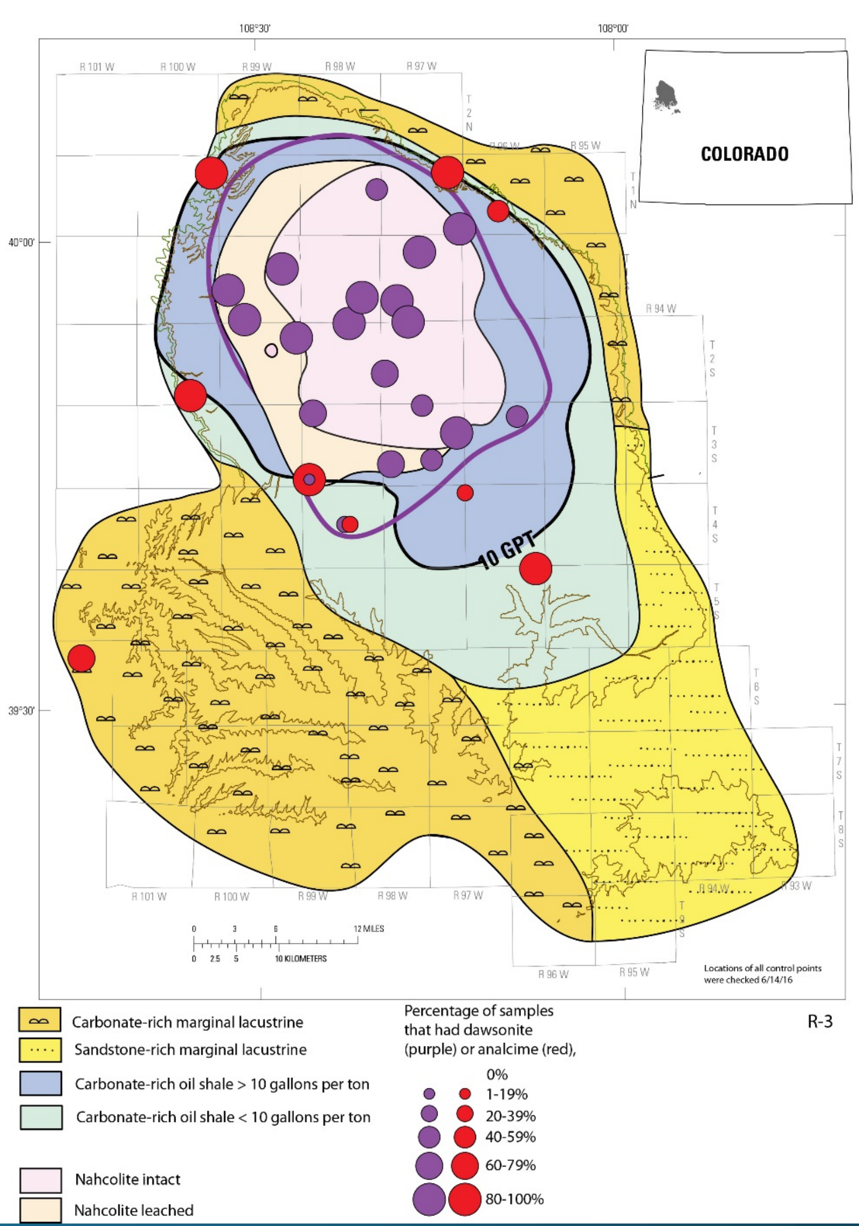
In the R-3 zone (lower part of Parachute Creek Member) illite is missing in the depocenter of the lake where it has broken down to form dawsonite [$NaAl(CO_3)(OH)_2$] and authigenic feldspars. Analcime [$NaAlSi_2O_6 \cdot H_2O$] also disappears in the depocenter.

Illite and analcime persisted in marginal areas where the lake was less saline.





Maps generated using "Mineral Occurrence data for the Eocene Green River Formation in the Piceance and Uinta Basins" https://doi.org/10.5066/F7XP7334

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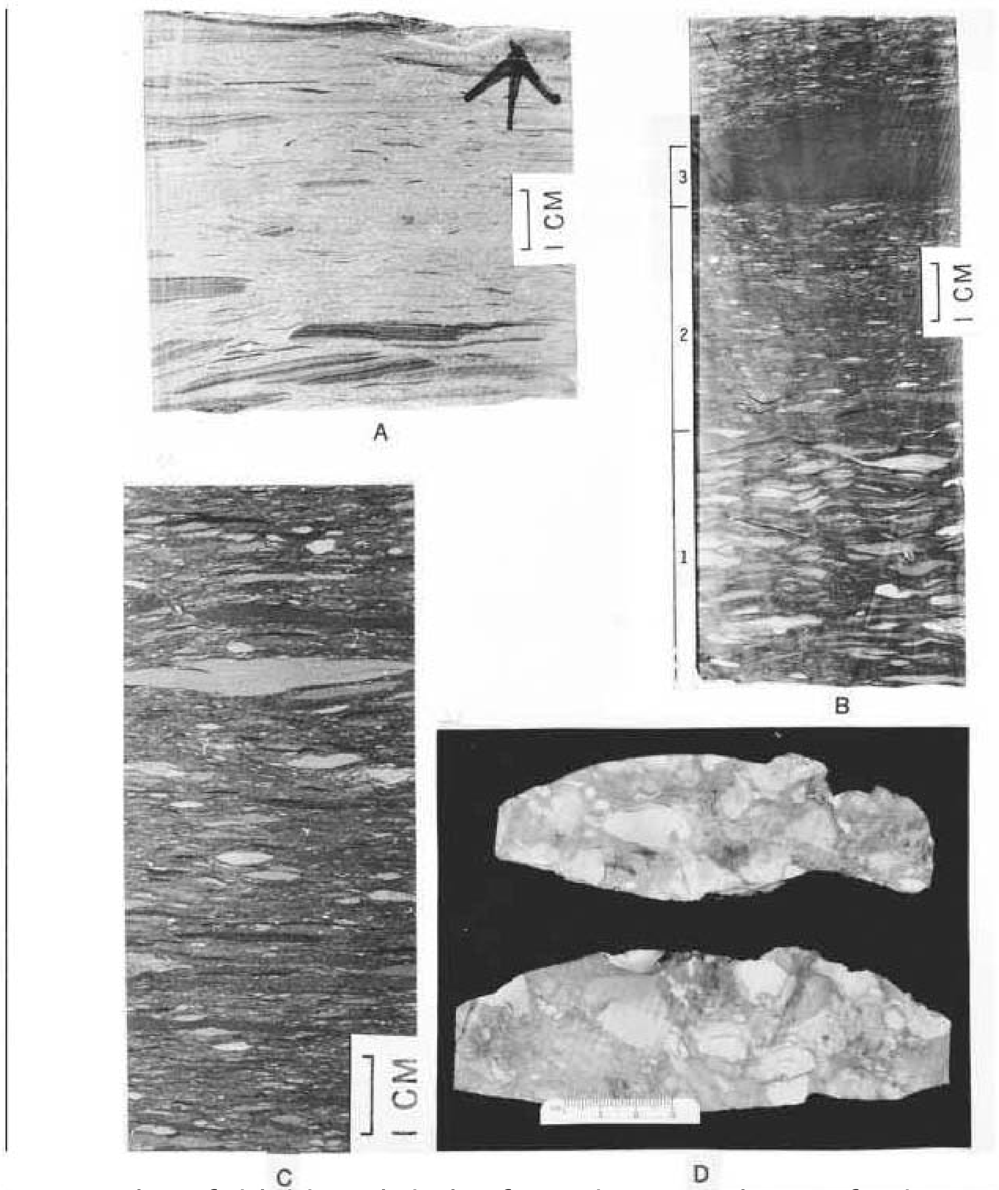
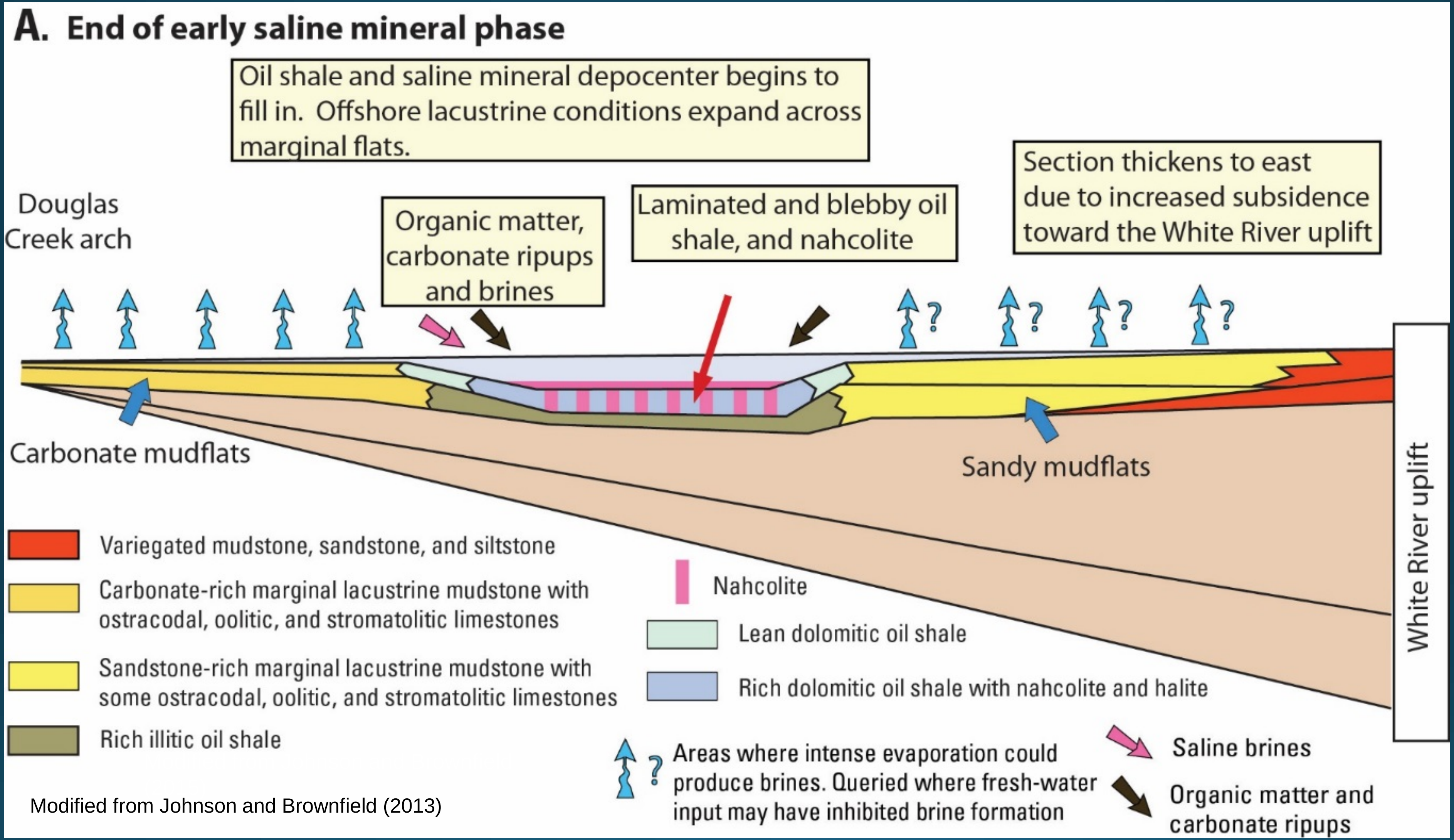
There are two types of oil shale: (1) “varved” as Bradley (1929) described, and (2) laterally transported oil shale.

Here, we will focus on just the varved oil shale but give an example of a zone that consists mainly of transported oil shale for comparison.

80-112, sec. 16, T. 5 S., R. 98 W., Desert Gulch quadrangle, elevation approx. 6,970 feet (ft), elevation top of Mahogany zone about 7,190. Photo is from 220 ft below top Mahogany zone, near middle of R-6 zone.



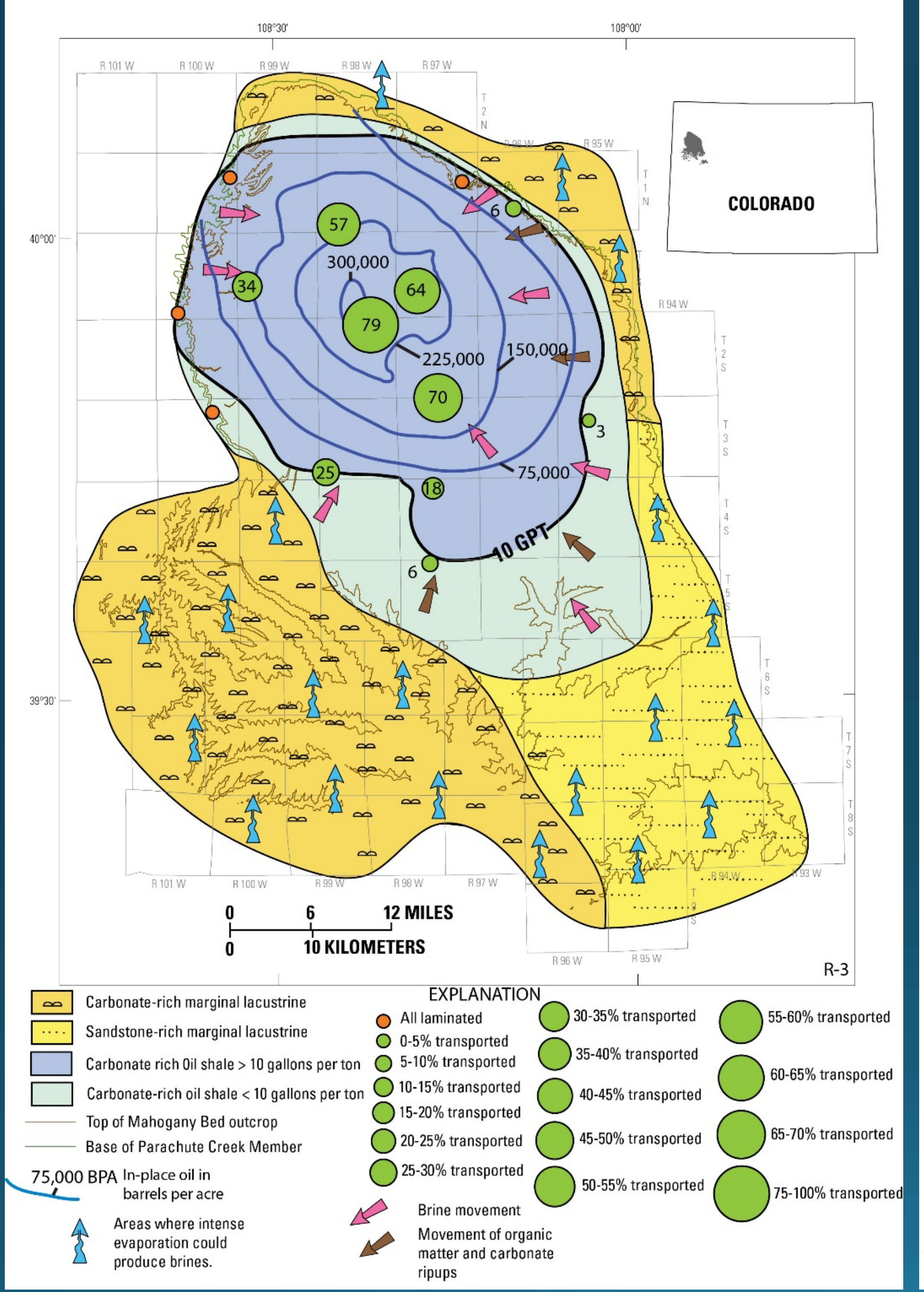
Examples of “blebby oil shale” from the central part of Lake Uinta Piceance Basin (from Dyni and Hawkins (1981)

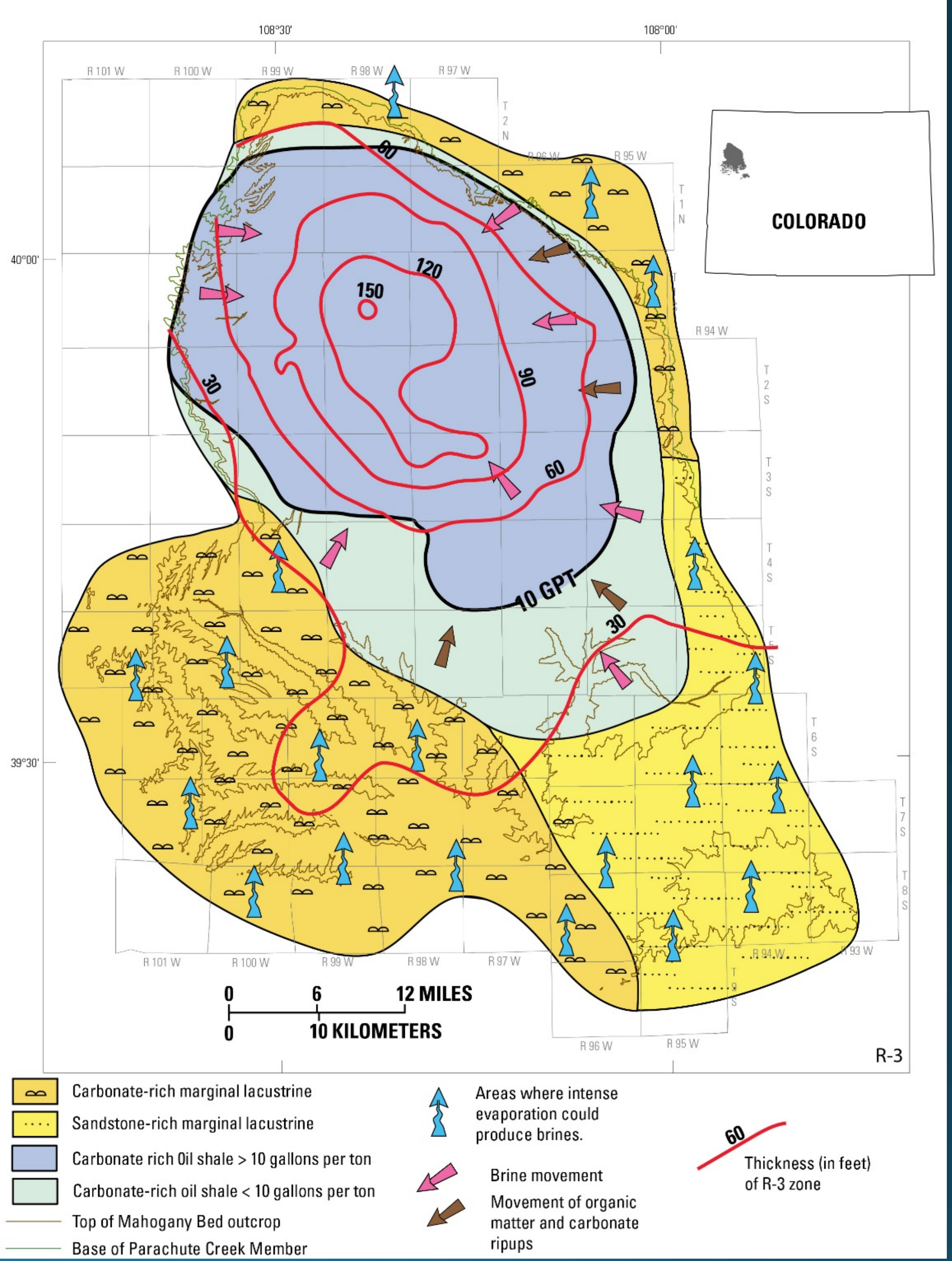


Modified from Johnson and Brownfield (2013)

Laterally transported oil shale is most abundant in the oil shale depocenter during the early period of saline Lake Uinta when the lake was surrounded by broad marginal shelves that produced highly saline brines. When the brines washed into the depocenter they appear to have brought abundant ripped up organic-rich material with them.

Laterally transported oil shale comprises the majority of many oil shale zones in the central part of the lake such as the R-3 zone shown here. Note that total in-place oil measured in barrels per acre and thickness increase as the percentage of transported oil shale increases.





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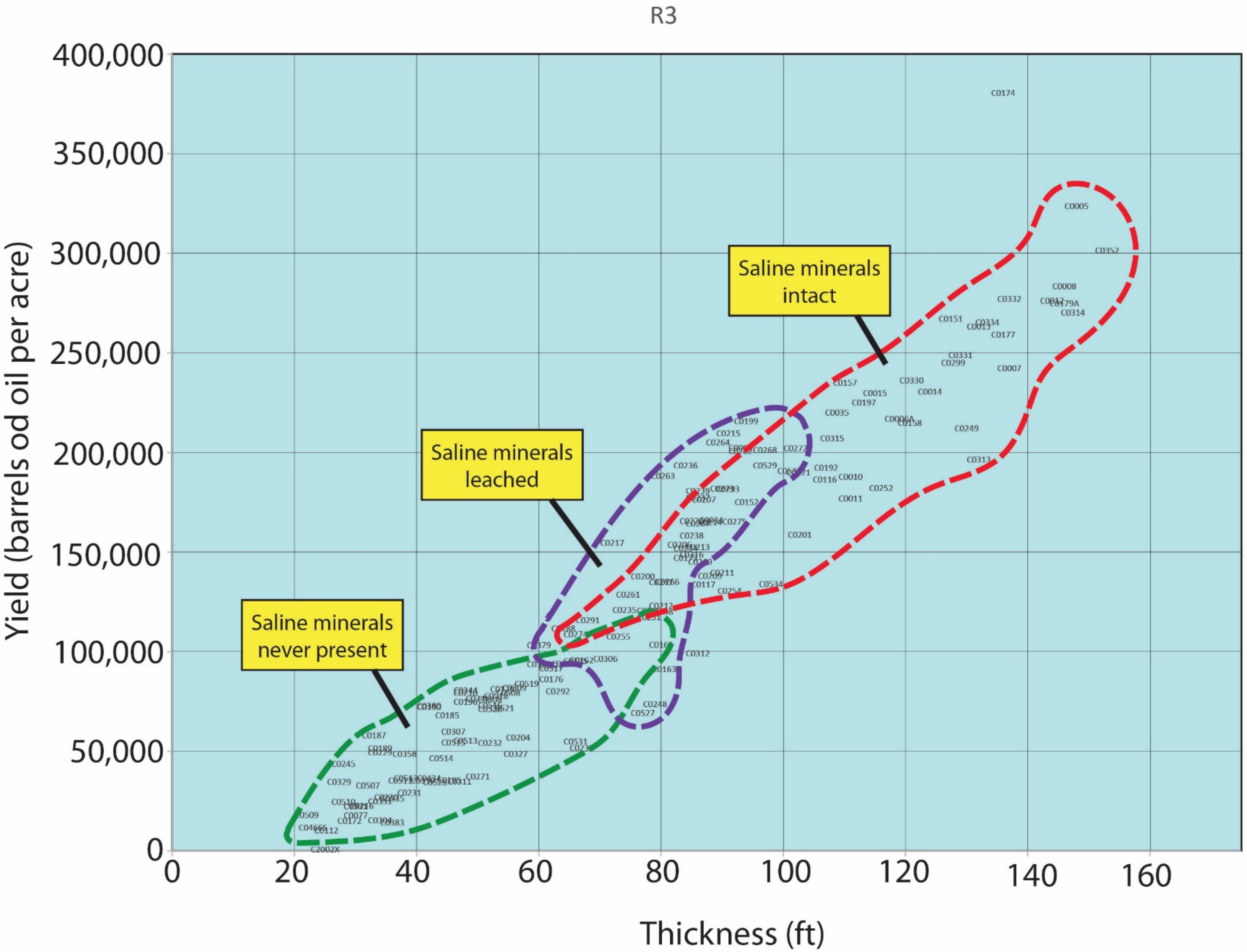
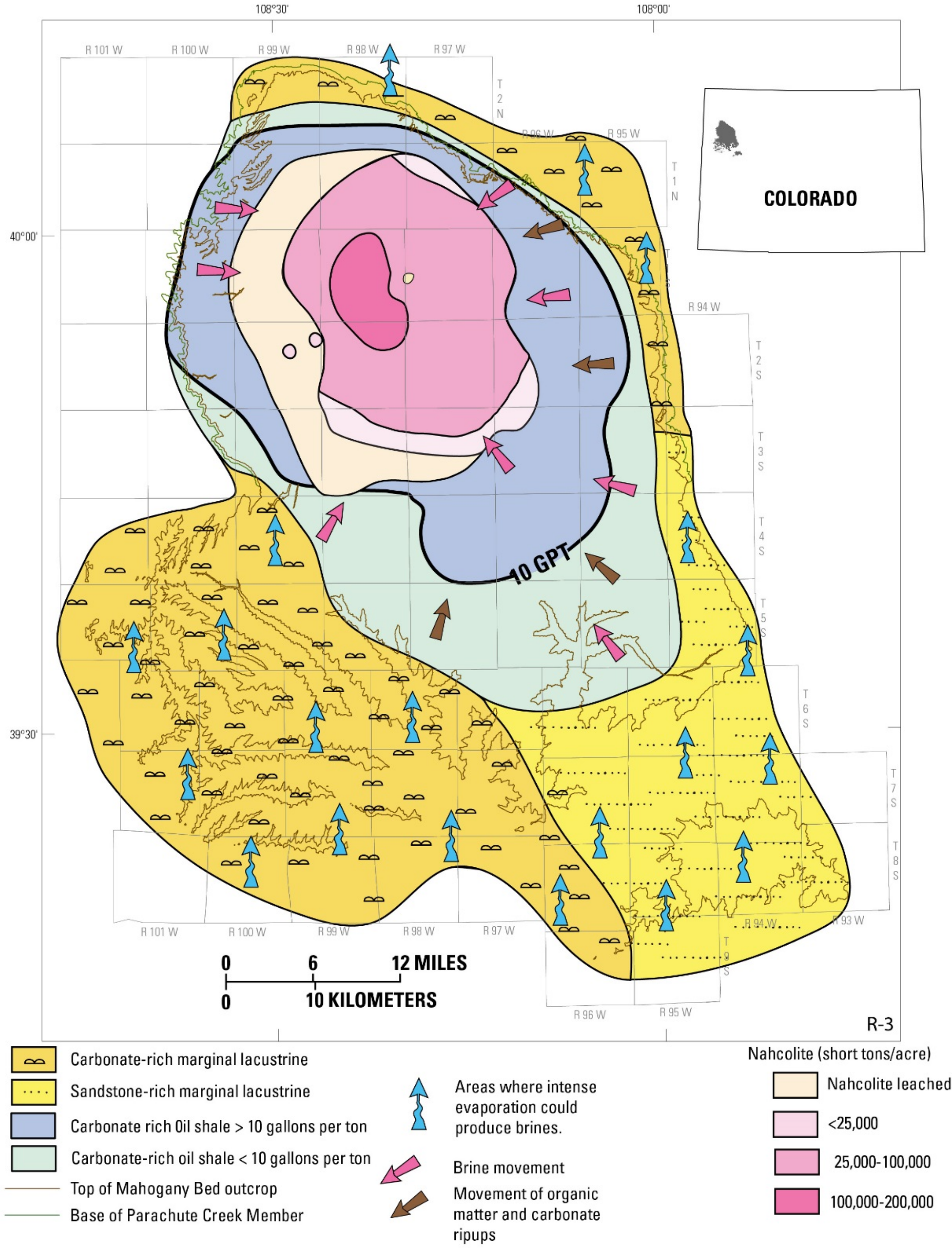
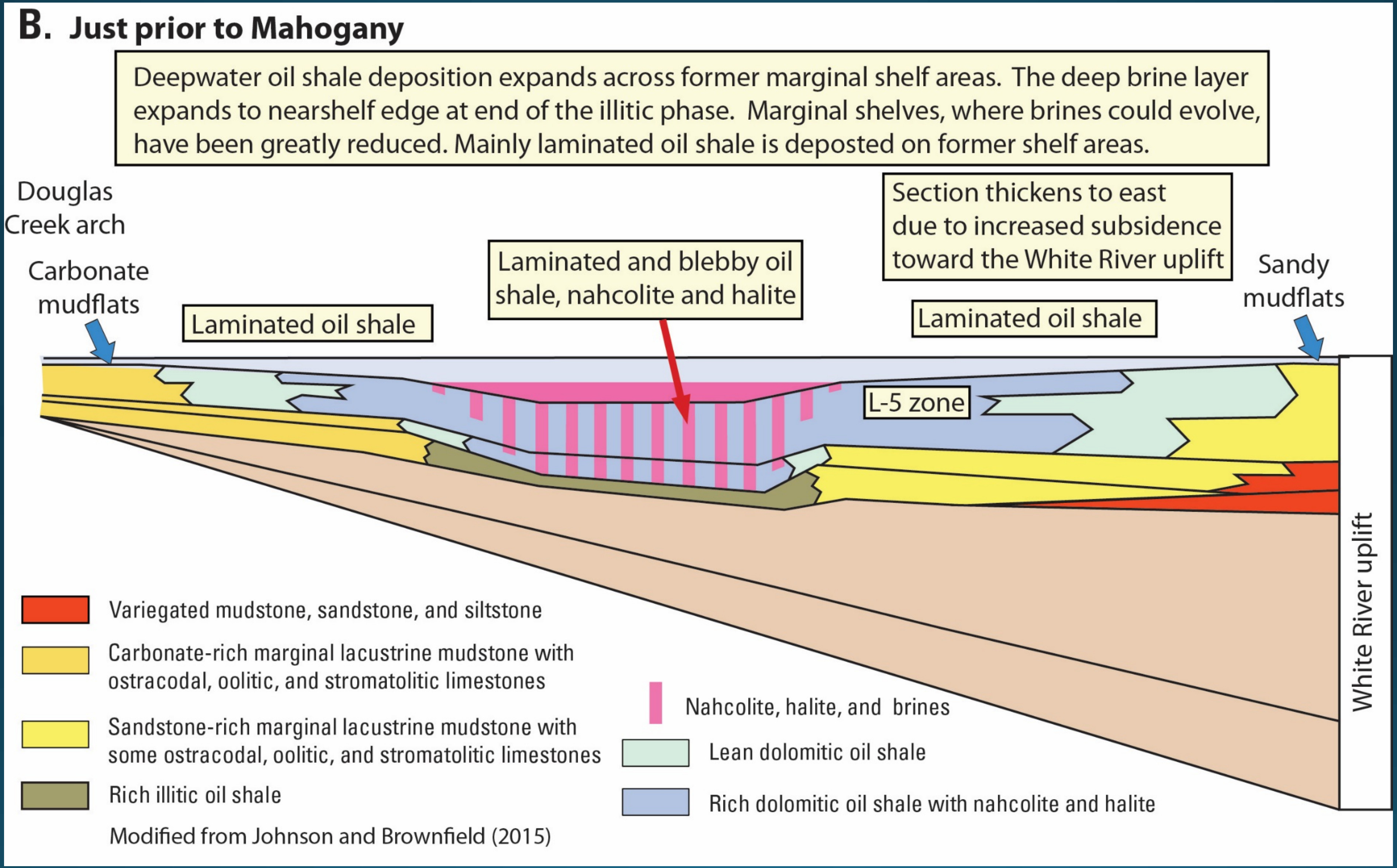




The R-3 zone can be subdivided into three areas: (1) where saline minerals are intact, (2) where saline minerals have been leached, and (3) where saline minerals were never deposited. Saline minerals can increase the thickness of the section where present and can thin the section where leached out due to collapse.



Lake Uinta gradually expanded across the marginal shelves, and by the beginning of Mahogany zone deposition, deep water conditions existed across much of the shelves. The Mahogany is largely laminated and contains little transported oil shale.

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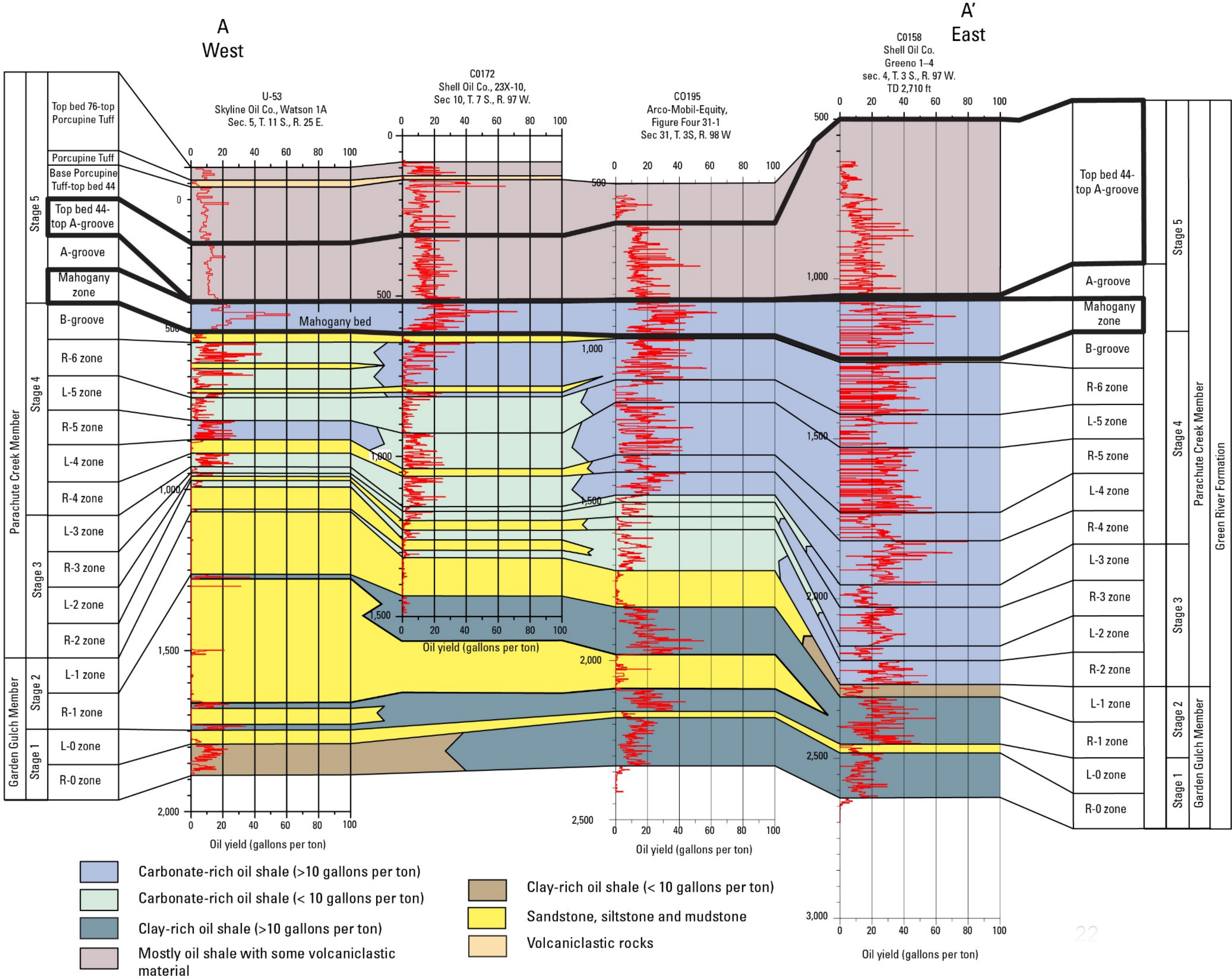
Herein we focus on two largely laminated intervals deposited late in the history of Lake Uinta:

(1) Mahogany zone, and
(2) bed 44 interval



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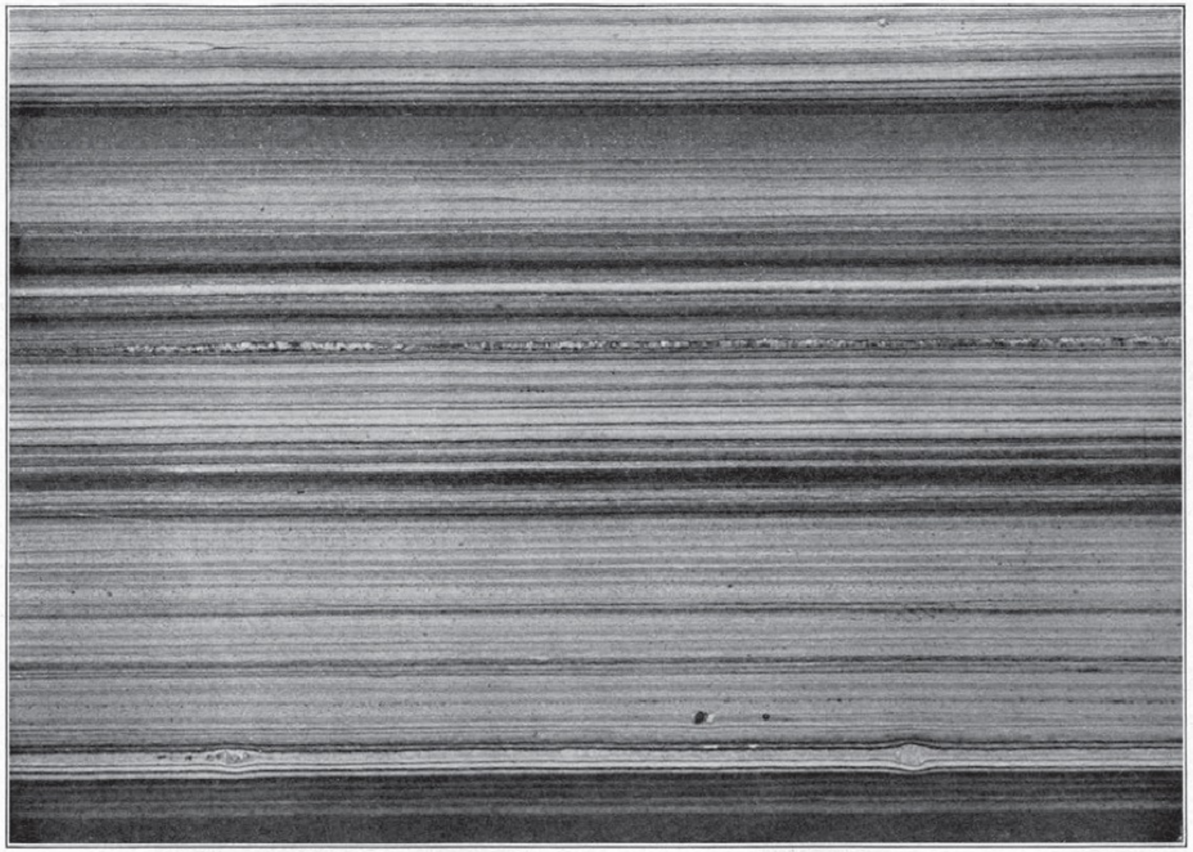
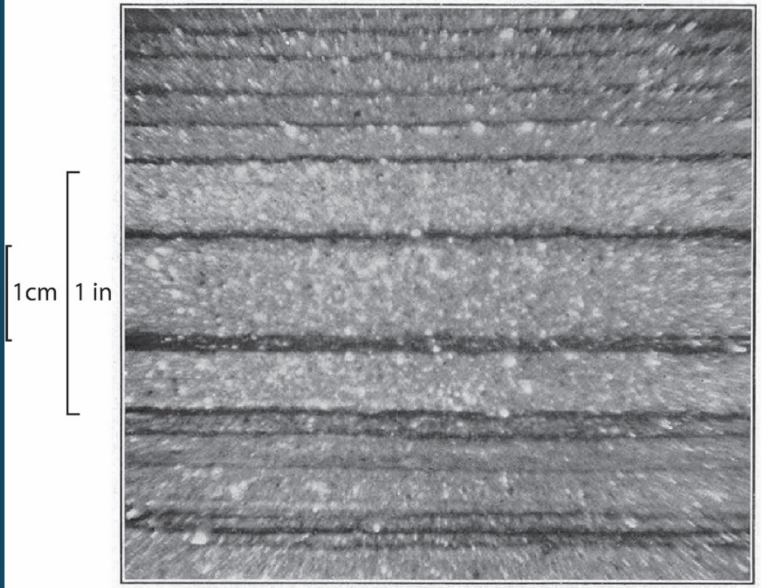
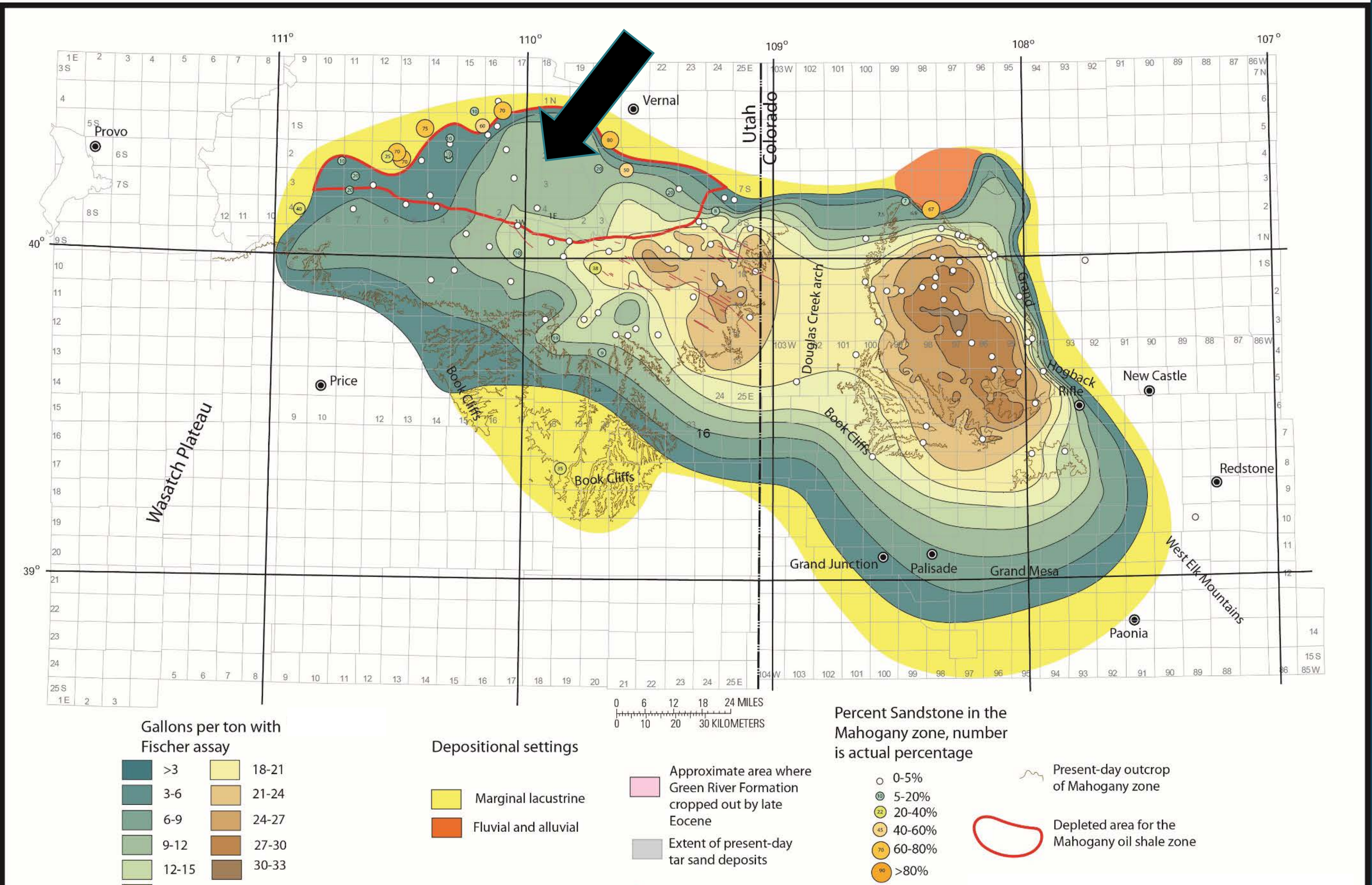




Photomicrographs of varves from Bradley (1929) Varves on the left average 1.16 mm. The thickest varve on the right is about a cm. The mineral-rich layers on the right were described by Bradley (1929) as "fine-grained limey sandstone." These layers resemble the distal portions of turbidites in modern lakes (Ludlam, 1969; 1974) and thus would not be annual varves.

During deposition of the Mahogany zone, Lake Uinta expanded to cover most of the former marginal shelves in the Uinta and Piceance Basins. It was recently proposed by Johnson et al. (2016) that the Mahogany has been depleted of some of its original kerogen by hydrocarbon generation and migration in the structurally deepest part of the Uinta Basin (outlined in red, black arrow). Note the decrease in gallons per ton values in that area.



Modified from Johnson et al, 2016

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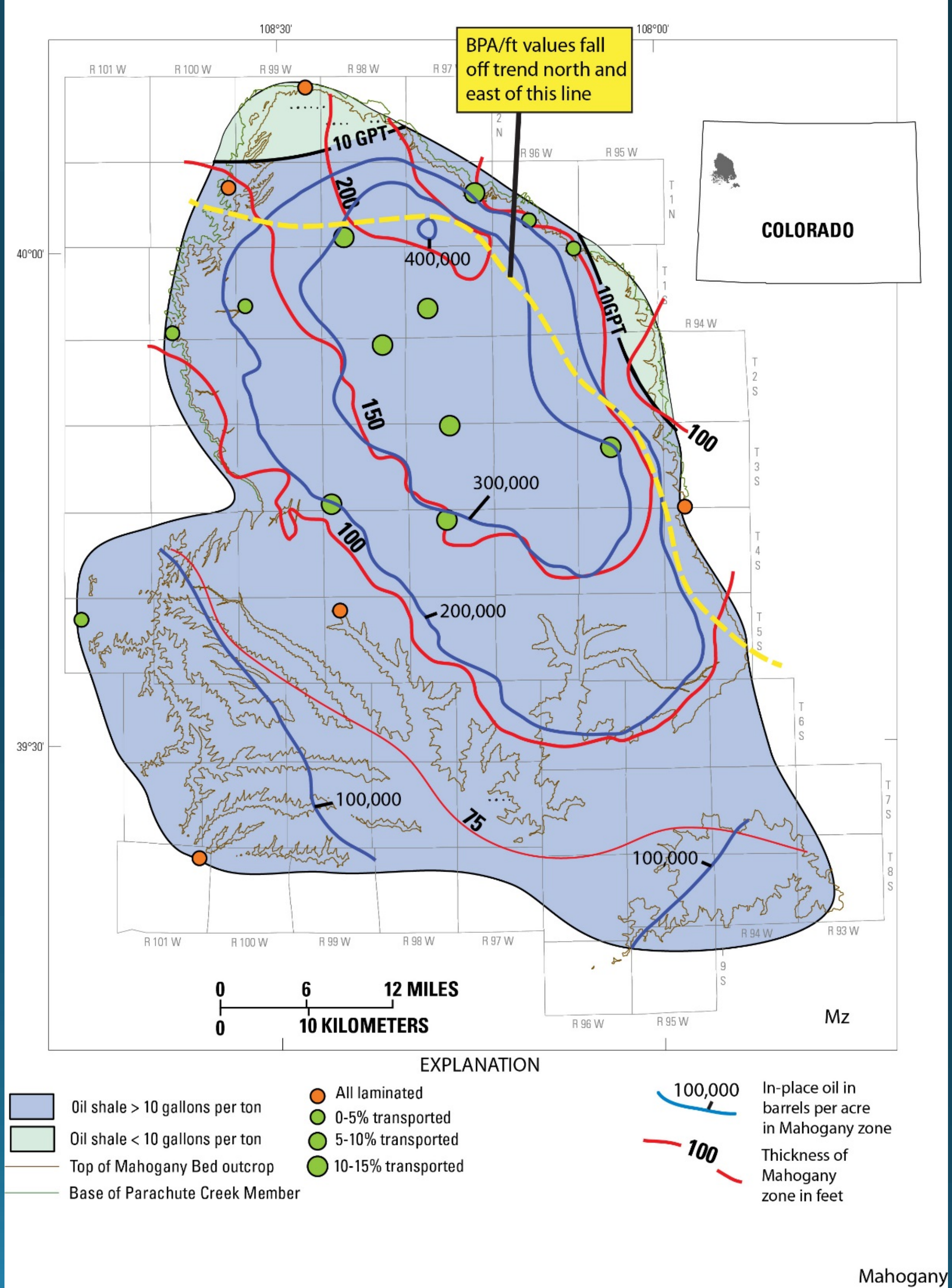
Note that isopach lines for the Mahogany zone (red) and in-place kerogen measured as barrels of oil per acre (blue) parallel each other except in marginal areas, defined by yellow line, where there was abundant clastic input from rivers.

The Mahogany zone is mainly laminated, the percent of transported oil shale (circles) is very low.



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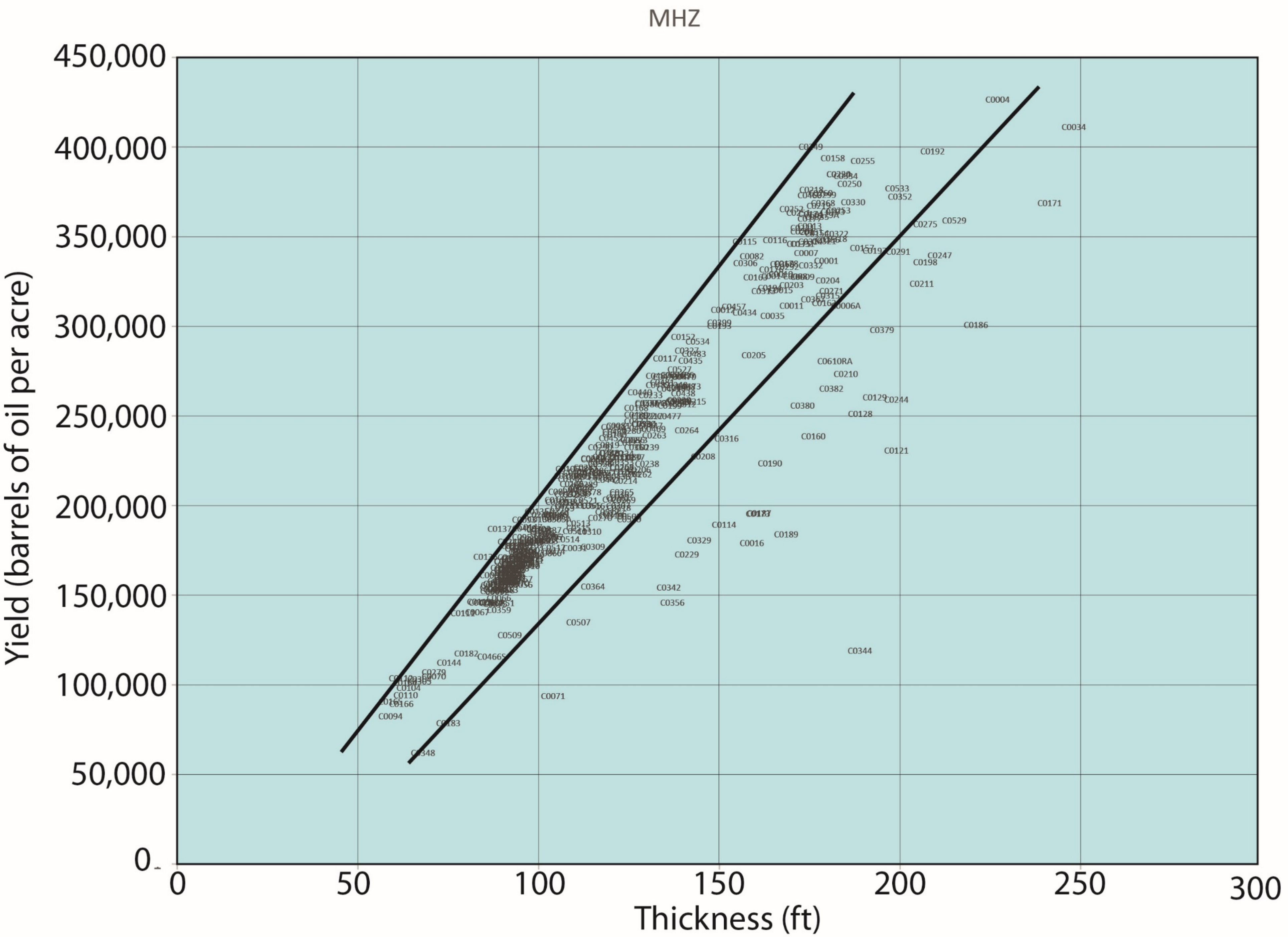
Maps generated from Johnson et al (2010), Johnson and Brownfield (2013)

There is a very strong linear correlation between thickness and total kerogen in place, with the majority of points falling between the two black lines.



Plot generated using USGS Piceance Basin Oil Shale Database https://pubs.usgs.gov/dds/dds-069/dds-069-y/

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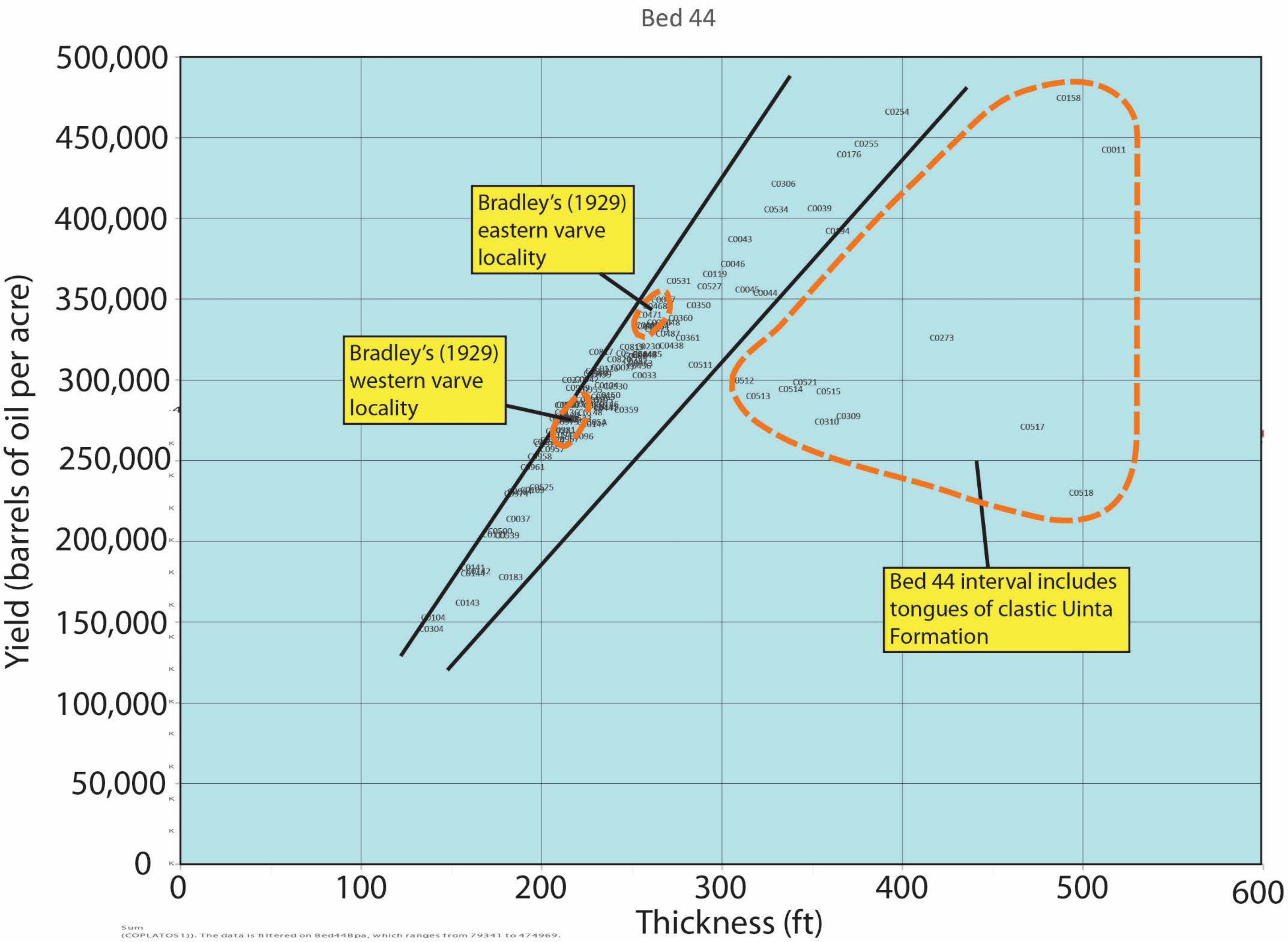
We will next look at the points that fall outside the trend.



Plot generated using USGS Piceance Basin Oil Shale Database https://pubs.usgs.gov/dds/dds-069/dds-069-y/

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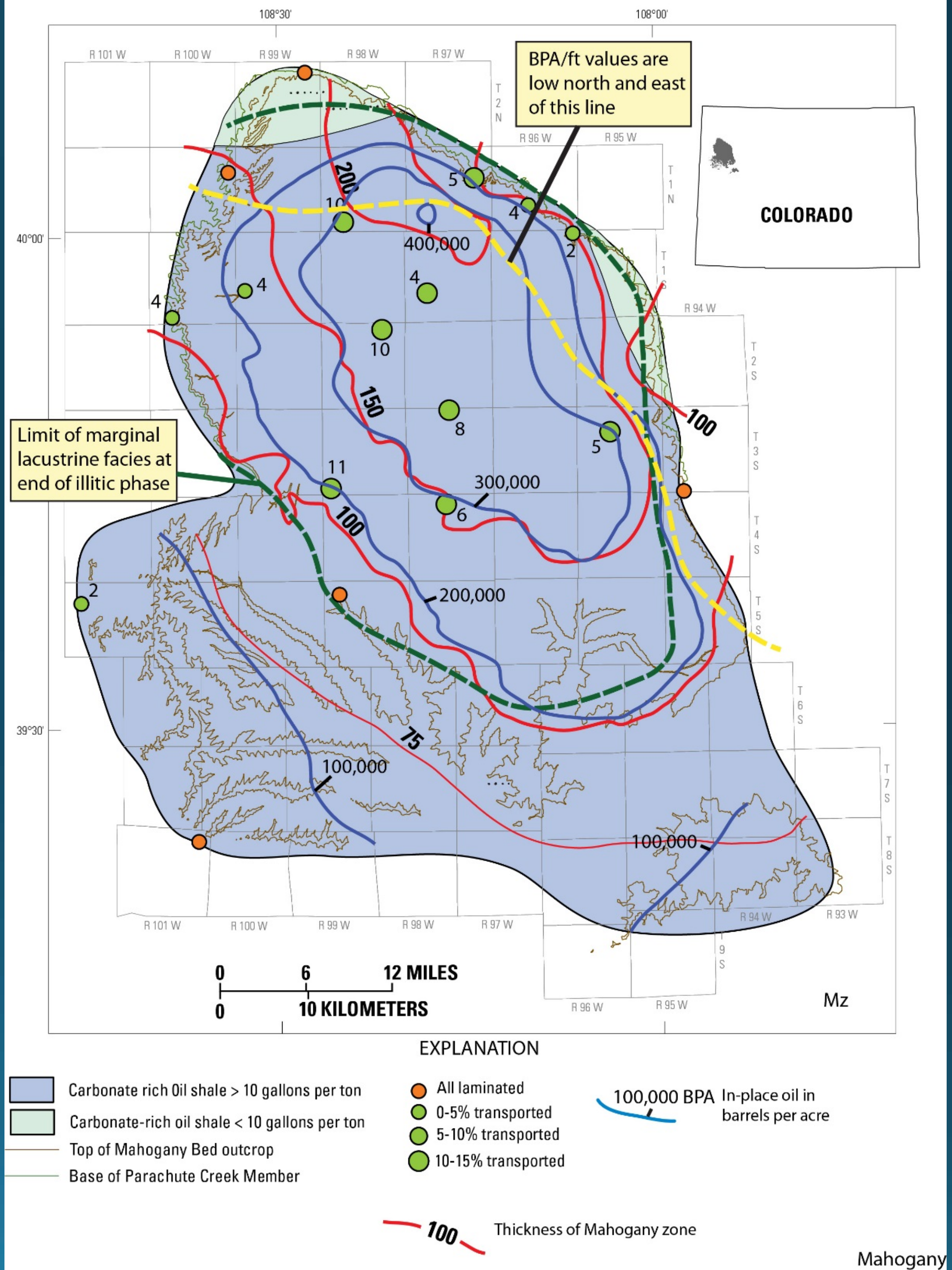
All of those points fall near the margins of the basin where major rivers entered the lake. We suggest that the Mahogany zone contains large amounts of coarser detrital debris in these areas.



Isopach map and barrels per acre contours from Johnson et al (2010).

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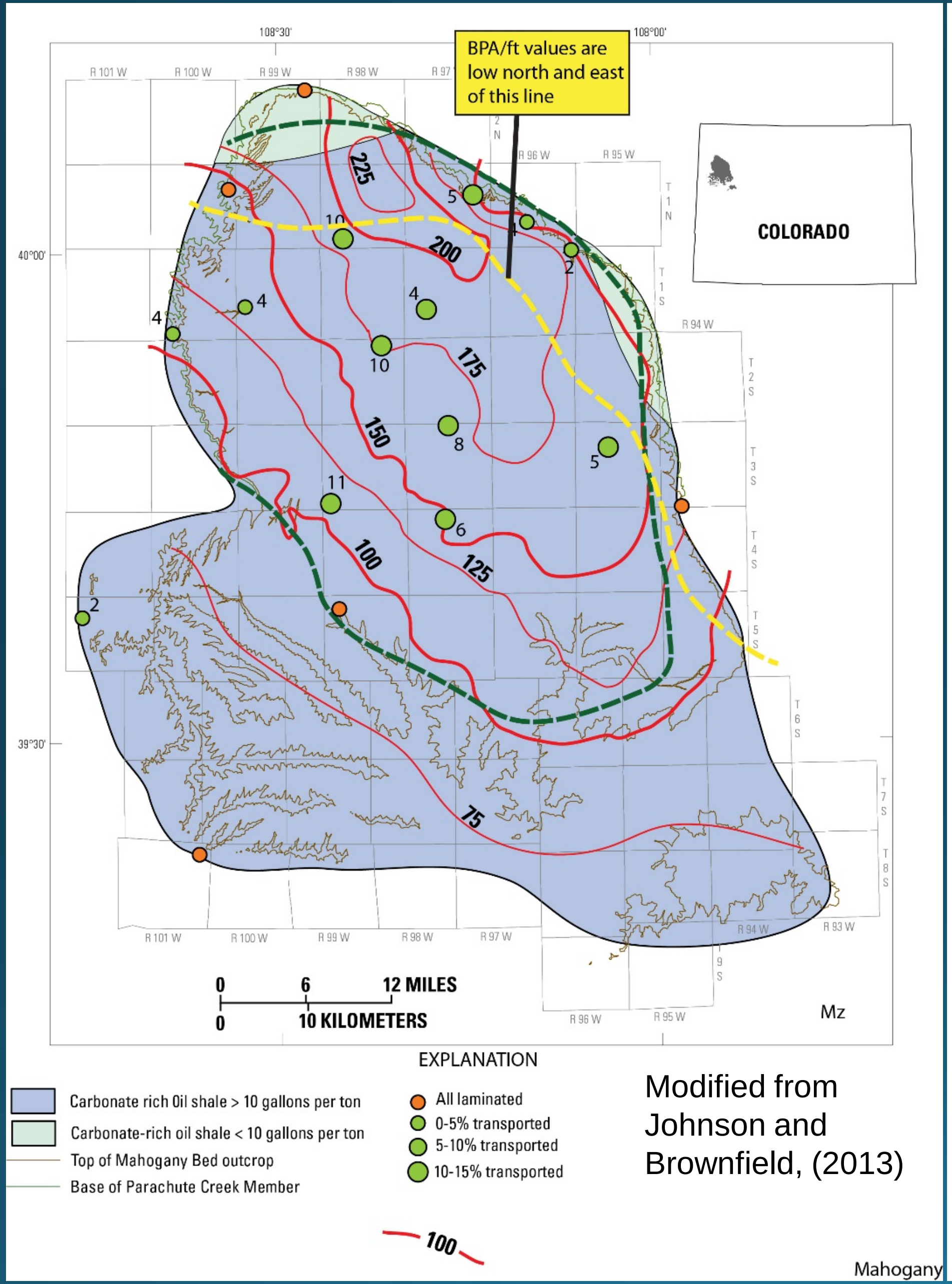
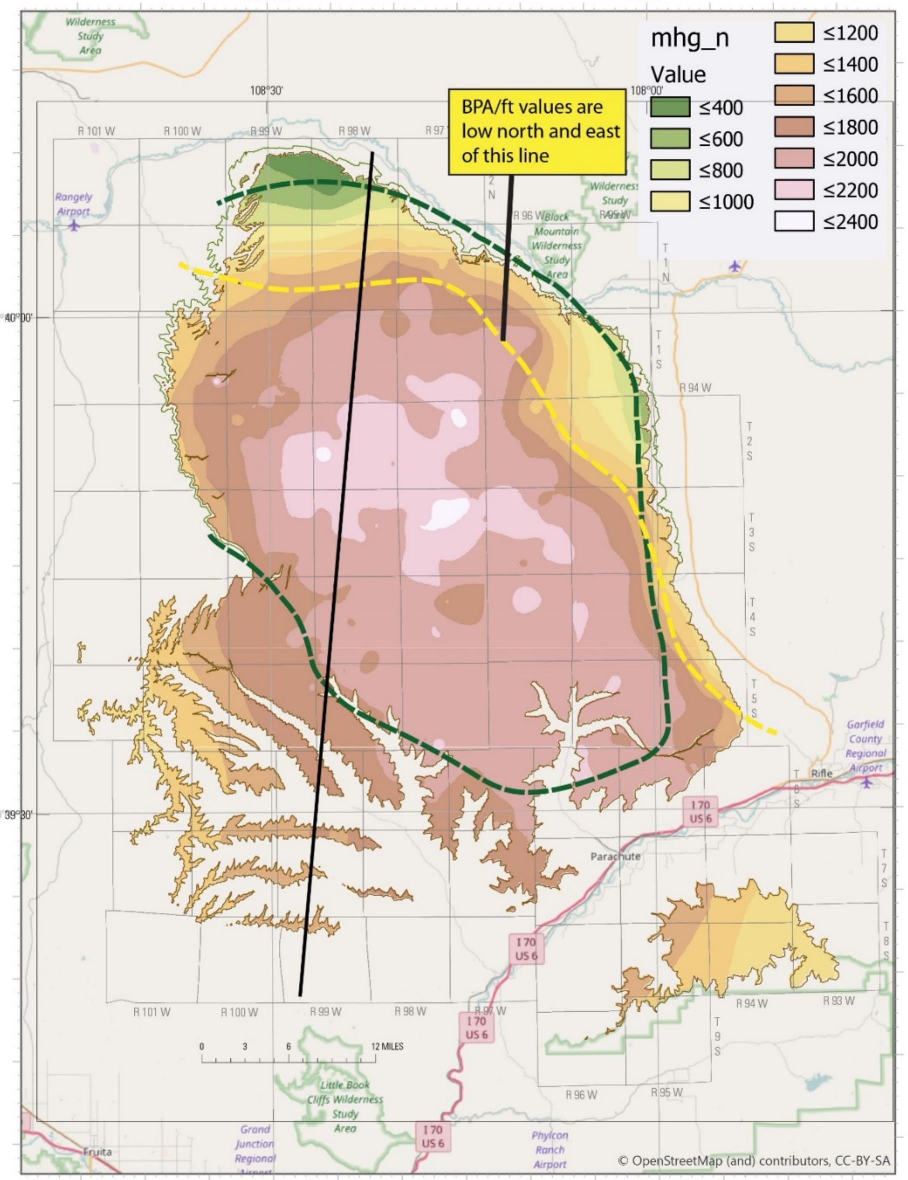
The map of the Mahogany zone on the right shows barrels per acre per foot of section. Toward the center of the lake, total mineral matter increases and it becomes increasingly more efficient at capturing organic matter possibly because it includes a greater percentage of clay there.



Modified from Johnson and Brownfield, (2013)



Geology paper-fig. 20 Mahogany zone blebby copy (PDF) BPA-ft layer near bottom

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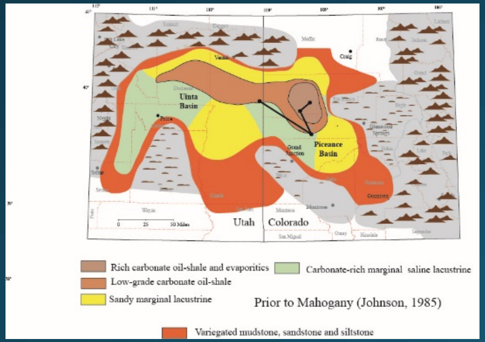
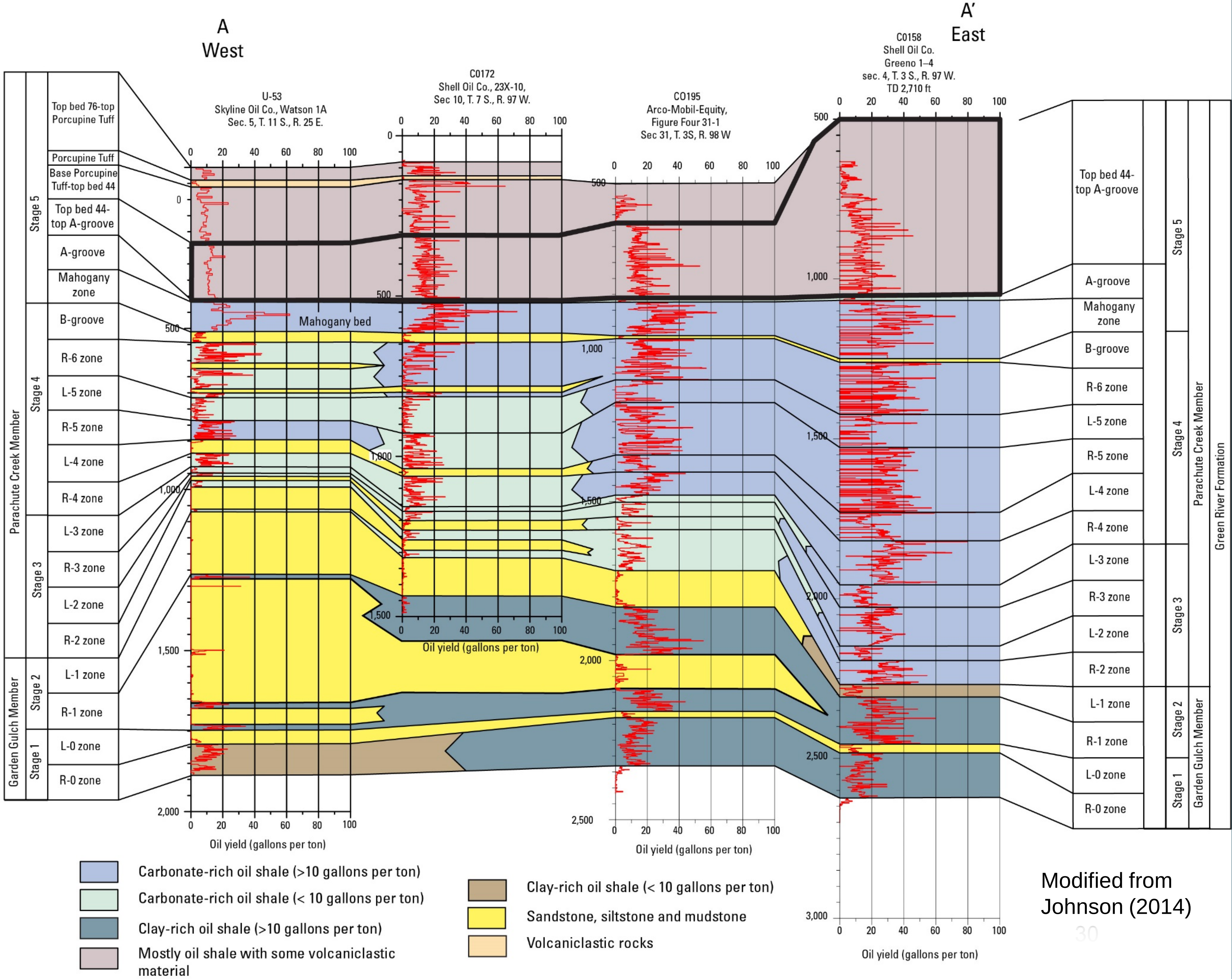
Bed 44 interval was deposited during the infilling stage of Lake Uinta when the Piceance Basin part of the lake was being filled in by volcaniclastic sediments from Wyoming. Like the Mahogany zone, the bed 44 interval is largely laminated away from sources of clastic influx.





Modified from Johnson (2014)

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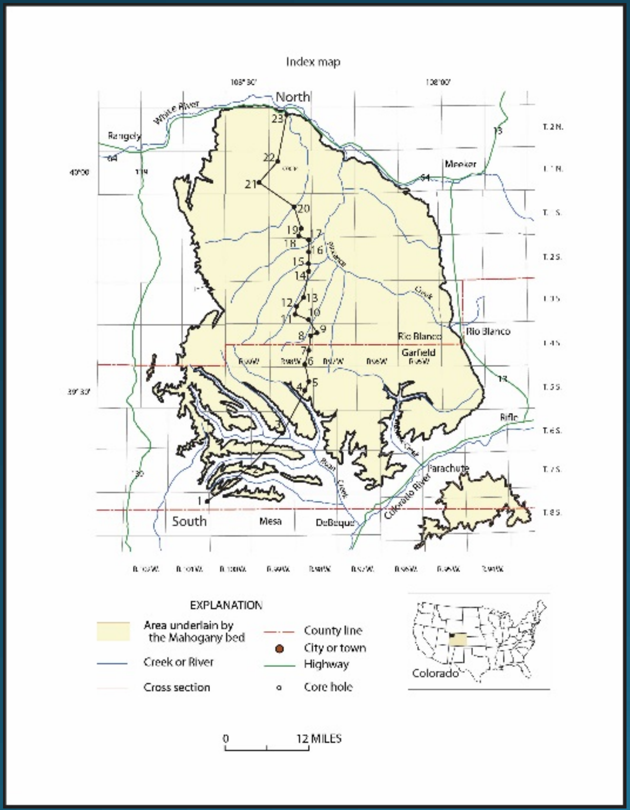
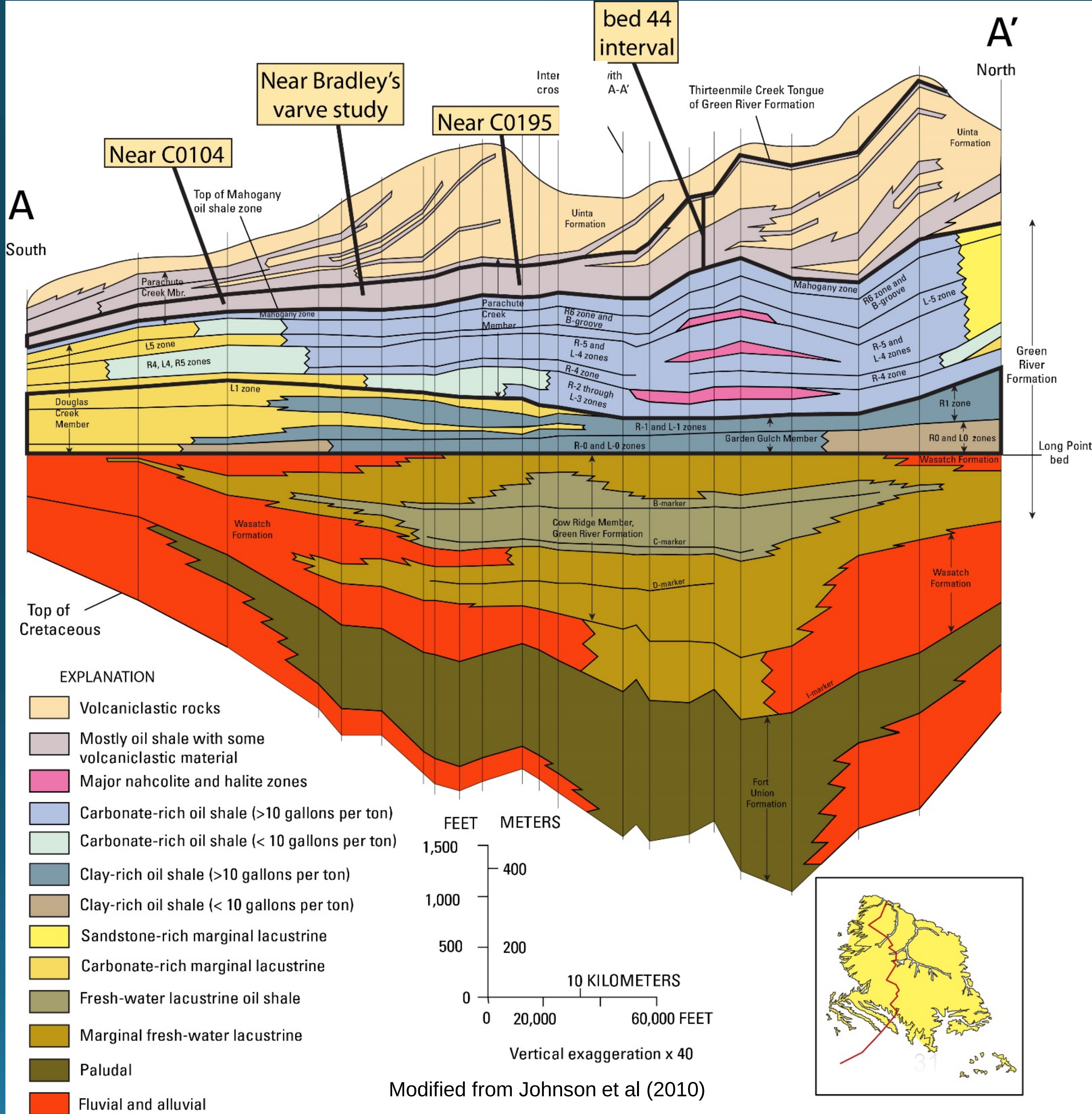
The bed 44 interval was deposited during the infilling stage of Lake Uinta when the Piceance Basin part of the lake was filled in by volcaniclastic sediments from Wyoming. Note the position of Bradley's varve study at the base of the prograding delta.





Modified from Johnson et al (2010)

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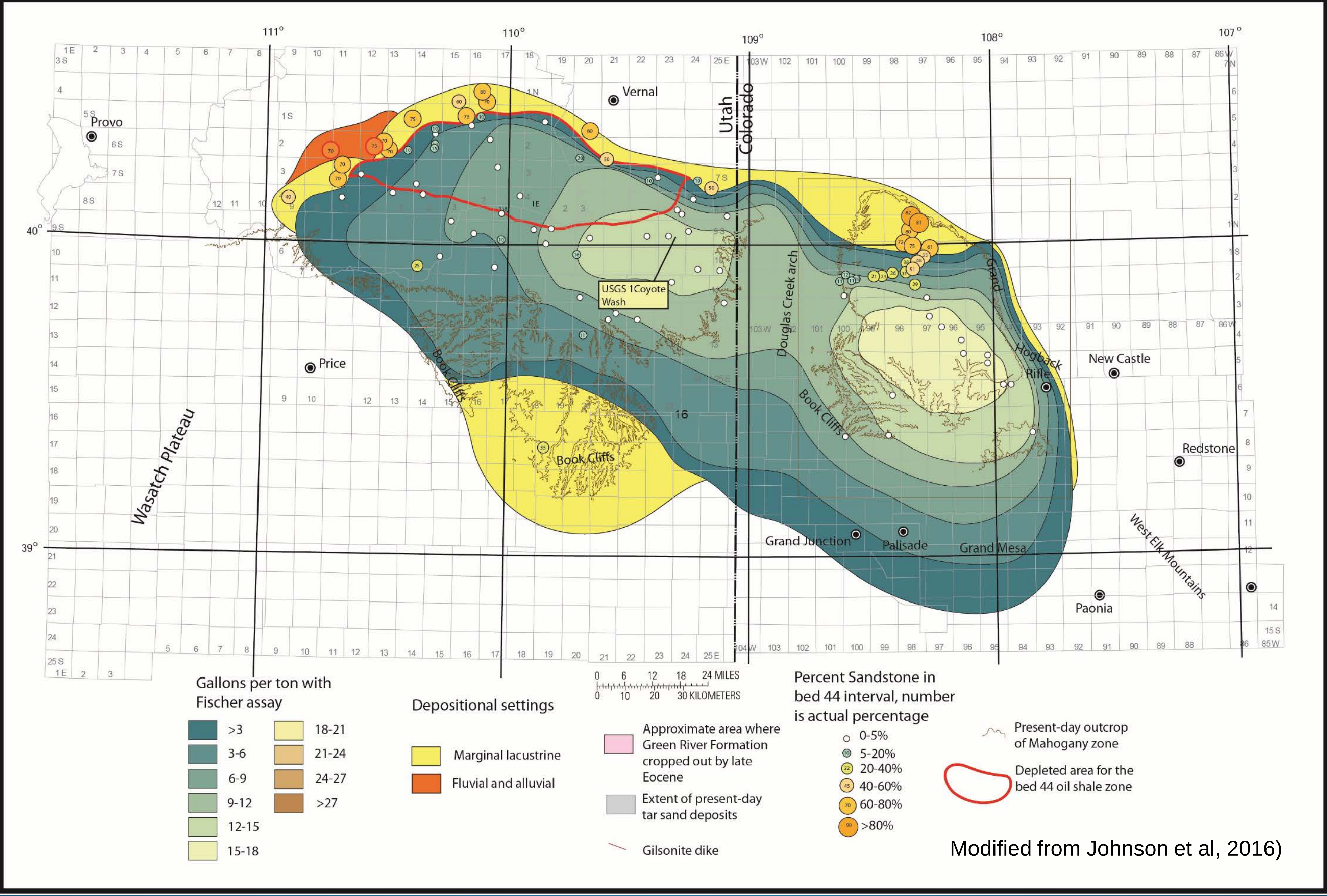
During deposition of the bed 44 interval, the Piceance part of Lake Uinta began to fill in with volcano-clastics from Wyoming.

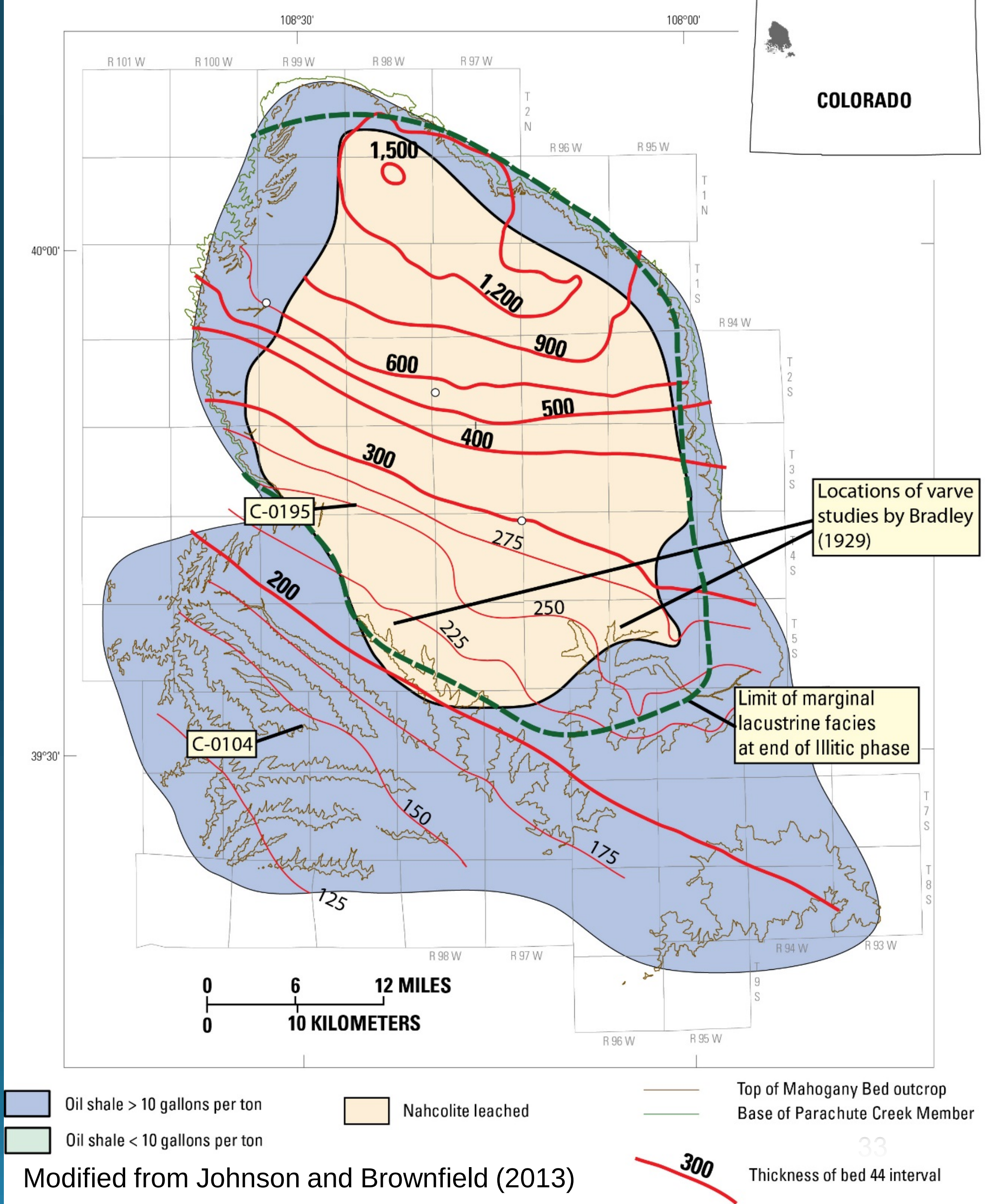
By the end of bed 44 time, the northern part of the former depocenter had been largely filled in.



Modified from Johnson et al, 2016)

Isopach map of the bed 44 interval showing locations of Bradley's varve studies and locations of two coreholes studied in detail. Bradley's varve studies are near the toe of the prograding delta, which may explain the presence of turbidite deposits.

GSA 2017-fig. 21 bed 44 locations



Modified from Johnson and Brownfield (2013)

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There is also a strong correlation between thickness and total kerogen (barrels per acre oil) for the bed 44 interval with most of the points falling between the two black lines.

It is also possible that the upper end curves (red dashed line)

Locations of two coreholes studied in detail fall on the trend line.

Plot generated using USGS Piceance Basin Oil Shale Database https://pubs.usgs.gov/dds/dds-069/dds-069-y/

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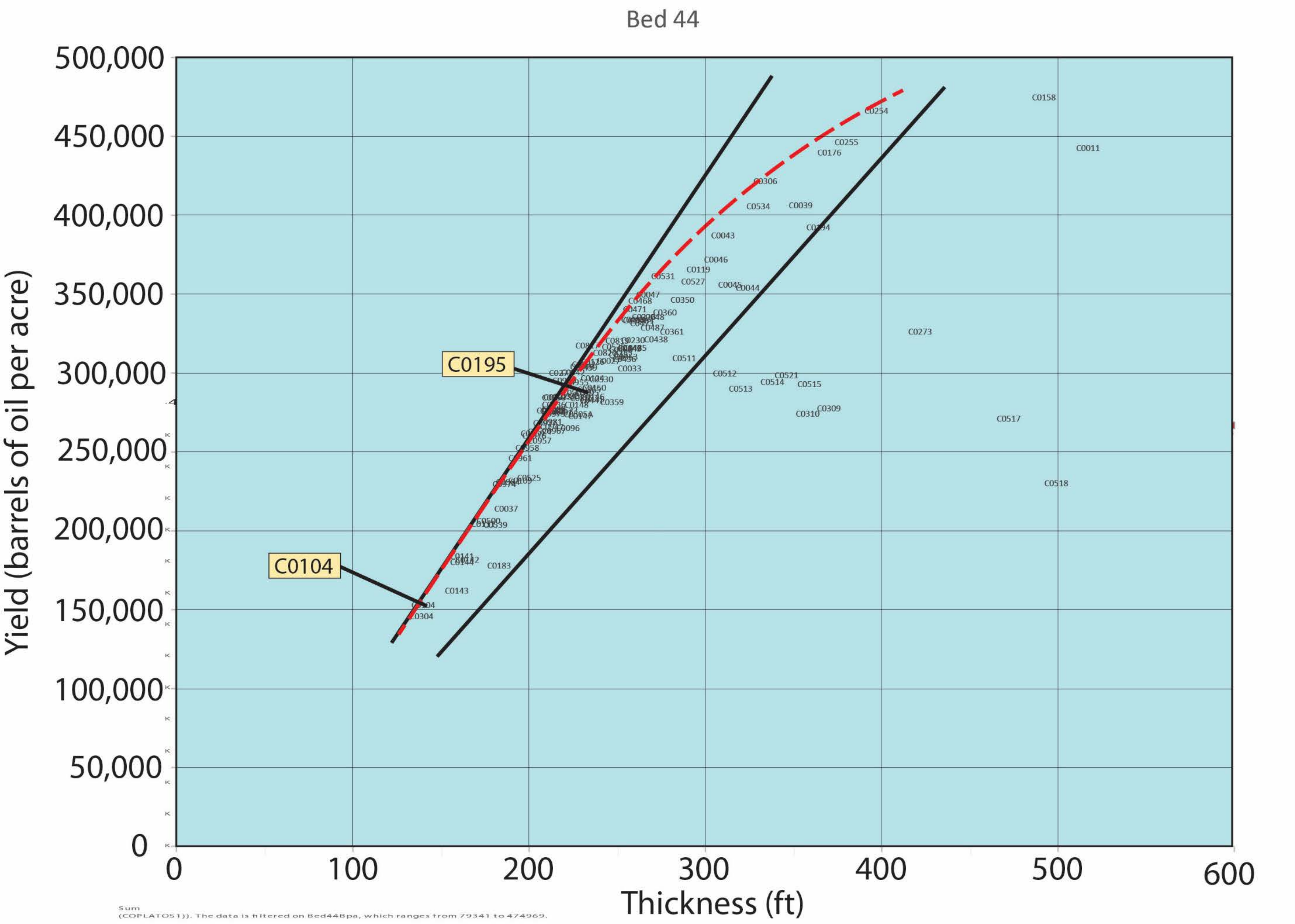
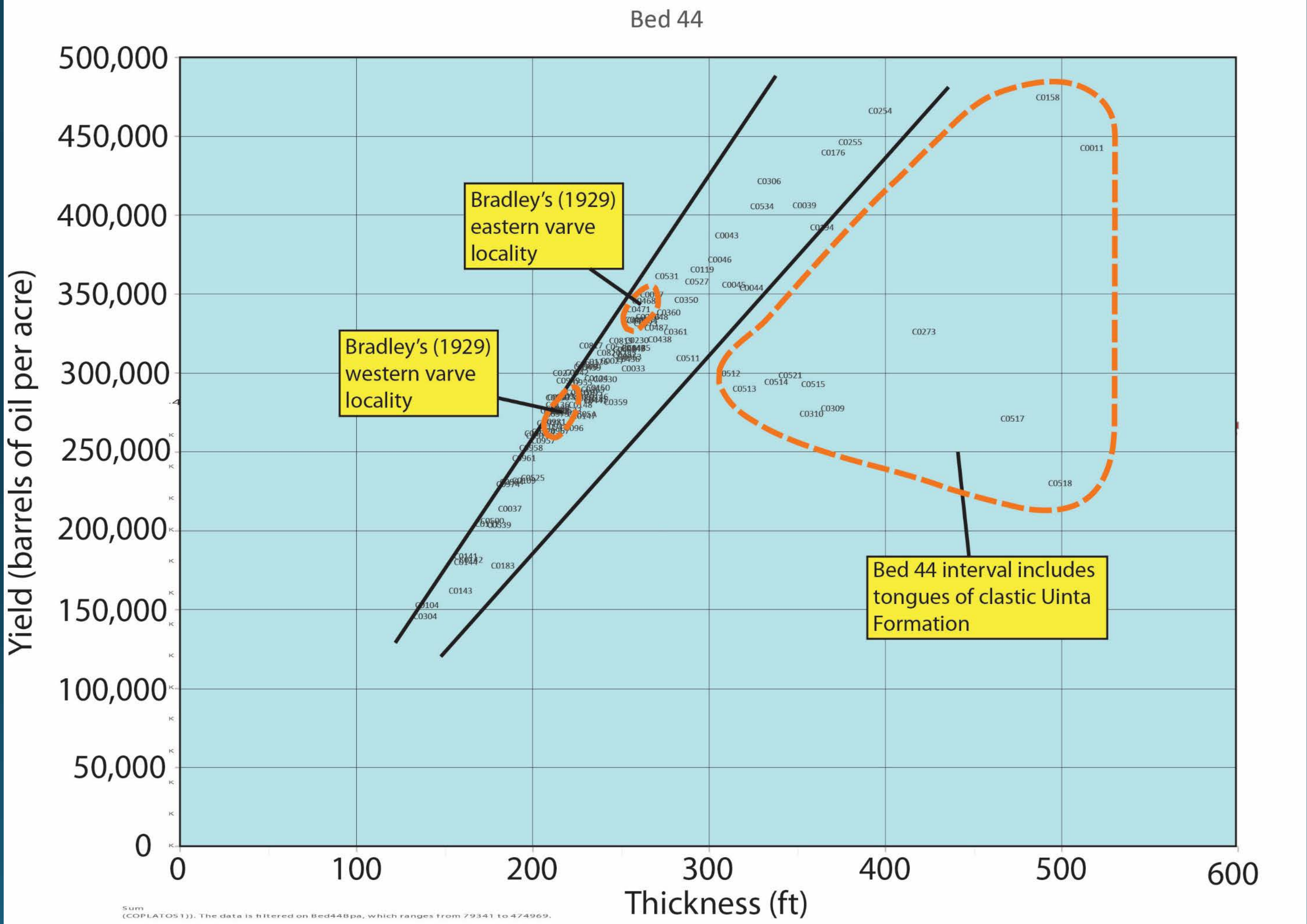


All of the points that fall off the trend include clastic tongues of the Uinta Formation.

Coreholes near Bradley's 1929 varve localities are circled.



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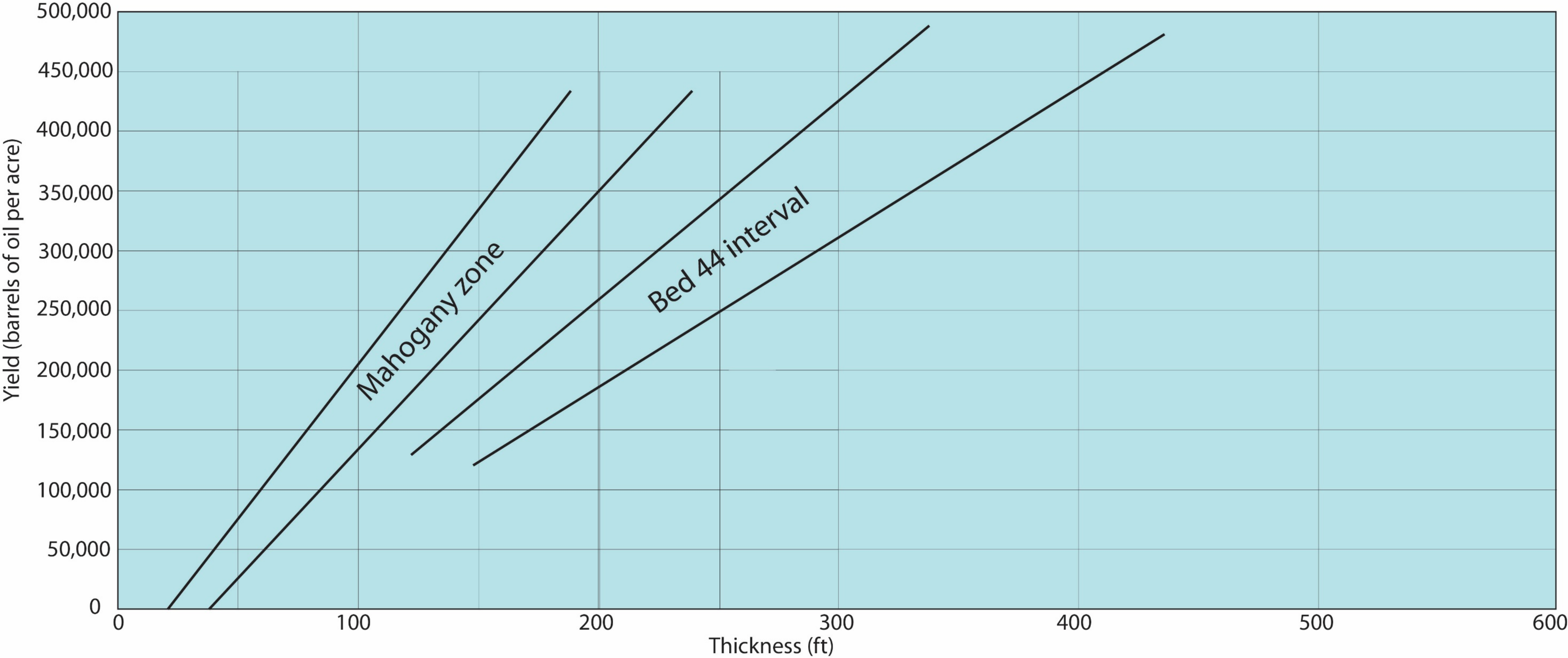

The trend for Bed 44 interval is significantly different from that of the Mahogany zone. The Mahogany zone has a greater amount of kerogen for a given thickness than the bed 44 interval.

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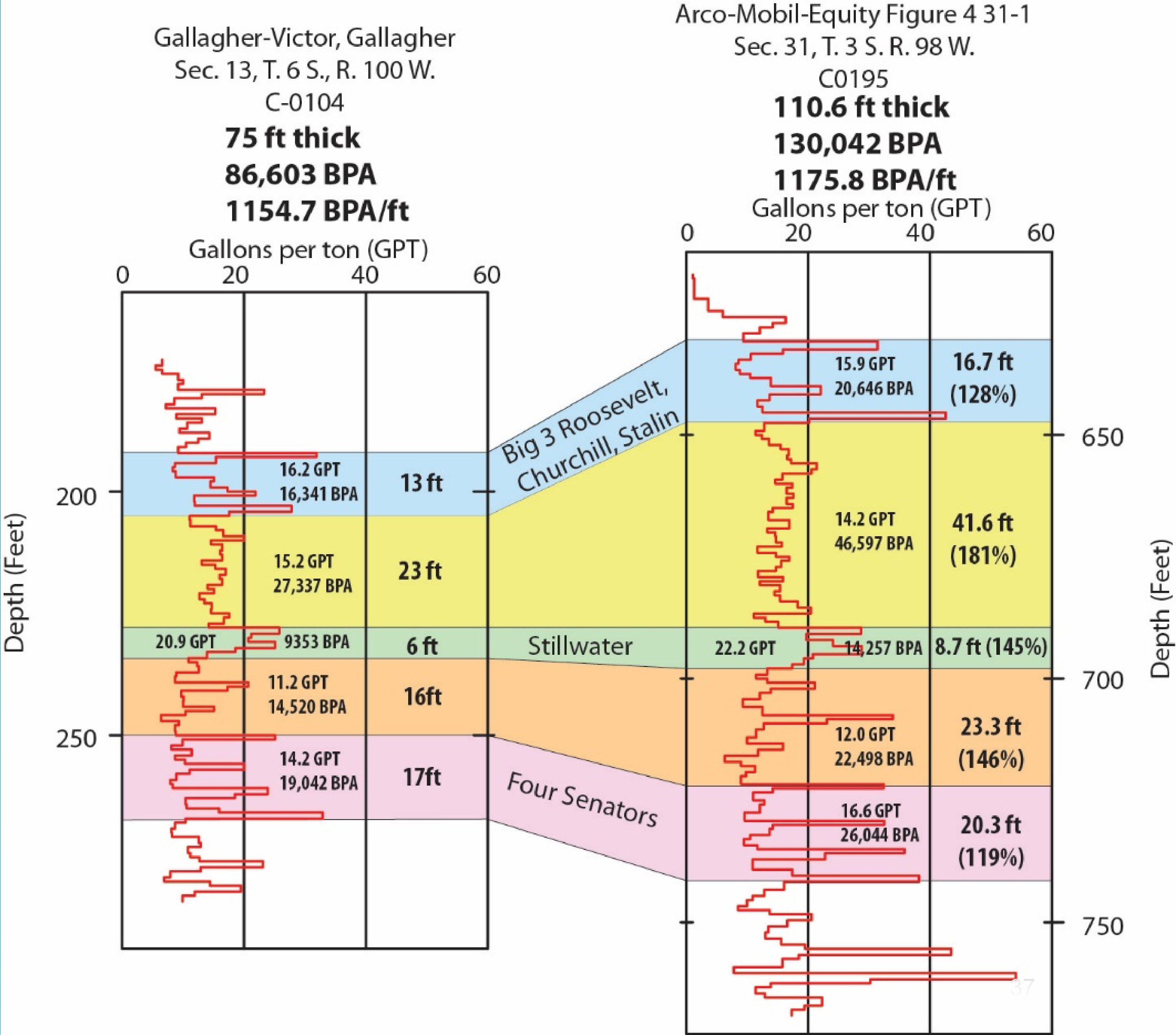
Here we examine in detail variations in thickness, barrels per acre, and oil yield for the upper part of bed 44 interval in two coreholes, one near basin center (right) and the other near the basin margin (left).

The four subdivisions are time-stratigraphic intervals each consisting of thousands of individual annual varves. Thickness, BPA and gallons per ton (GPT) values are shown for each of the subdivisions. Thickness of the combined 4 intervals in the corehole on the left is 75 ft and the corehole on the right 110.6 ft.



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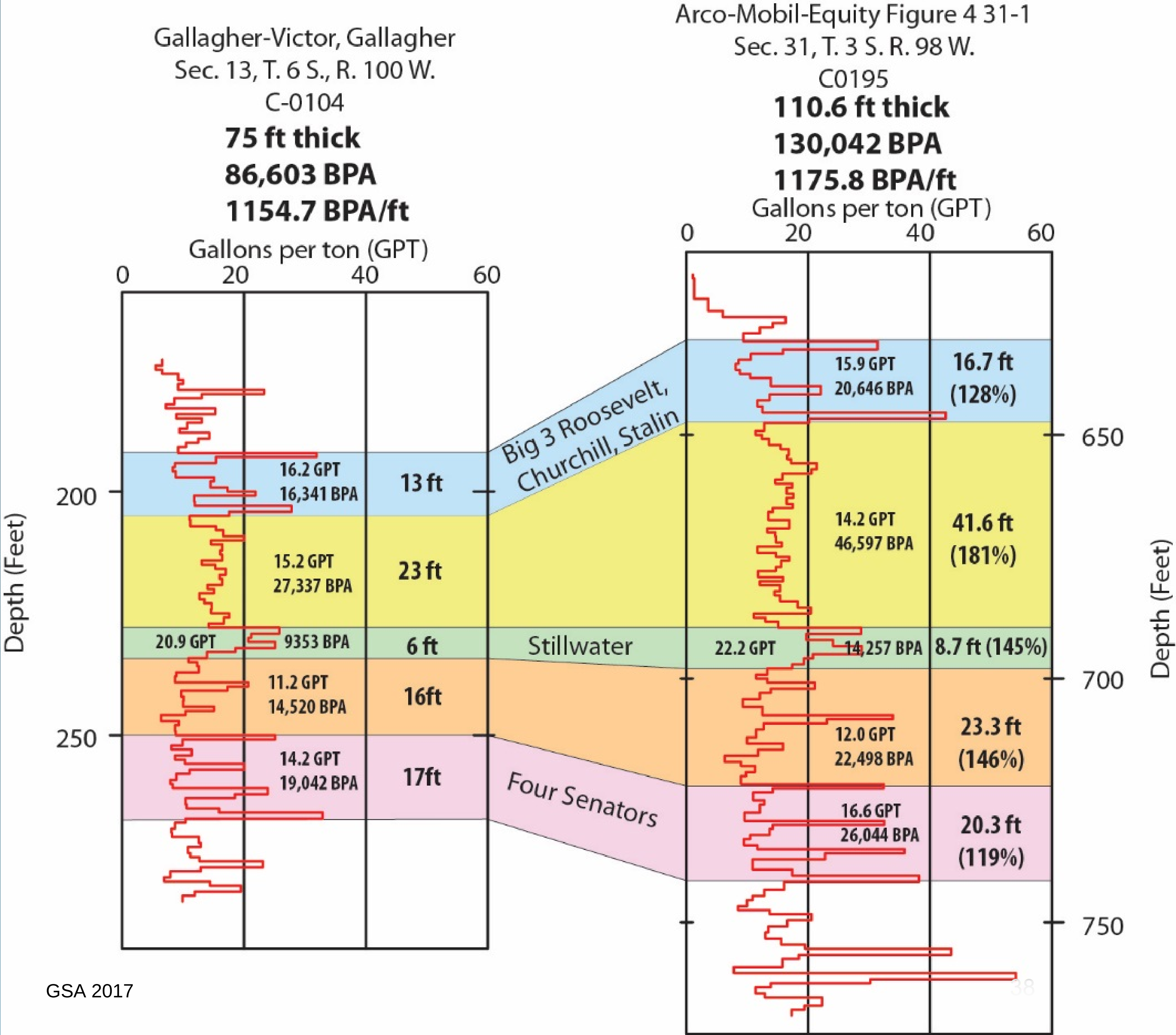
The GPT values for the four intervals are similar in the two coreholes, and the character of the GPT graphs are very similar, but the overall interval on the right is 36.6 ft thicker than the one on the left.

BPA/ft is slightly greater for the hole on the right (1175.8 BPA/ft versus 1154.7 BPA/ft).

As each interval thickens, the total organic matter proportionally increases. In essence, more mineral matter equals more organic matter.



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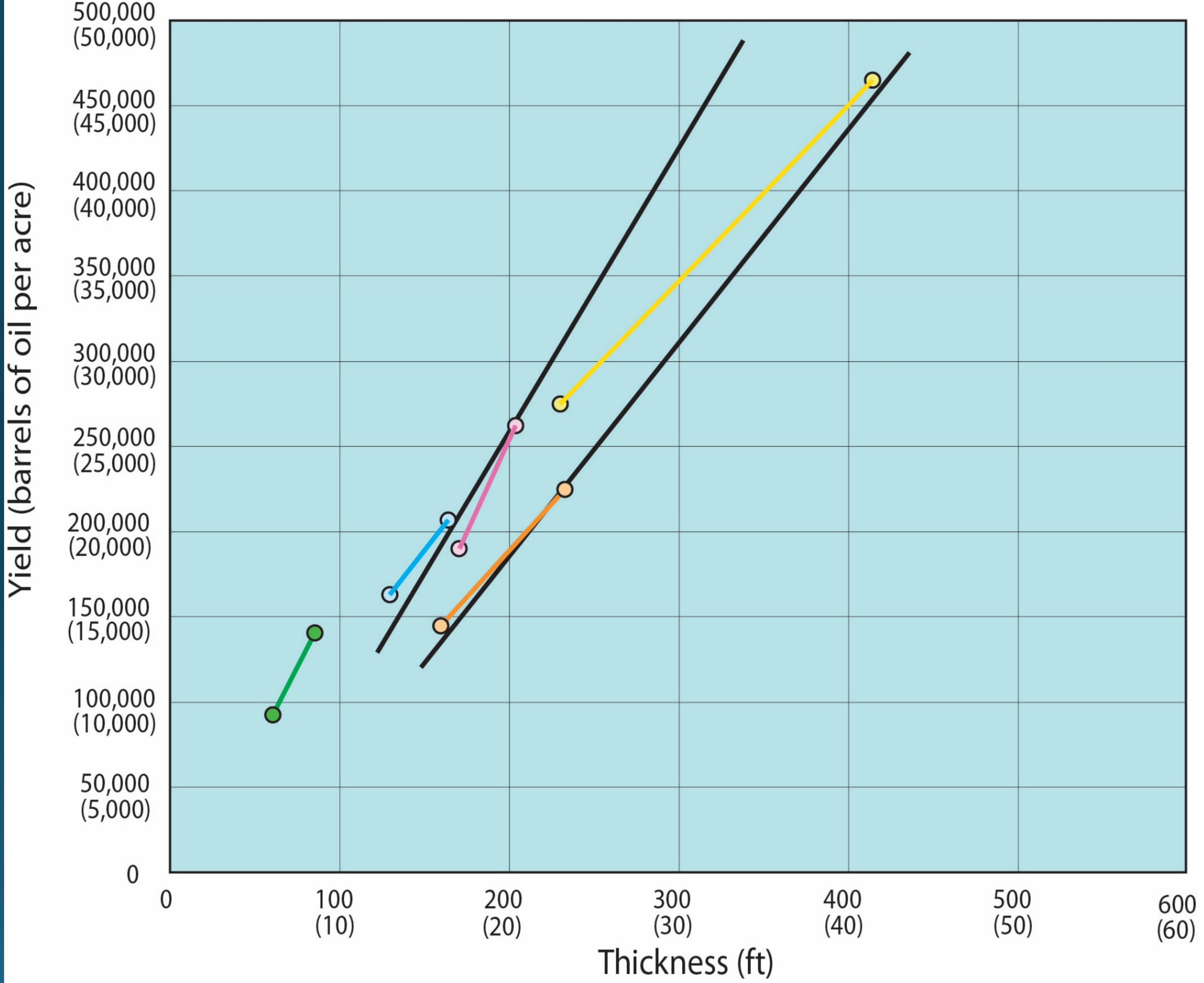
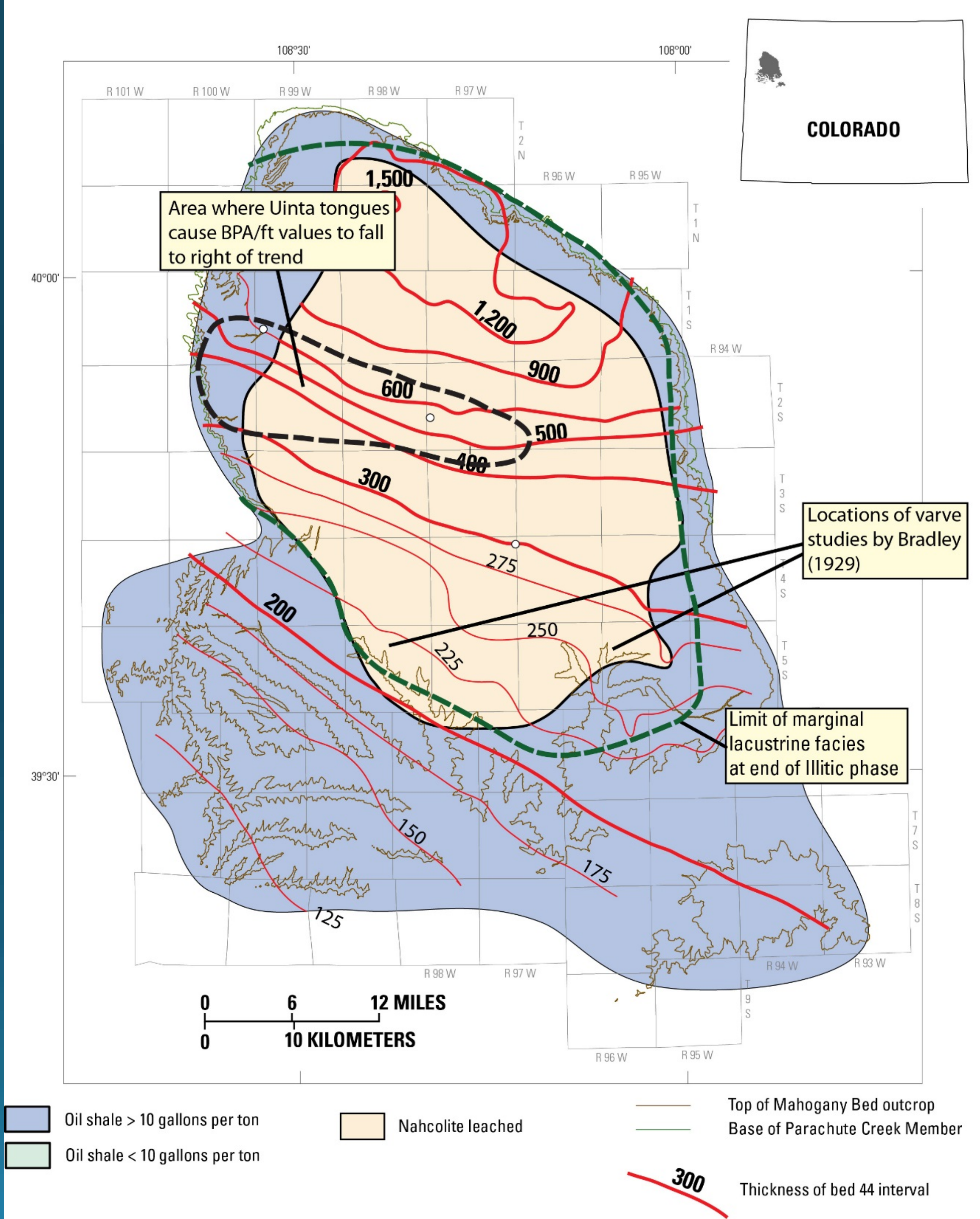
Thickness vs BPA trends for the five intervals in the two coreholes. Note the two scales for BPA and thickness one for the total bed 44 interval and the other for the subdivisions within the overall interval. Colors for each zone are same as previous slide

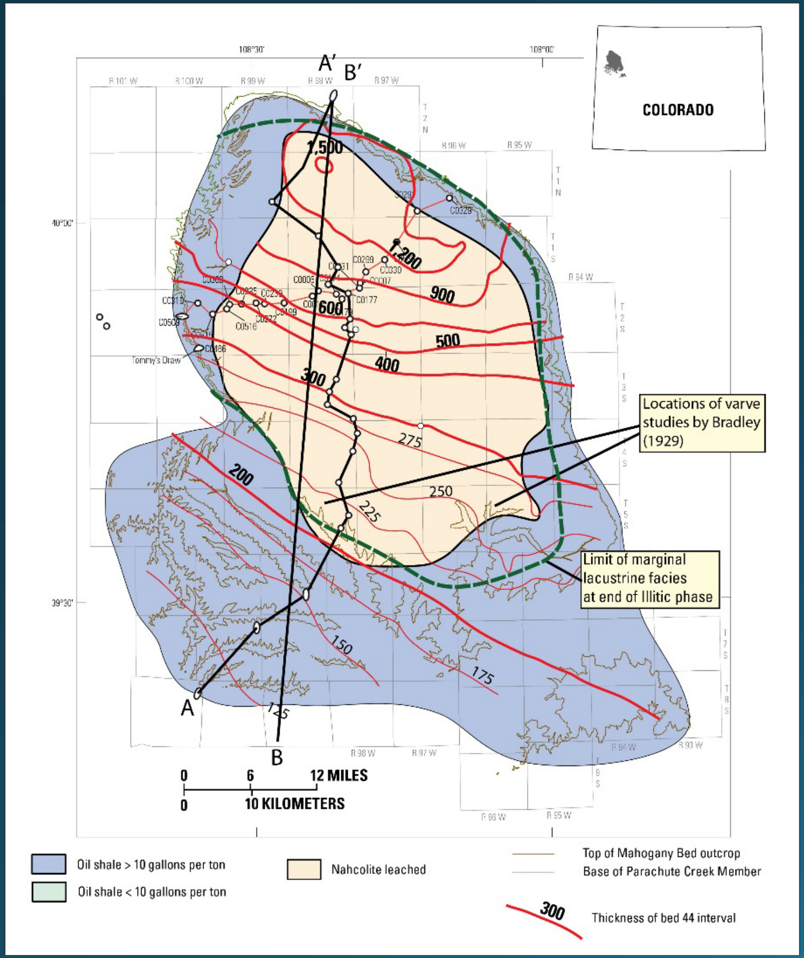
Four of the five subdivisions fall within or close to the trend for the entire bed 44 interval.

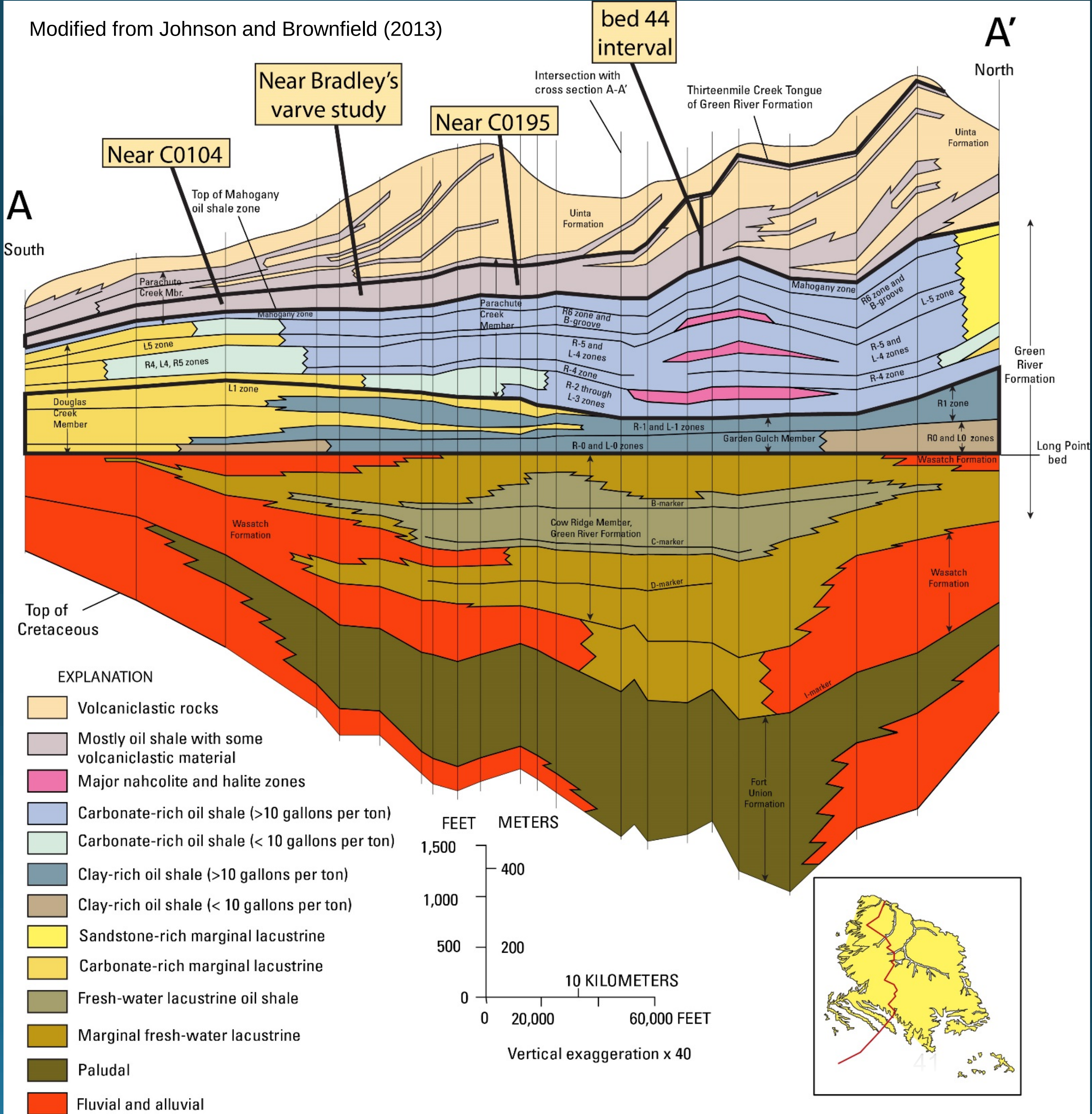


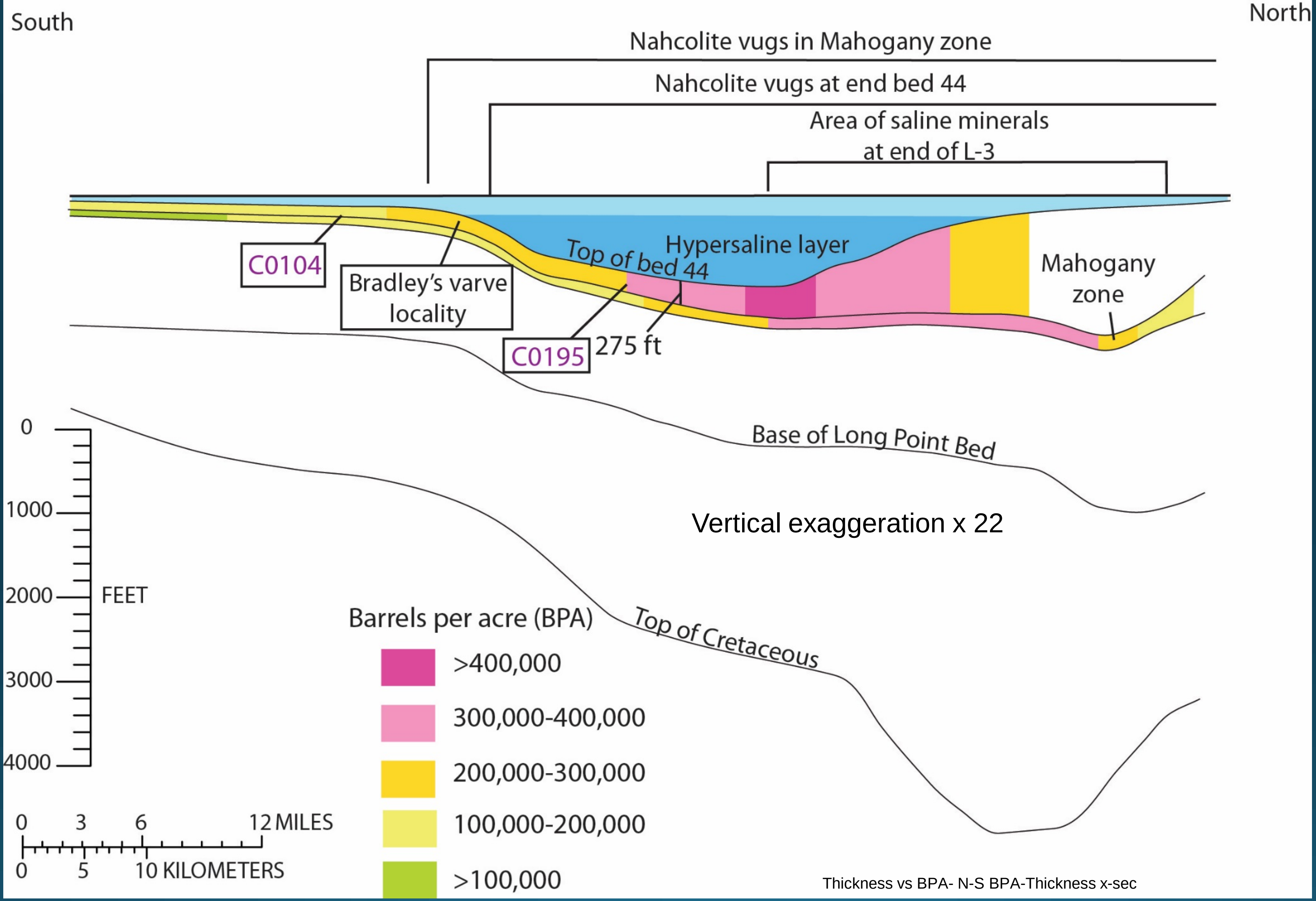
Tongues of volcaniclastic Uinta Formation are present in the bed 44 interval in the outlined area causing the BPA/ft values to shift to the right of the trend. Uinta tongues are present north of the outlined area as well, but Fischer assay of the bed 44 interval is incomplete there.



This published cross section is hung on the Long Point Bed. Next we will present a similar cross section that attempts to reconstruct the topography of Lake Uinta at the end of the bed 44 interval.







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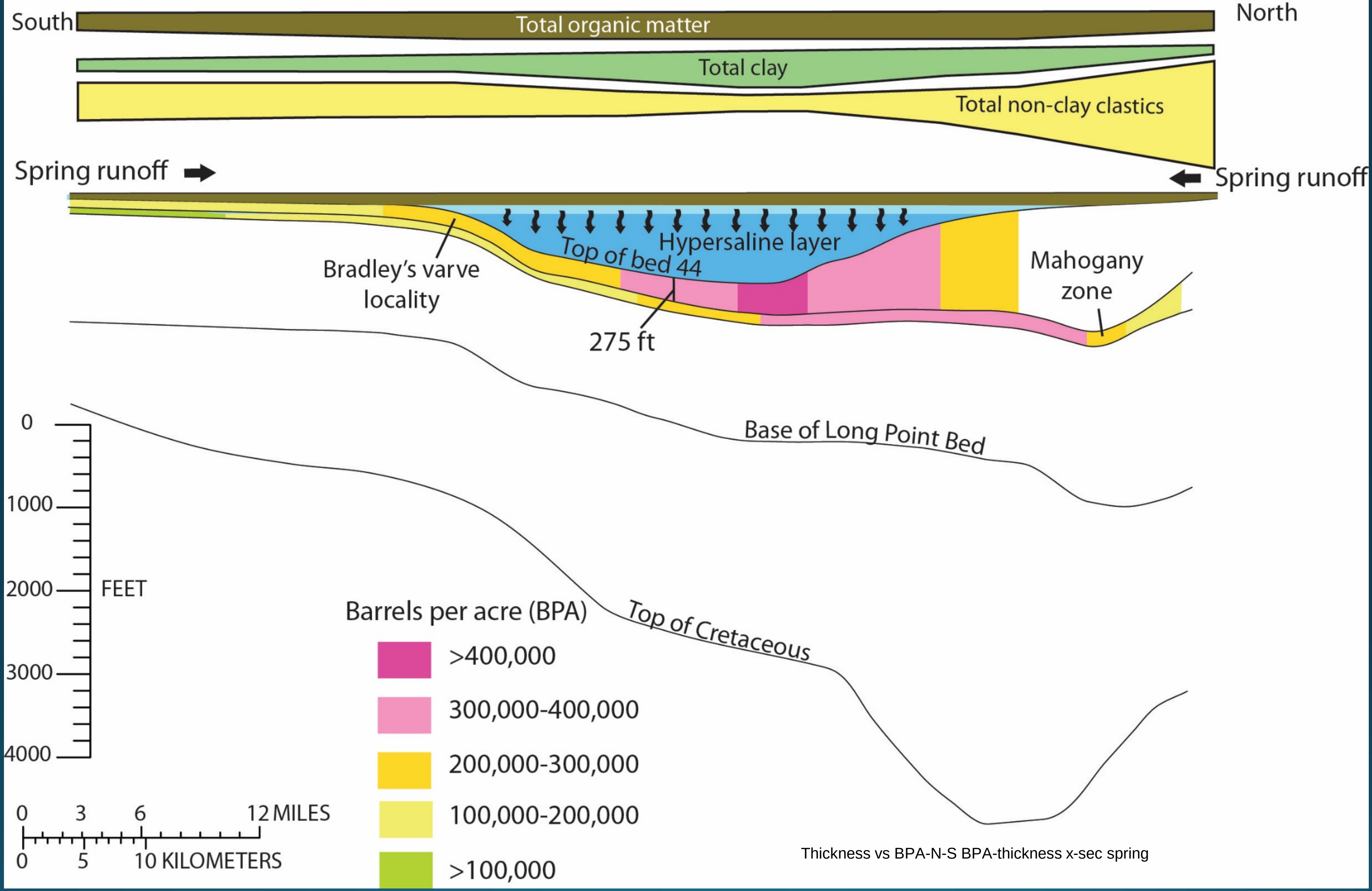
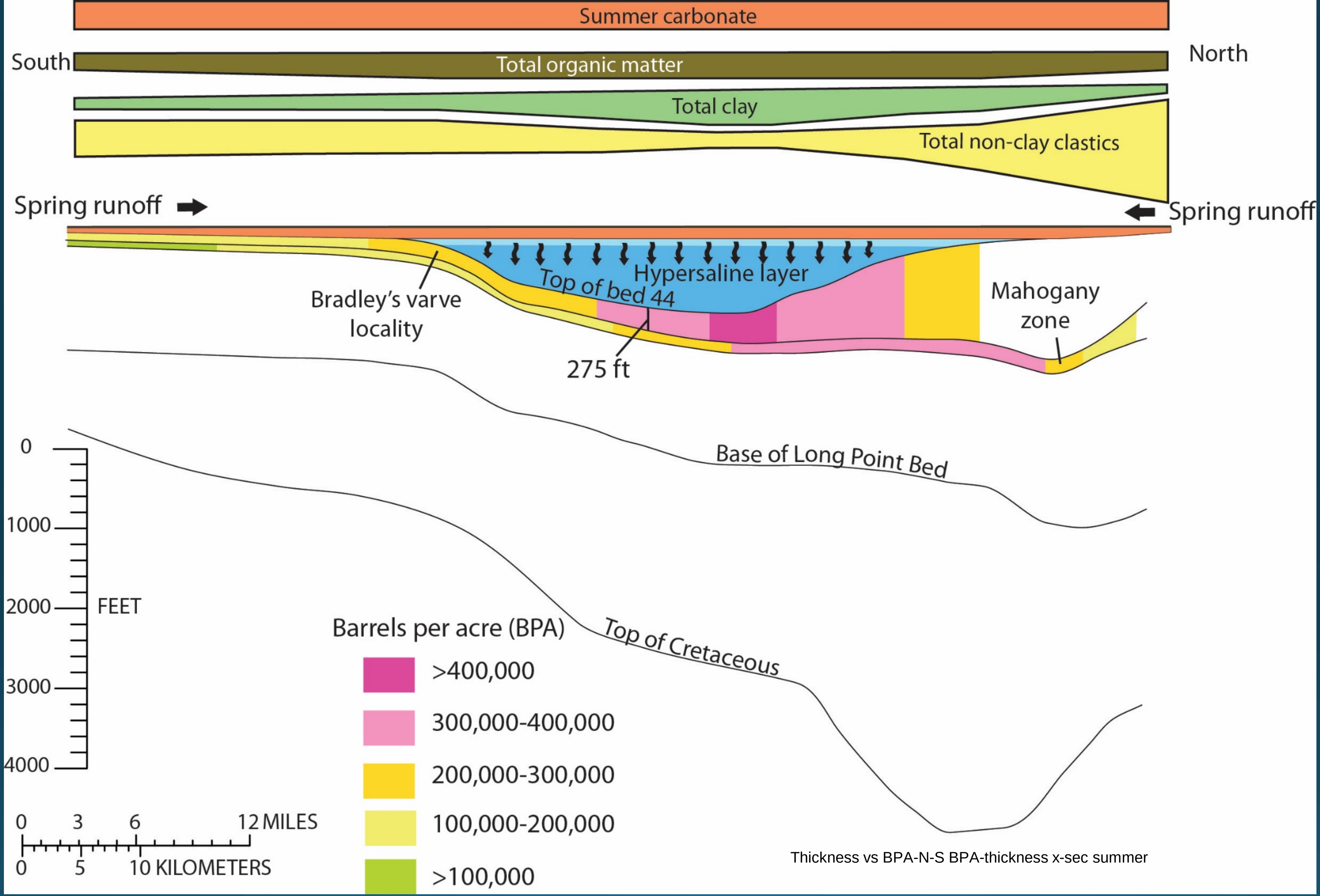
End of bed 44 showing: (1) barrels per acre, (2) hypersaline and upper less saline layers, (3) areas of saline mineral deposition for various time periods, and (4) hypothesized lake bottom topography. The hypersaline lower layer is shown to extend as far margin-ward as nahcolite vugs in the bed 44 interval.



During spring floods, muddy water entered the lake and was circulated in the upper less saline layer across the entire extent of the lake. Clay particles picked up organic matter in the water column and fell to the bottom of the lake. Total clay and total preserved organic matter increased toward the center of the lake.



During the summer, carbonate precipitated out of the water column uniformly (?) across the lake and drops to the bottom.

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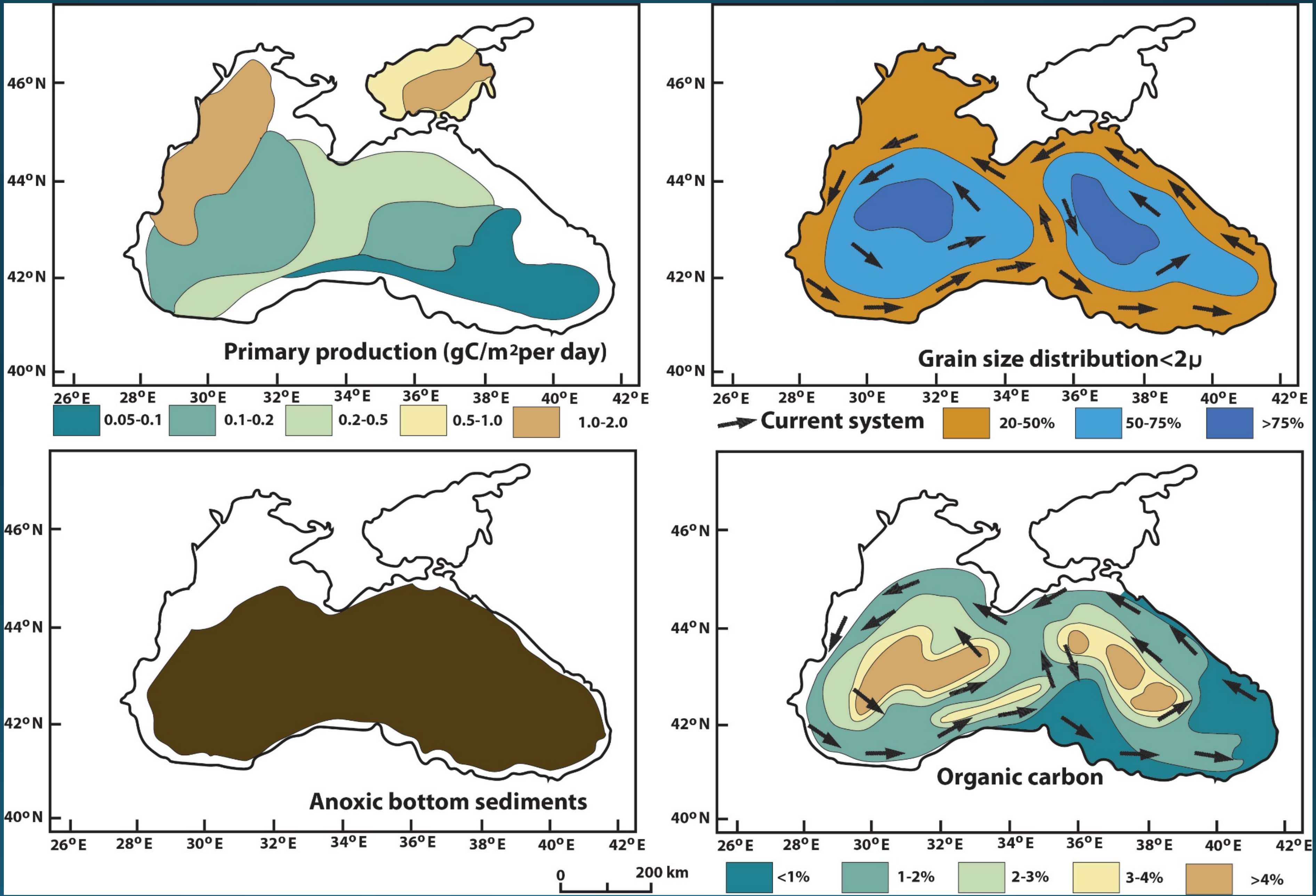
In the Black Sea, surface currents are highly variable, but in the deepwater areas, isolated cyclonic currents and the morphology of the basin control the distribution of sediments and organic matter (Shimkus and Trimonis (1974)



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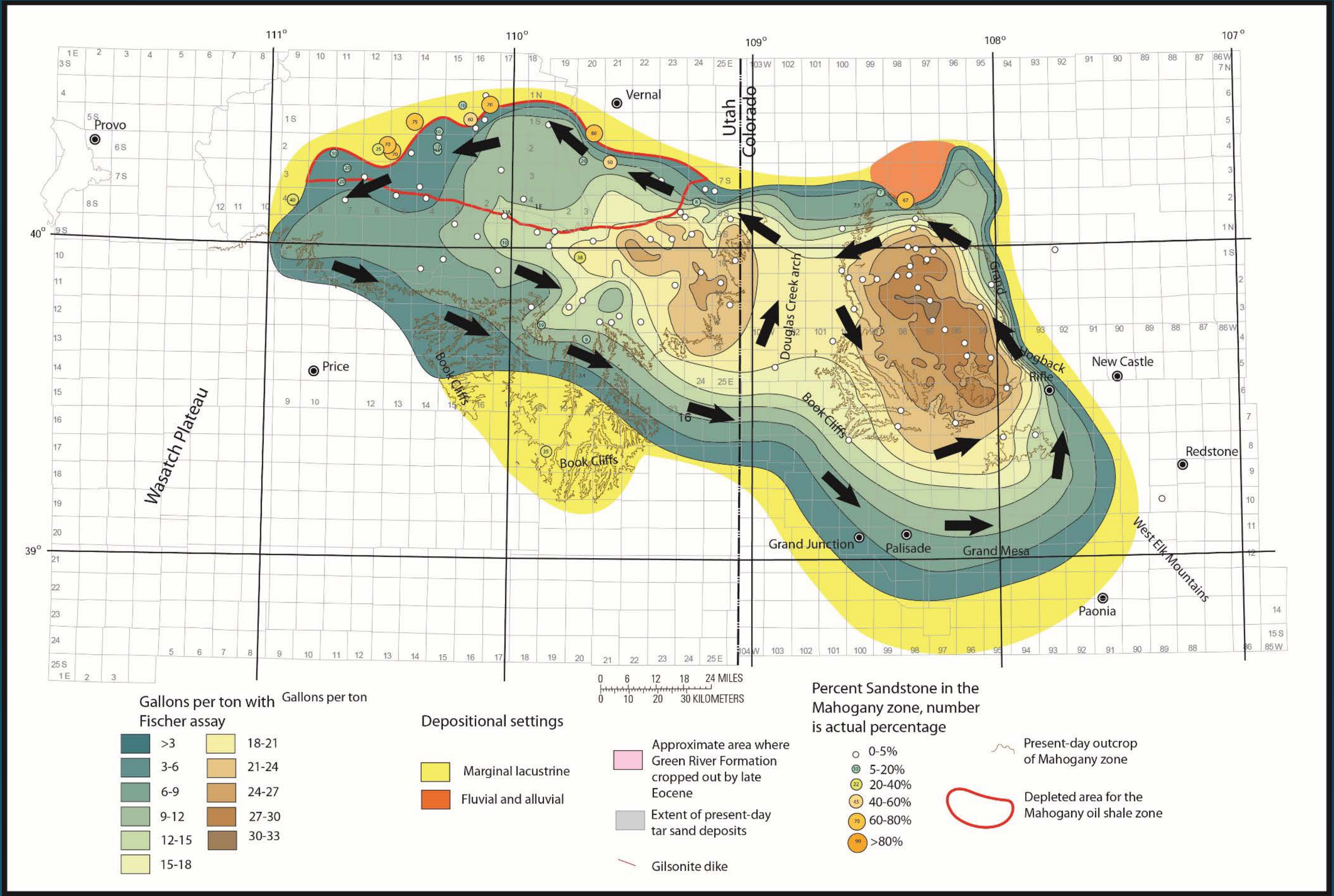
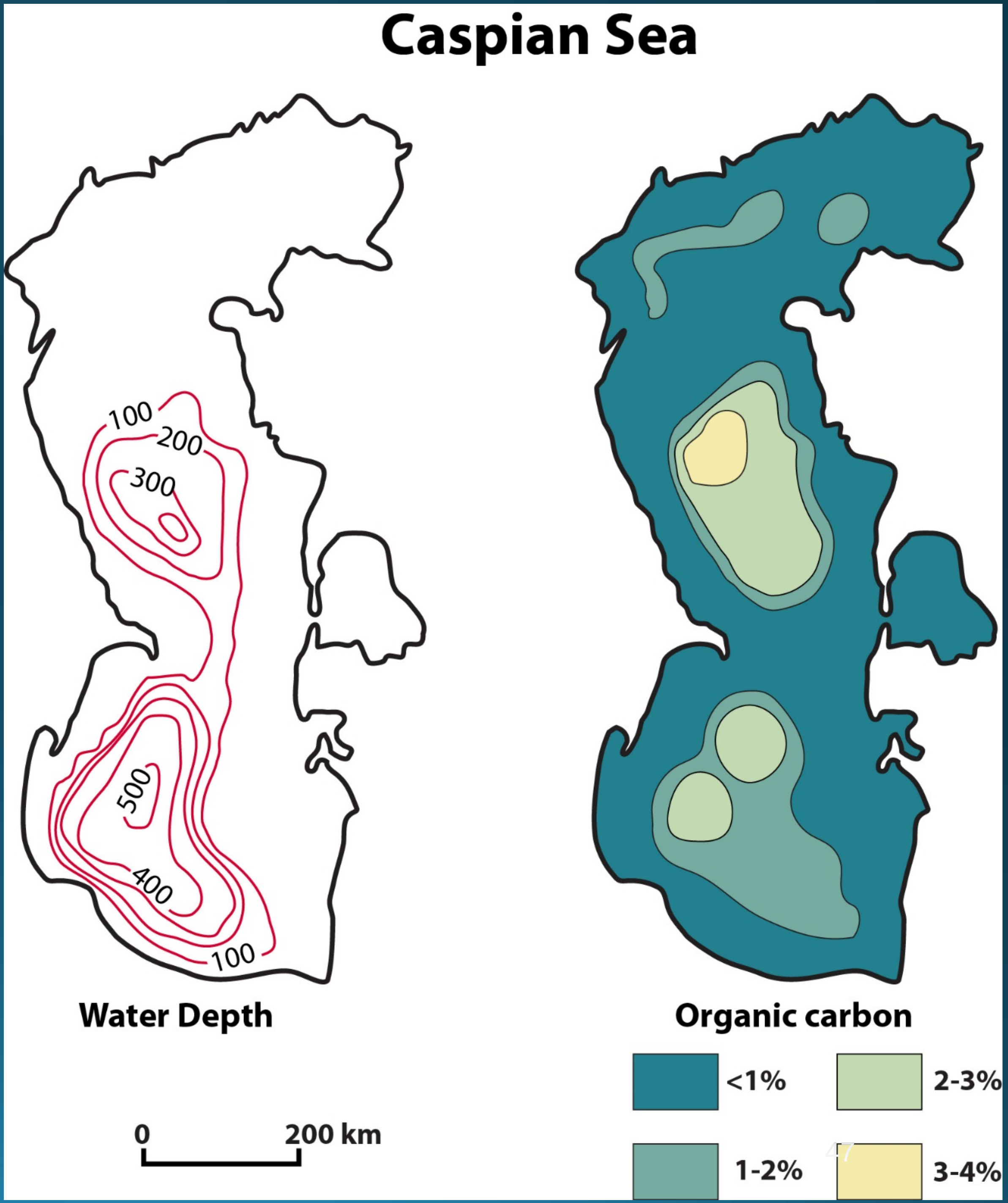
We propose that similar cyclonic currents with the Douglas Creek arch acting as a shallow sill could explain the distribution of organic matter in Lake Uinta.

Much of the organic matter in the deep Uinta Basin, however, has generated and expelled hydrocarbons.



Total organic carbon in the Caspian Sea is closely related to water depth.

Total organic matter in Lake Uinta may also have been related to water depth. As currents homogenized organic matter and mineral matter in the water column, more of both would drop out of the water column where the water is deepest.



Modified from Pakhomova, 1969

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CONCLUSIONS

- We propose that in Lake Uinta most of the organic matter deposited in laminated intervals was captured by clay particles brought into the lake during spring floods with the organic-rich clay particles subsequently settling through the lower an denser highly alkaline, hypersaline layer to the bottom of the lake.
- Slow deep circulation similar to that found in present day inland seas such as the Black Sea might explain the distribution of organic matter in Lake Uinta with the percentage of clay and organic matter increasing toward the deepest parts of the lake.

Thank You

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- Mineral occurrence maps were generated using recently released USGS data release:

  Map generated using “Mineral Occurrence data for the Eocene Green River Formation in the Piceance and Uinta Basins”, https://doi.org/10.5066/F7XP7334

- The database includes 9443 analyses from 30 cores in the Piceance Basin and 1200 samples from 14 cores in the Uinta Basin. We did not try to quantify mineral percentages.

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