Mass-Movement Deposits in the Lacustrine Eocene Green River Formation, Piceance Basin, Western Colorado*

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Abstract

Mass-movement deposits interbedded with laminated sediments are common in lacustrine strata of the Eocene Green River Formation, Piceance Basin, western Colorado, comprising the majority of some stratigraphic intervals. Lake Uinta, a saline lake, formed when much smaller freshwater lakes expanded across surrounding alluvial plains. Mass-movement deposits were rare early in the history of Lake Uinta, but increased in abundance as marginal shelves prograded into the newly expanded lake. Mass-movement deposits accumulated near the base of these expanding shelves. Total organic matter increases in areas where mass-movement deposits accumulated, suggesting that organic matter from marginal areas was entrained along with mineral matter. In addition, intervals that include abundant mass-movement deposits generally contain a higher concentration of organic matter that laminated intervals. Saline Lake Uinta frequently transgressed and regressed across the marginal shelves as water supply varied, providing opportunities to erode and transport mineral matter and organic matter toward the center of the lake. In the central part of the lake, mass-movement deposits consist of massive organic-rich beds that typically contain clasts or “blebs” of mineral matter. Lake Uinta expanded later in its history, and deepwater conditions prevailed over much of the marginal shelves. Mass-movement deposits became rare during this period, and laminated oil shale was deposited over most of the lake. Mass-movement deposits again became common during the infilling stage of Lake Uinta as volcaniclastic sediments progressively filled in the lake from the north.

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The Eocene Green River Formation was deposited in two large Eocene saline lakes, Lake Uinta in the Uinta and Piceance Basins and Lake Gosiute in the Greater Green River Basin.

Here we will discuss mass-movement deposits in just the Piceance Basin part of Lake Uinta.

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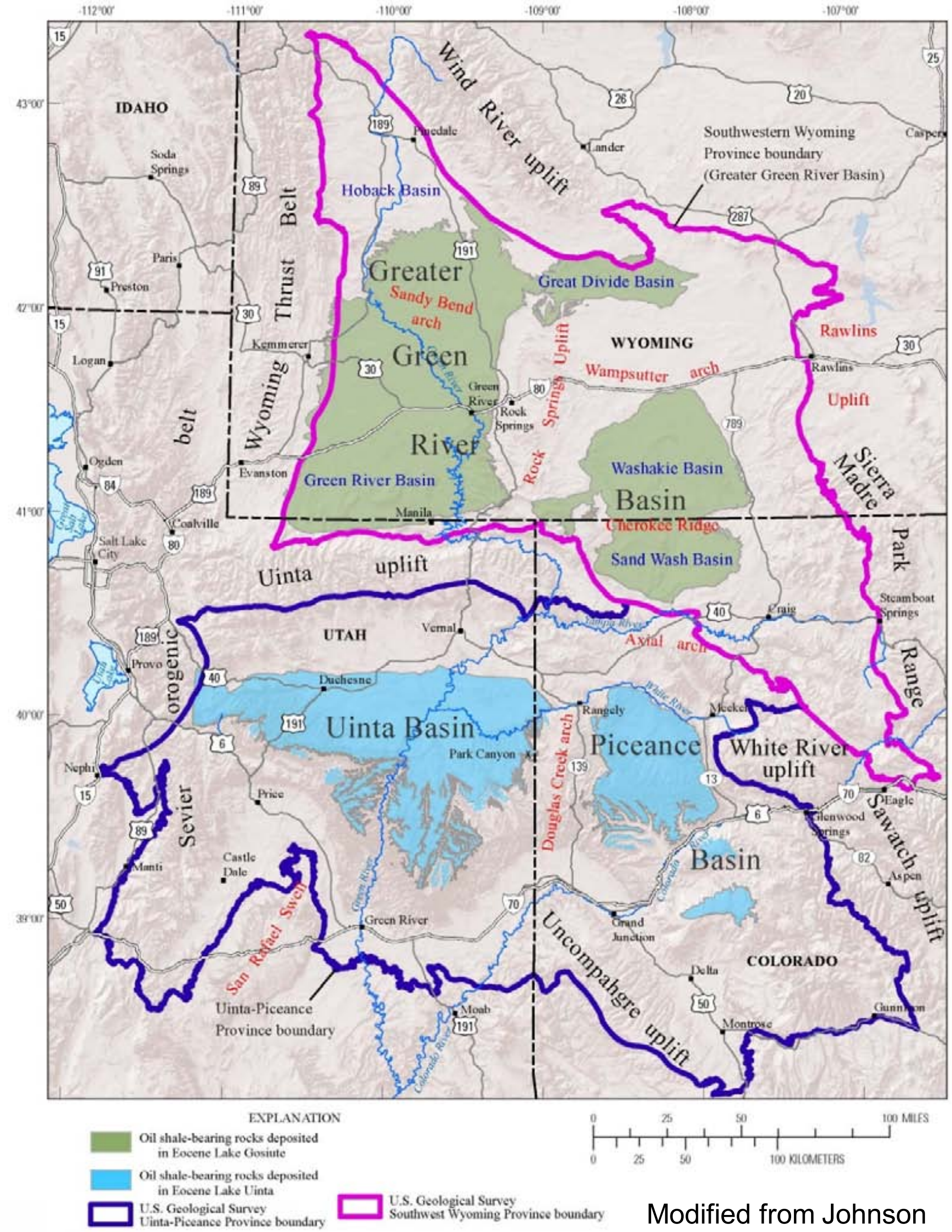

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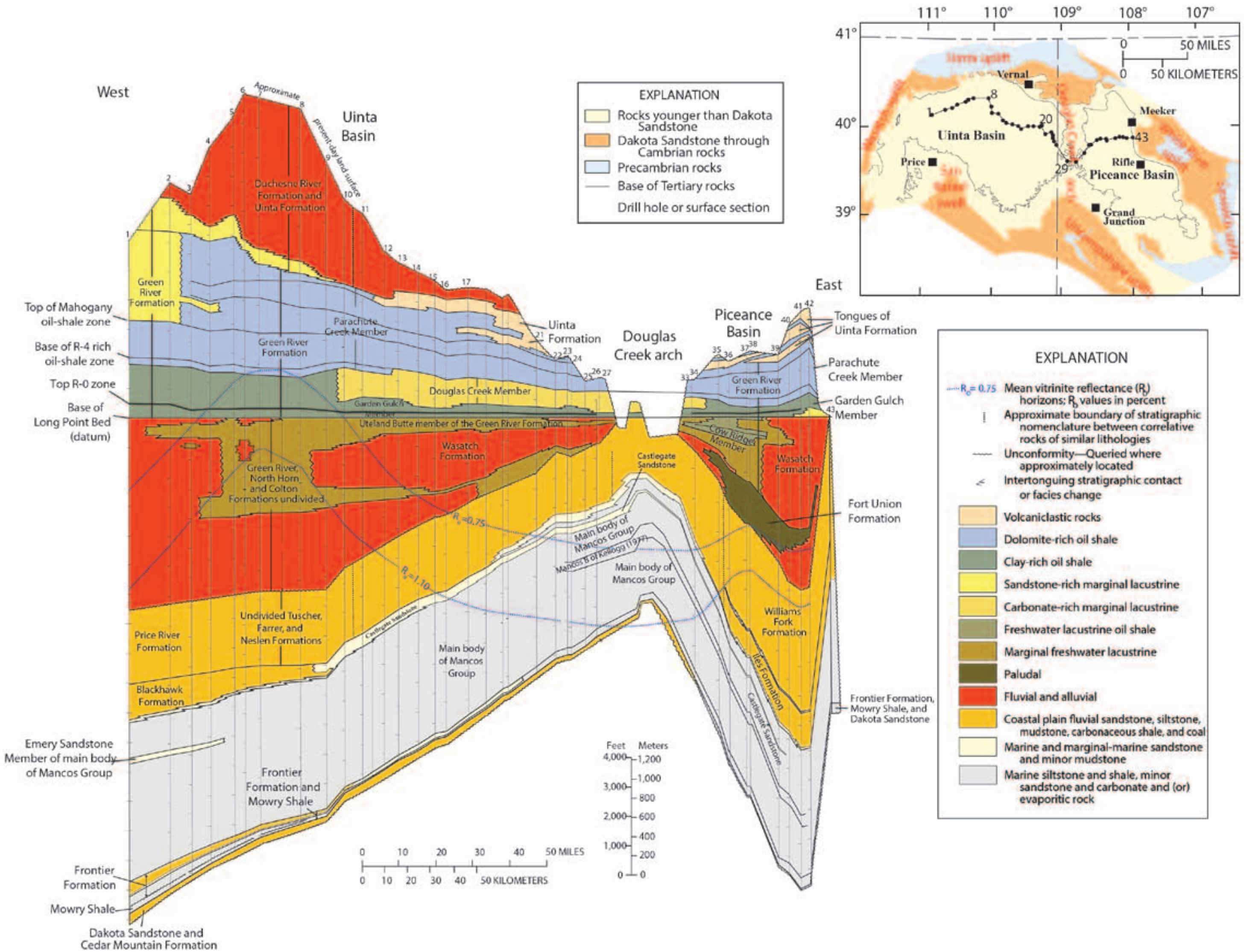

West-east cross section across the Uinta and Piceance Basins and the Douglas Creek arch. The arch acted as a hinge-line between the two subsiding basins. Little sediment was deposited on the crest of the arch prior to the development of saline Lake Uinta.

In a depositional sense, there are generally two types of oil shale in the Piceance Basin

Most people associate the Green River Formation with well-laminated oil shale shown here, largely because it is the dominant type of oil shale where the Green River Formation crops out around the basin margins.

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.

But another type of oil shale, generally referred to as “blebby oil shale,” appears to have been deposited by mass-movement processes.

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Bradley (1931, p. 28) noted the occurrence of “shale breccias” or oil shales that “contain as inclusions many comparatively large angular fragments or flakes of more or less similar rock, which are clearly derived from the breaking up of a bed elsewhere.”

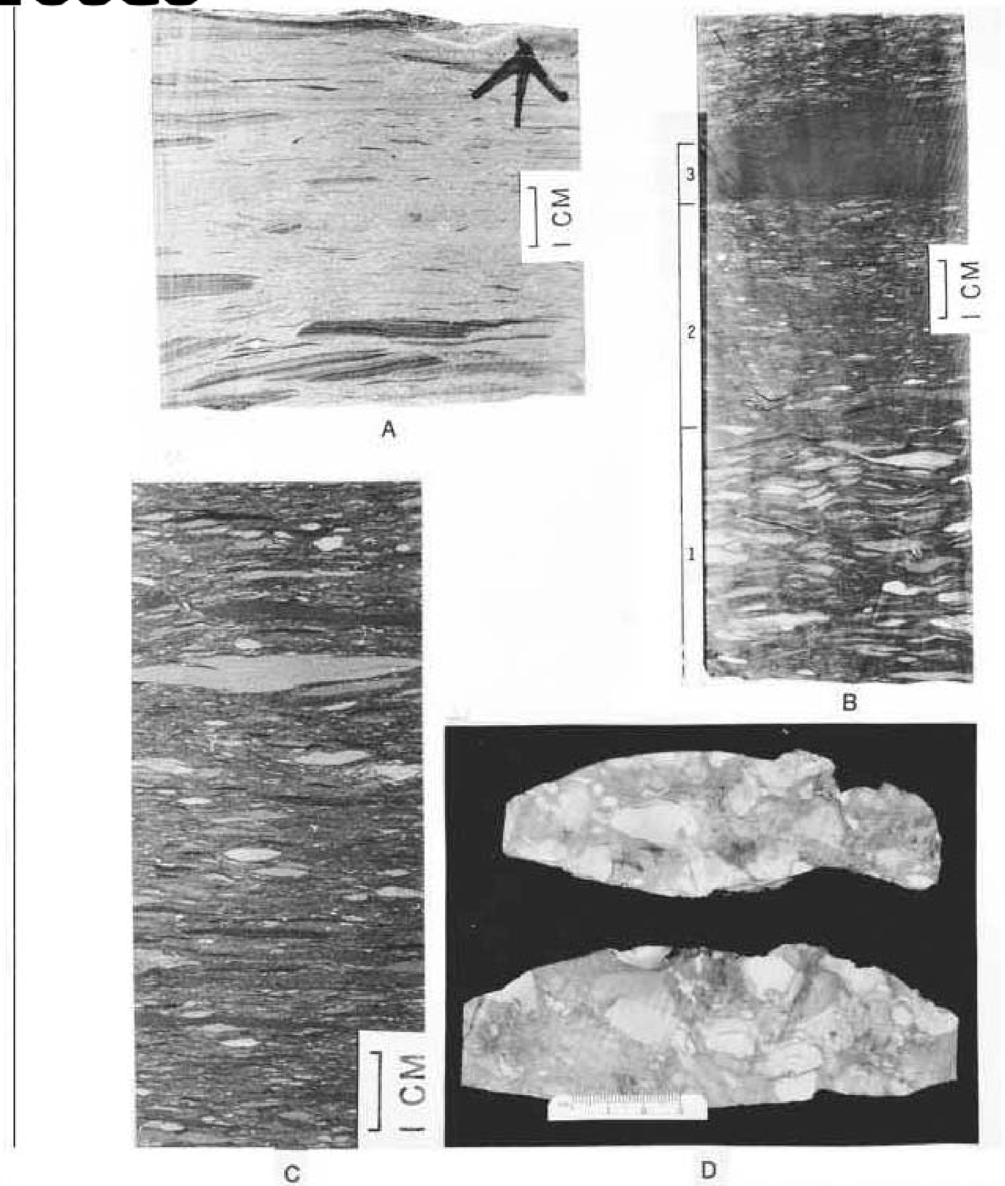
Middle of the R-6 zone in the southwest part of the basin (Sec. 22, T. 5 S., R. 99 W., field location 80-112)

Bradley (1931) also noted that the boundaries of the fragments, some laminated, were commonly sharply defined indicating that they were lithified prior to being exhumed and incorporated into the breccias.

Dyni (1981) and Dyni and Hawkins (1981) studied these mass-movement deposits in core from the central part of the basin and attributed some of them to deep-water turbidity currents.

Dyni (1981) and Dyni and Hawkins (1981) estimated 40–50 percent of the lower part of the Parachute Creek Member in the central part of the basin consisted of “blebby oil shale.”

Note the grading in the blebby oil shale bed in the upper right, from abundant large marlstone fragments at the base to kerogen in a very fine-grained matrix at the top.



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

Tanavsuu-Milkeviciene and Sarg (2012) studied the distribution of lacustrine facies in the Piceance Basin, and like Dyni (1981) and Dyni and Hawkins (1981), they found an increase in oil shale that was affected by mass-movement processes toward the central part of the basin.

Here we attempt to build on the excellent work of these previous authors by placing mass-movement deposits into a detailed spatial and temporal framework

Data sources

- Photos from nine coreholes that are housed at the U.S. Geological Survey Core Research Facility in Lakewood, Colorado, were examined for bedding features. The photos are available online at the Core Facility's Web Site.
- Outcrop sections were measured and described by the authors. All of the sections have been published, but thickness of individual beds were not reported. Thickness values were obtained from the original descriptions in field notebooks.

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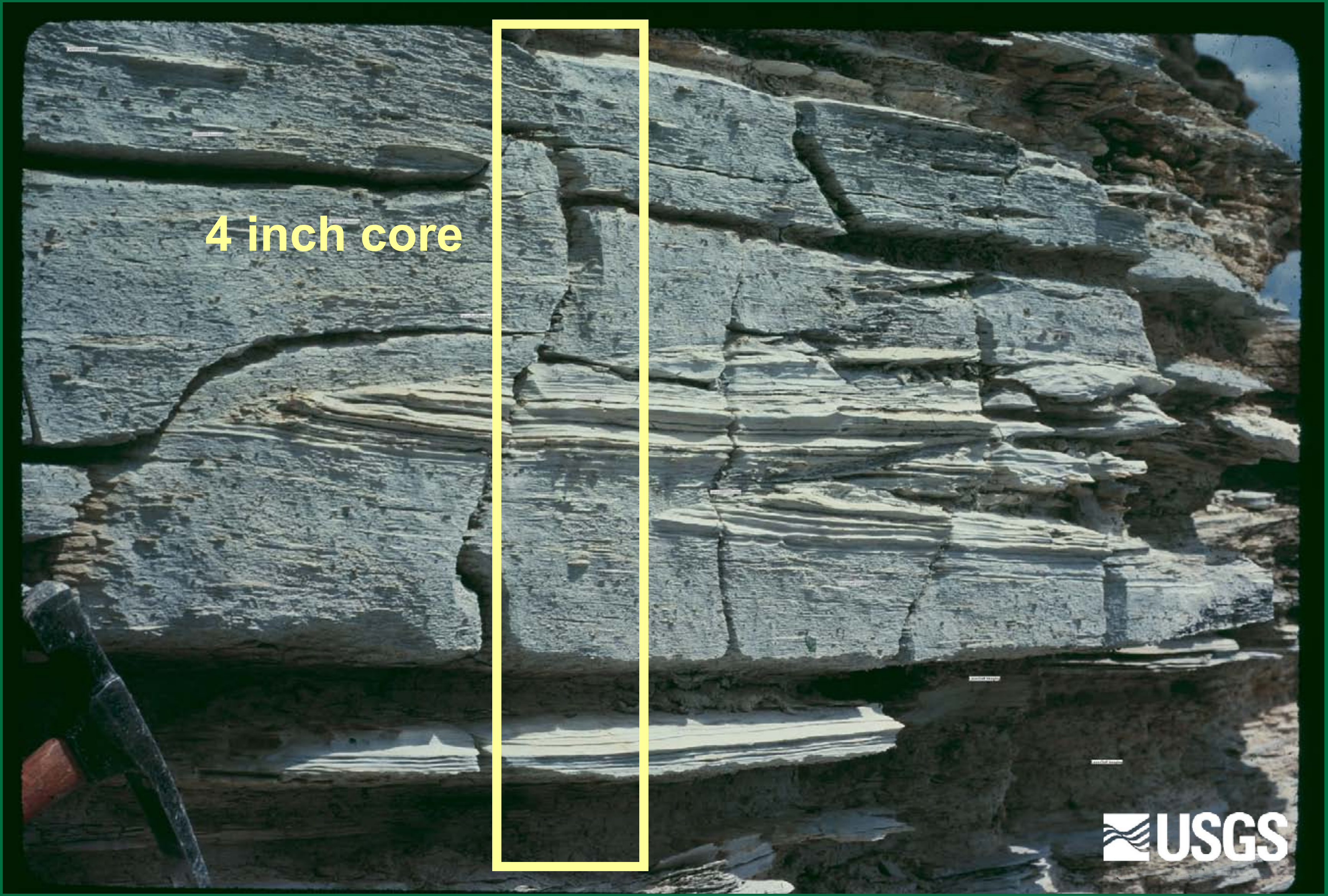
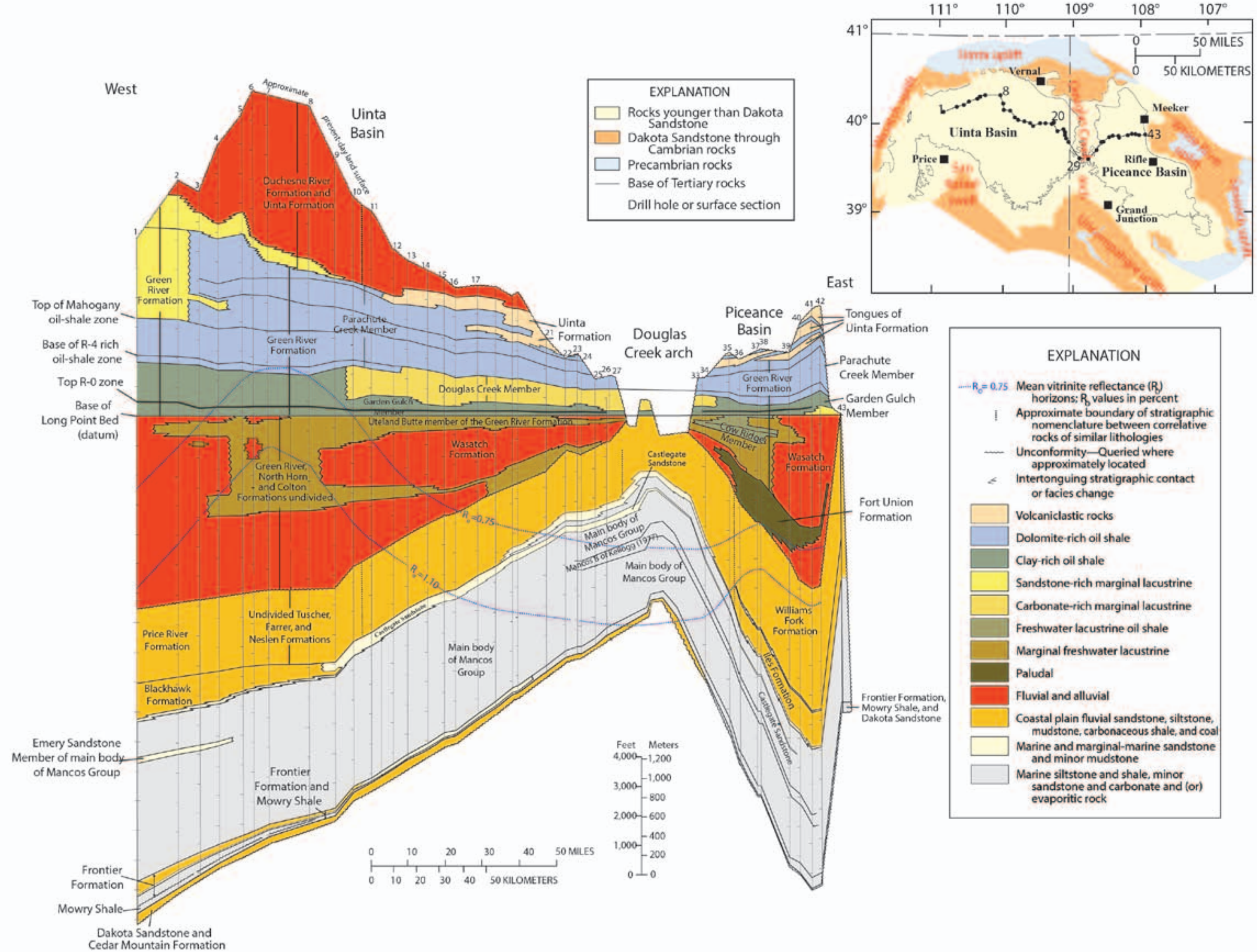
81-36 Tommys Draw Section, 2256' Mahogany zone

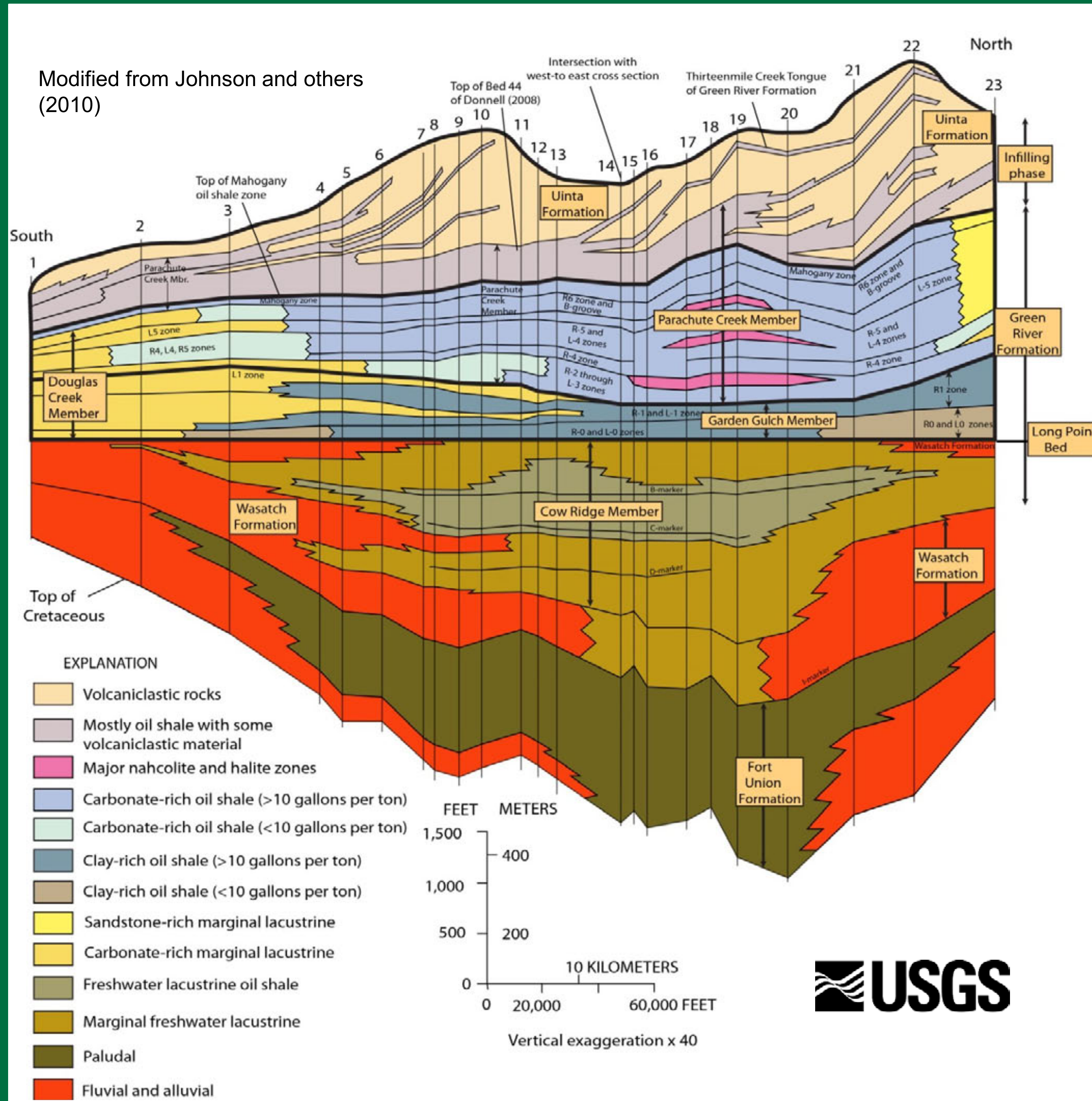


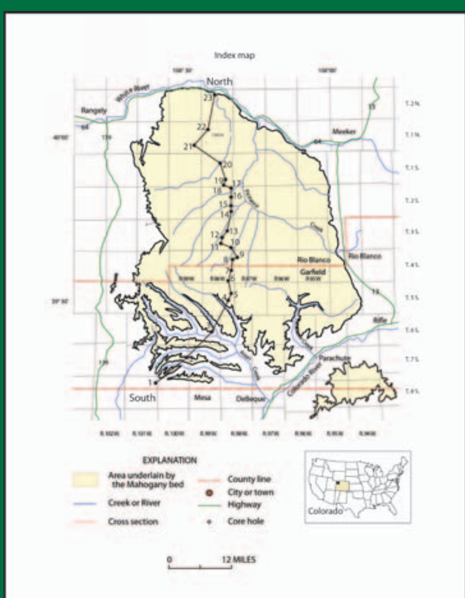
Mass-movement deposits commonly incorporated large blocks of laminated oil shale that appear to have been largely lithified prior to re-deposition. These blocks can look like laminated intervals in core.



West-east cross section across the Uinta and Piceance Basins and the Douglas Creek arch.

Lake Uinta began as a freshwater lake (Cow Ridge Member), became increasing saline during the illitic phase (Garden Gulch Member), finally becoming a carbonate- and saline-mineral precipitating lake (Parachute Creek Member). Infilling with volcaniclastics began in the latter part of the carbonate phase (light purple).





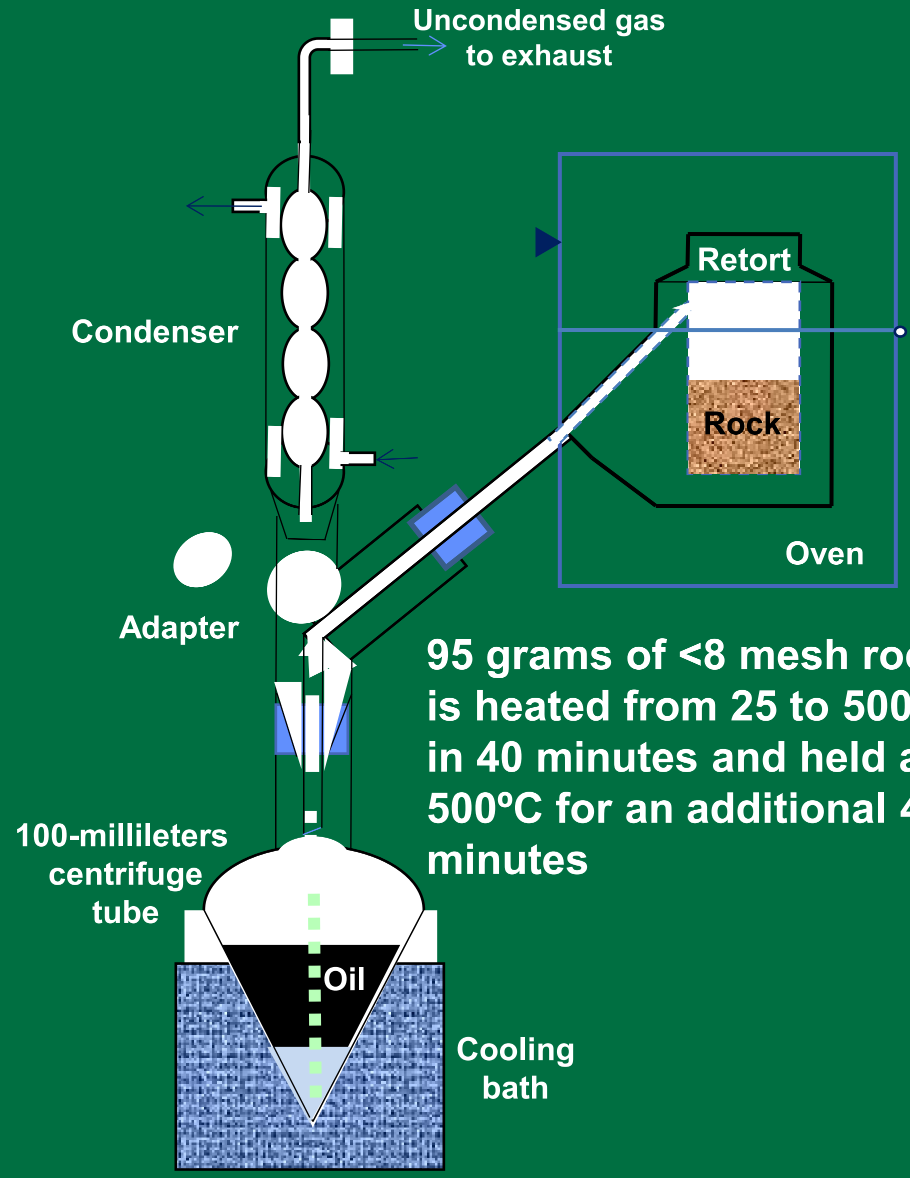
South to north cross section

Oil yields using the Fischer assay method are shown on the subsequent slides. Pictured is a Fischer assay retort.

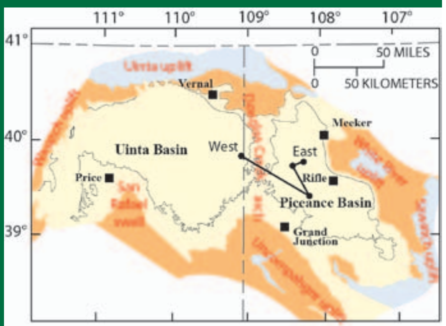
Products collected:
condensed oil
condensed water
spent rock

Reported values:
weight percent (wt%) oil
wt% water
wt% loss (gases)
oil density
coking tendency

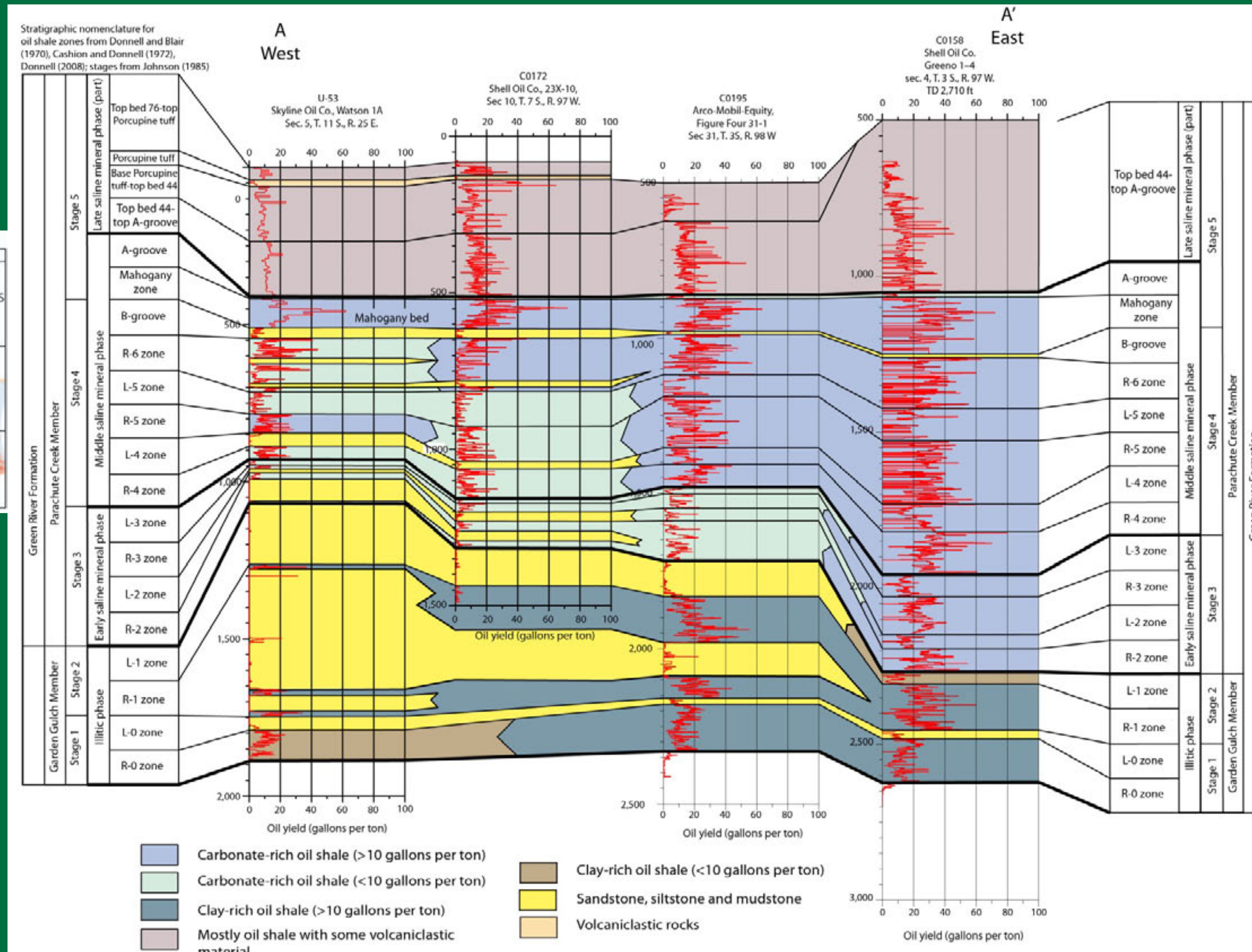
Wt% oil is converted to gallons per ton oil here.



95 grams of <8 mesh rock is heated from 25 to 500ºC in 40 minutes and held at 500ºC for an additional 40 minutes



Index map



Modified from Mercier and Johnson (2012)

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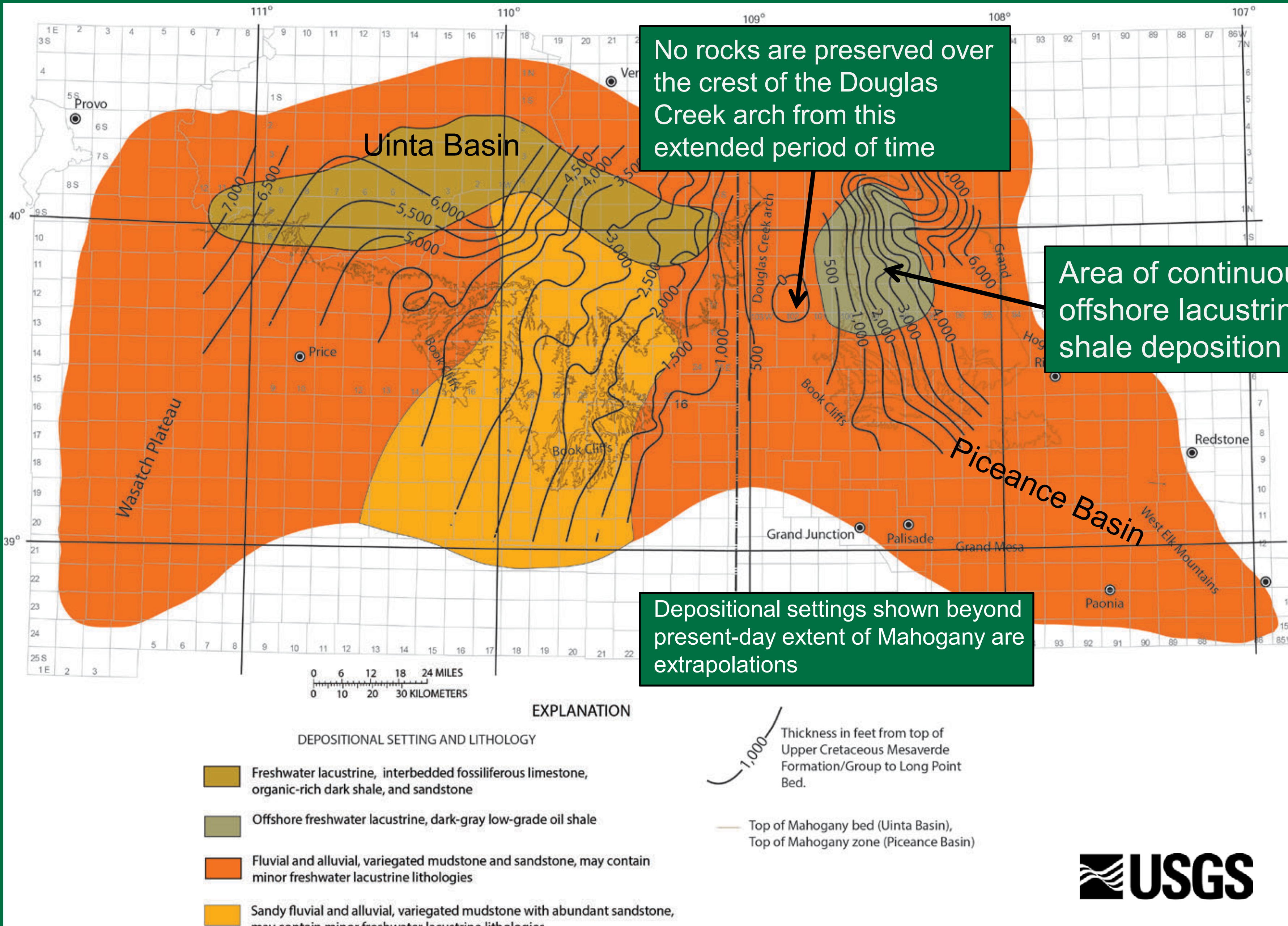
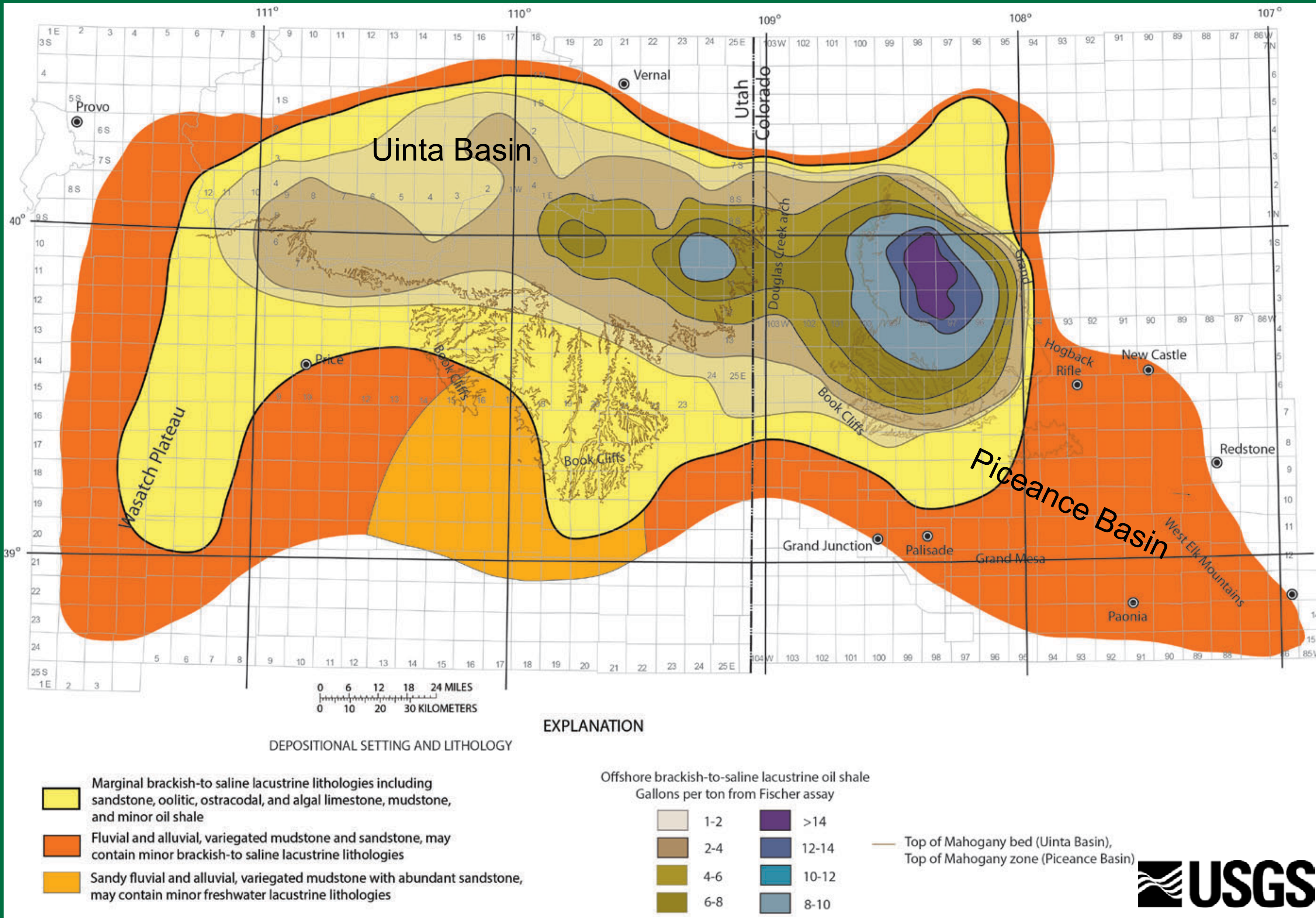
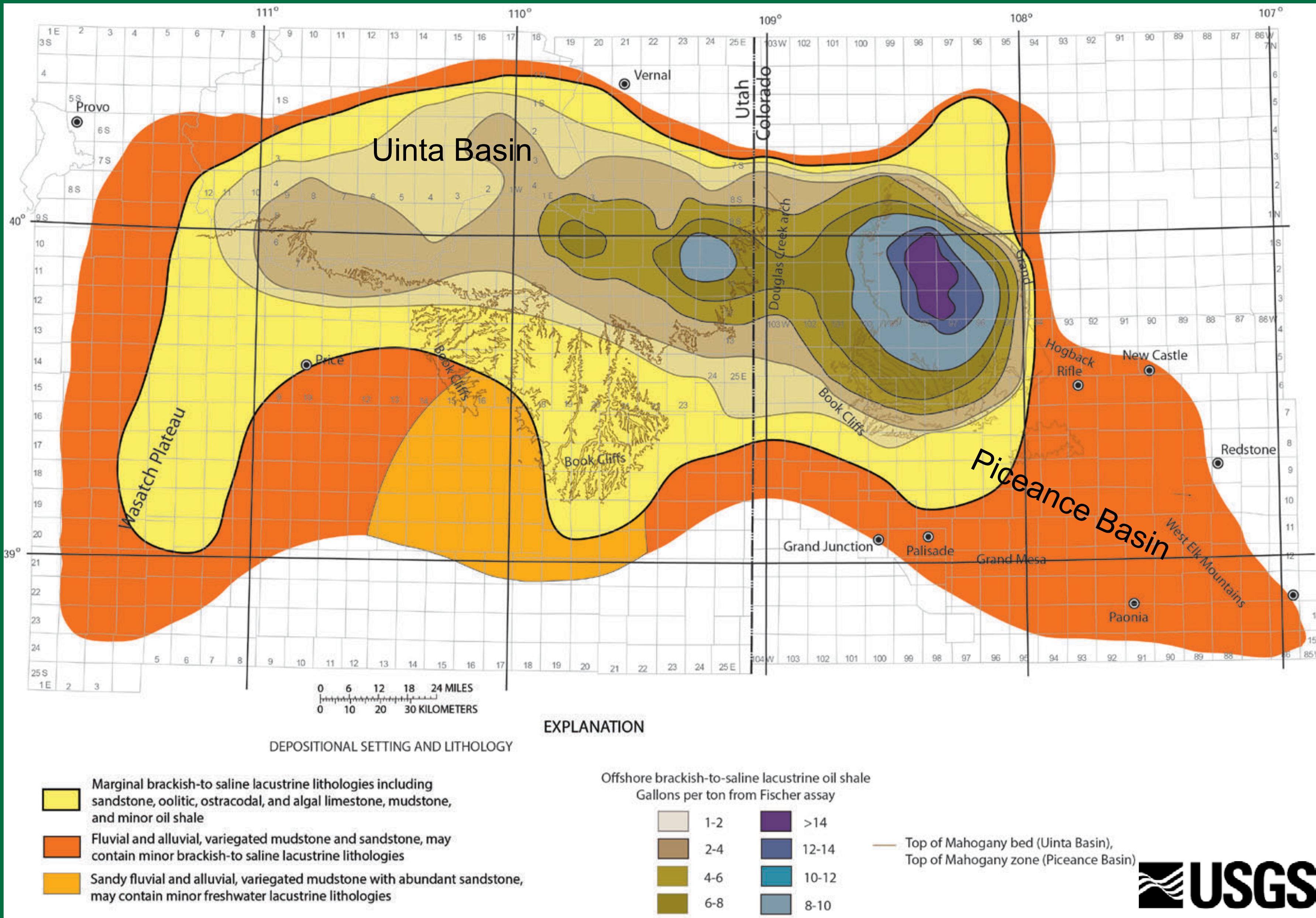
The Garden Gulch and Parachute Creek Members are subdivided into 16 recognized rich (R) and lean (L) oil-shale zones. Red graphs are gallons per ton oil using Fischer Assay. Maps showing percent of mass-movement deposits in each zone were constructed. The next slide is a paleogeographic map for the end of the preceding freshwater phase.



Extent of freshwater lakes just prior to the development of Lake Uinta. Isopach map is from the top of the Cretaceous to the top of the freshwater phase.



Lake Uinta formed as a result of a major transgression—the Long Point transgression. This map shows Lake Uinta during maximum transgression when low-grade oil shale was deposited over large parts of the Uinta and Piceance Basins. Oil yield in gallons per ton Fischer Assay is shown.



Subsequent slides progress through the development of the rich (R) and lean (L) oil shale zones in the Piceance Basin showing the distribution of mass-movement deposits.

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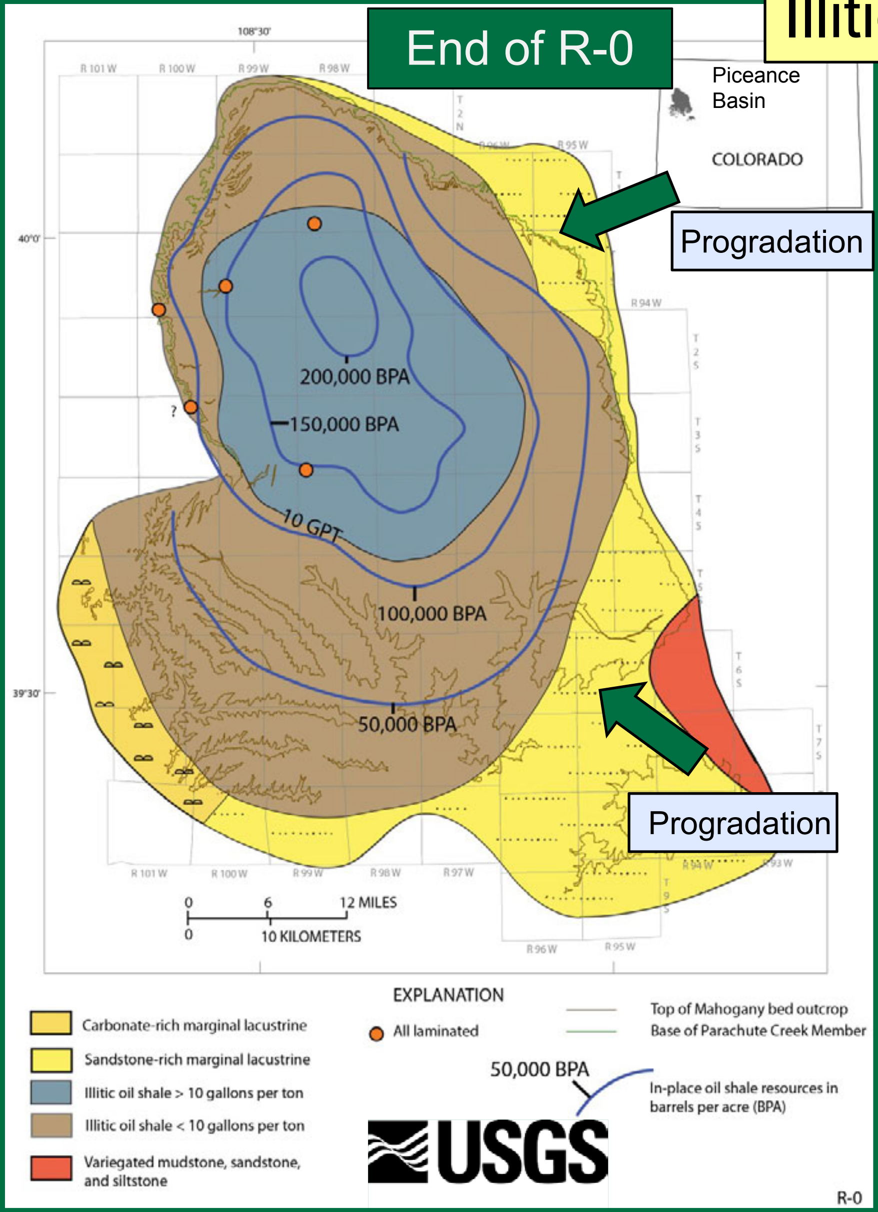
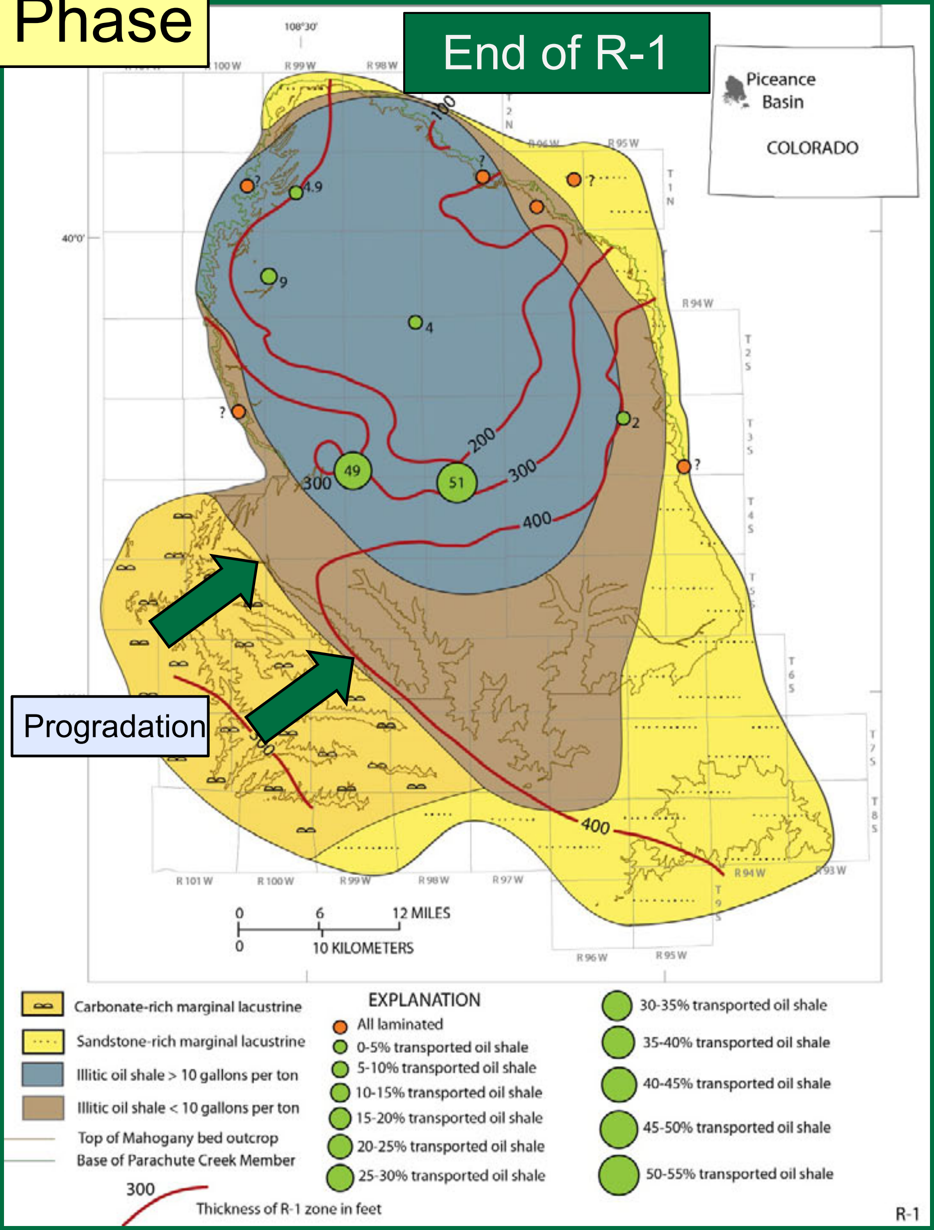
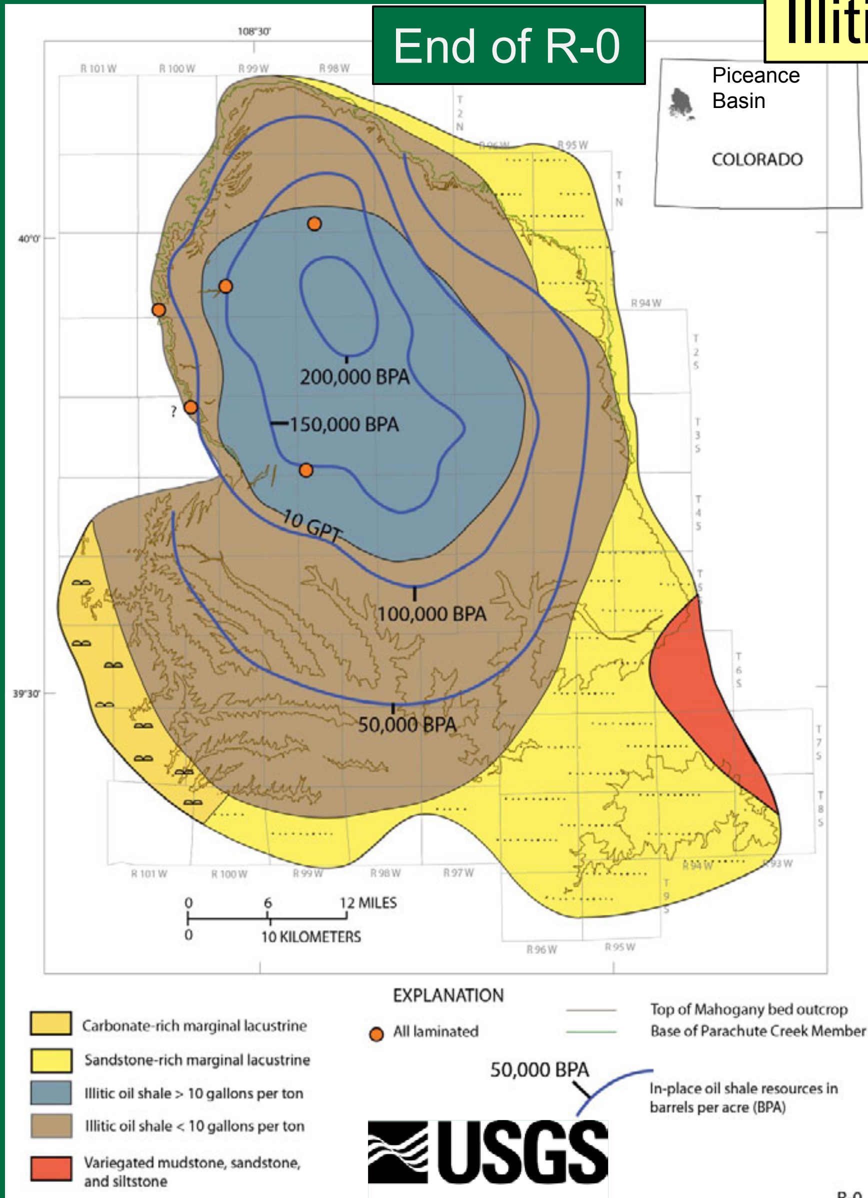
Illitic Phase

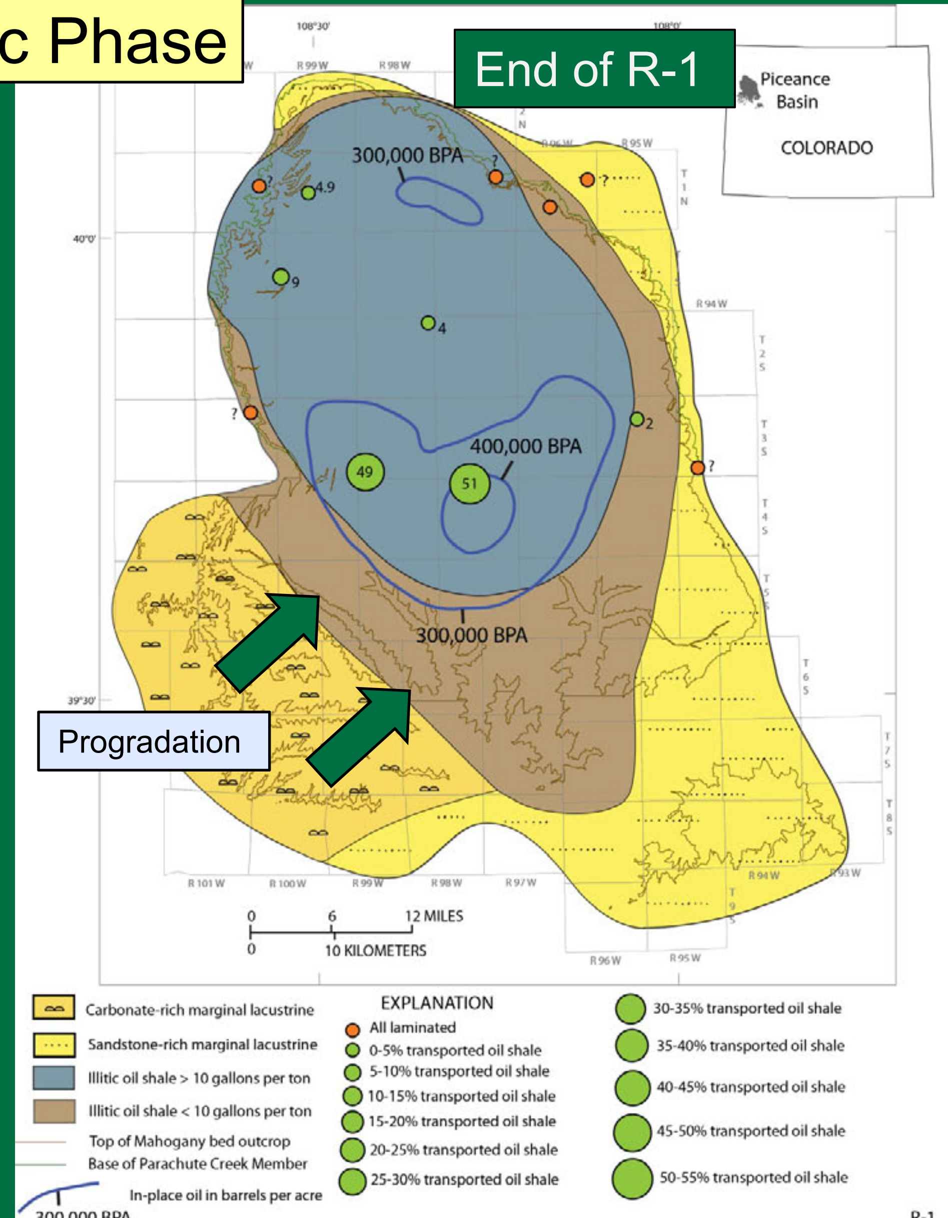




Marginal shelves prograded (green arrows) from the southeast and northeast during R-0 time and from the southwest during R-1 time. No mass-movement deposits were identified in the R-0 zone, whereas mass-movement deposits accumulated at the base of the expanding shelf during R-1 time.

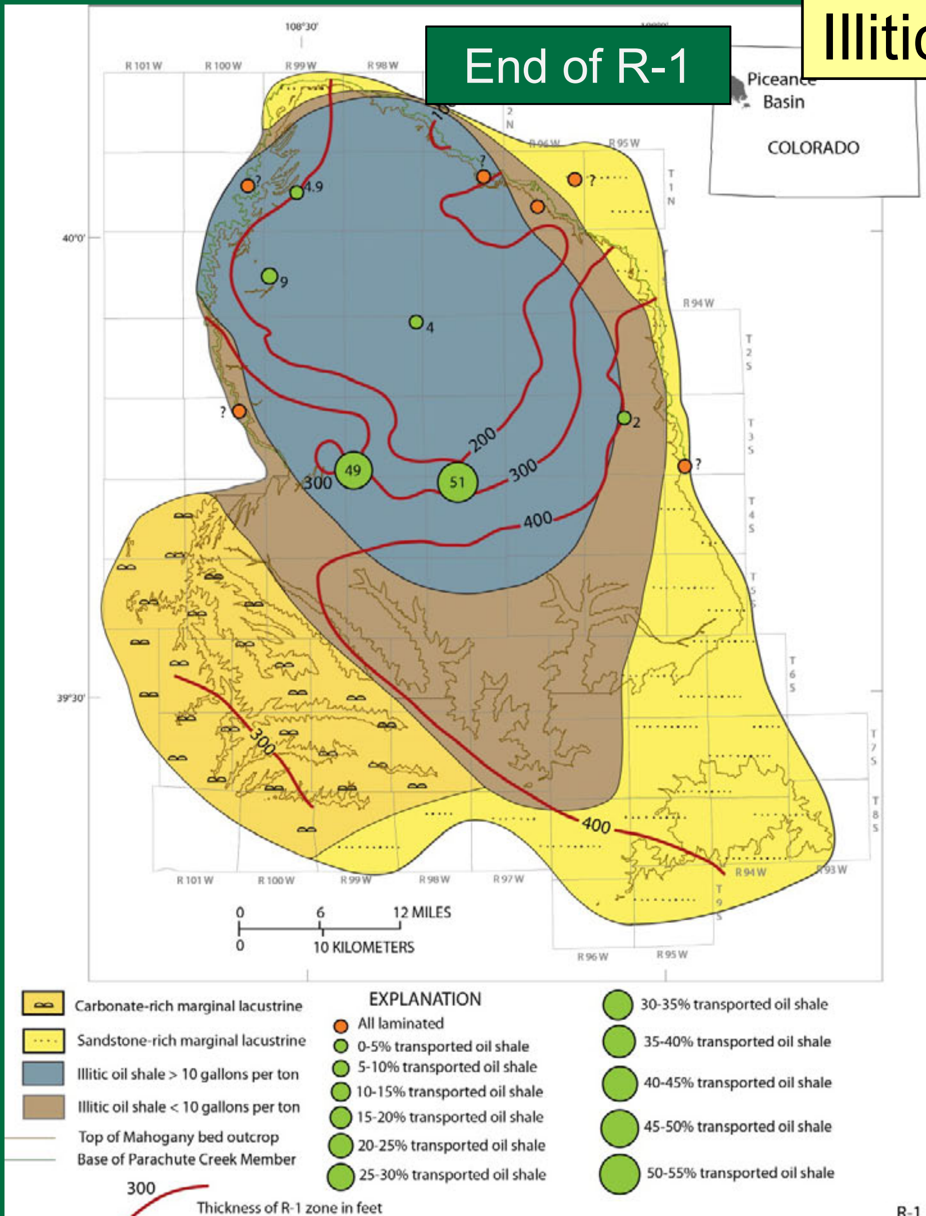
Illitic Phase

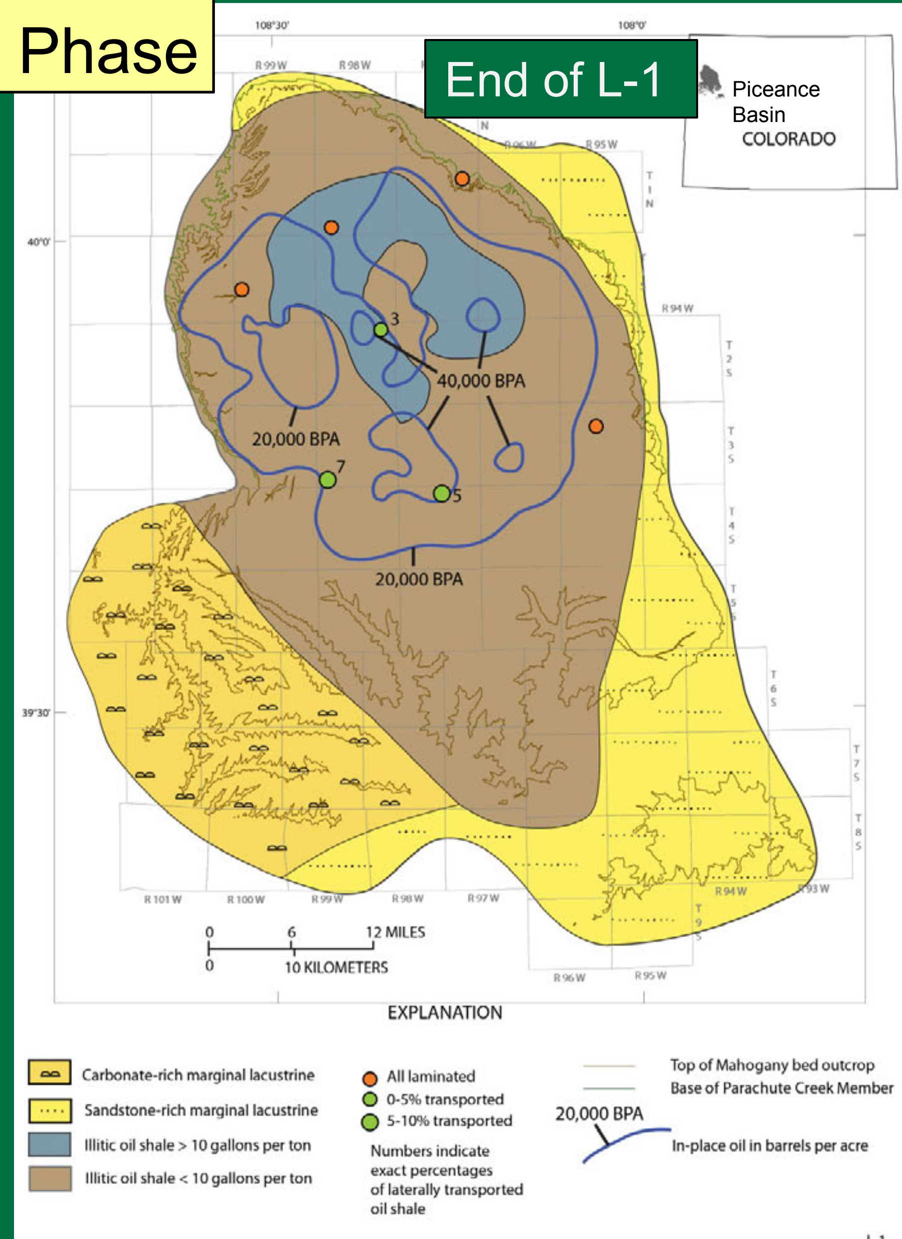




Total organic matter, measured by barrels of oil per acre (BPA), increases toward the center of the basin in the R-0 zone, which contains no mass-movement deposits, whereas total organic matter is greatest where mass-movement deposits are greatest in the R-1 zone.

Illitic Phase





Mass-movement deposits are much less common in the L-1 lean zone than the underlying richer R-1 zone.

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Illitic Phase

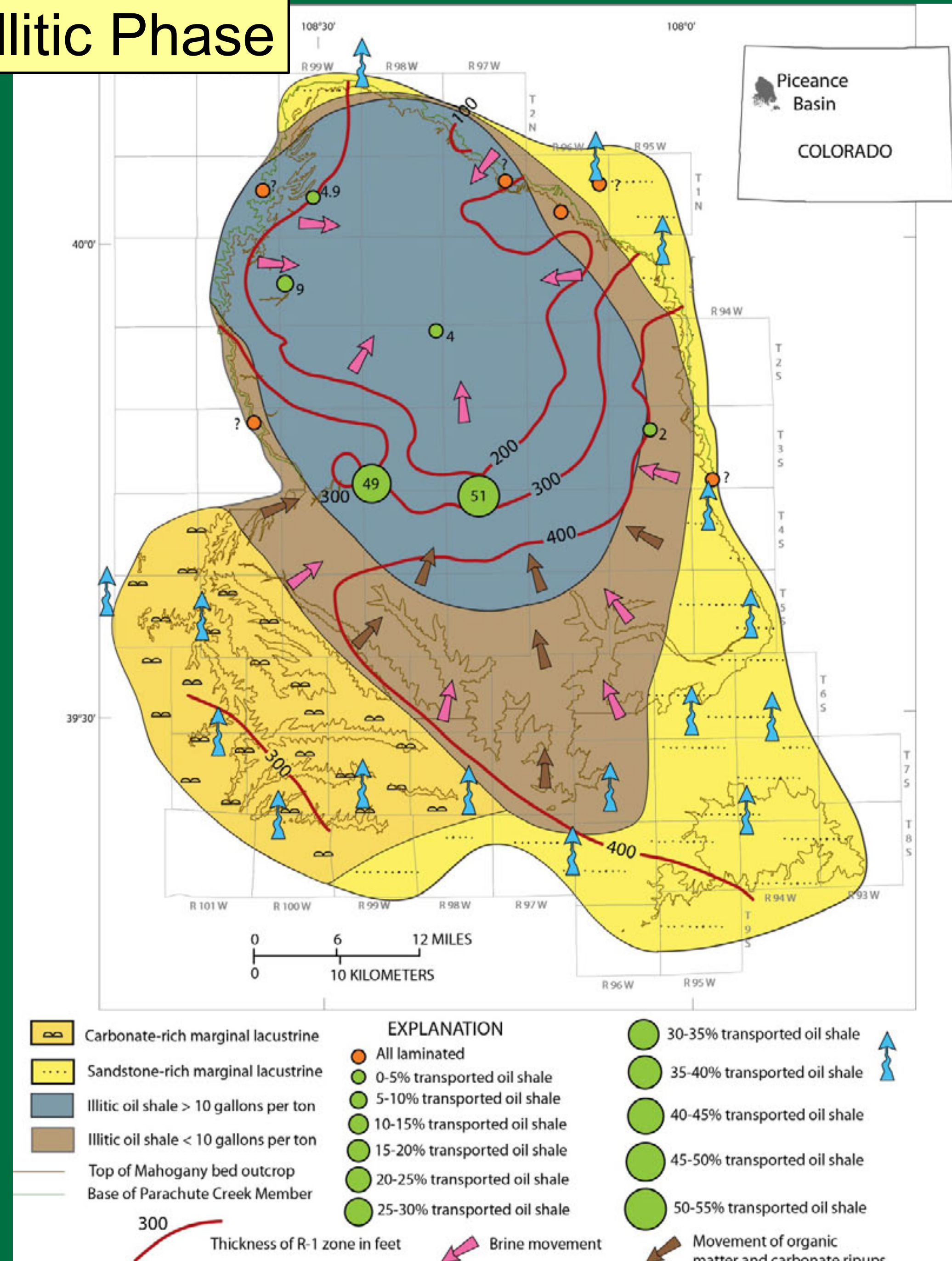
R.C. Johnson field locality 8/75, measured section North Dry Fork, The Saddle quad. Sec. 26, T. 7. S. R. 99W. Upper part of R-1

Oil-shale beds are preserved in marginal lacustrine environments, indicating that significant organic matter was accumulating there. Many of these beds occur above the bulbous structures on stromatolites that may have offered protection from lateral transport. This bed is in the R-1 zone.

Interpretation for R-1 zone

Illitic Phase

- Mass-movement deposits accumulated at the slope between marginal shelves and the deep lake area.
- The mineral matter and organic matter that made up the mass-movement deposits originated on the marginal shelves and slope on the southeast and southwest parts of the lake.
- Brines that formed on the marginal shelves may have been incorporated into the mass-movement deposits.
- Brines may also have formed on the northeast and north margins of the lake, but mass-movement deposits were rare there.



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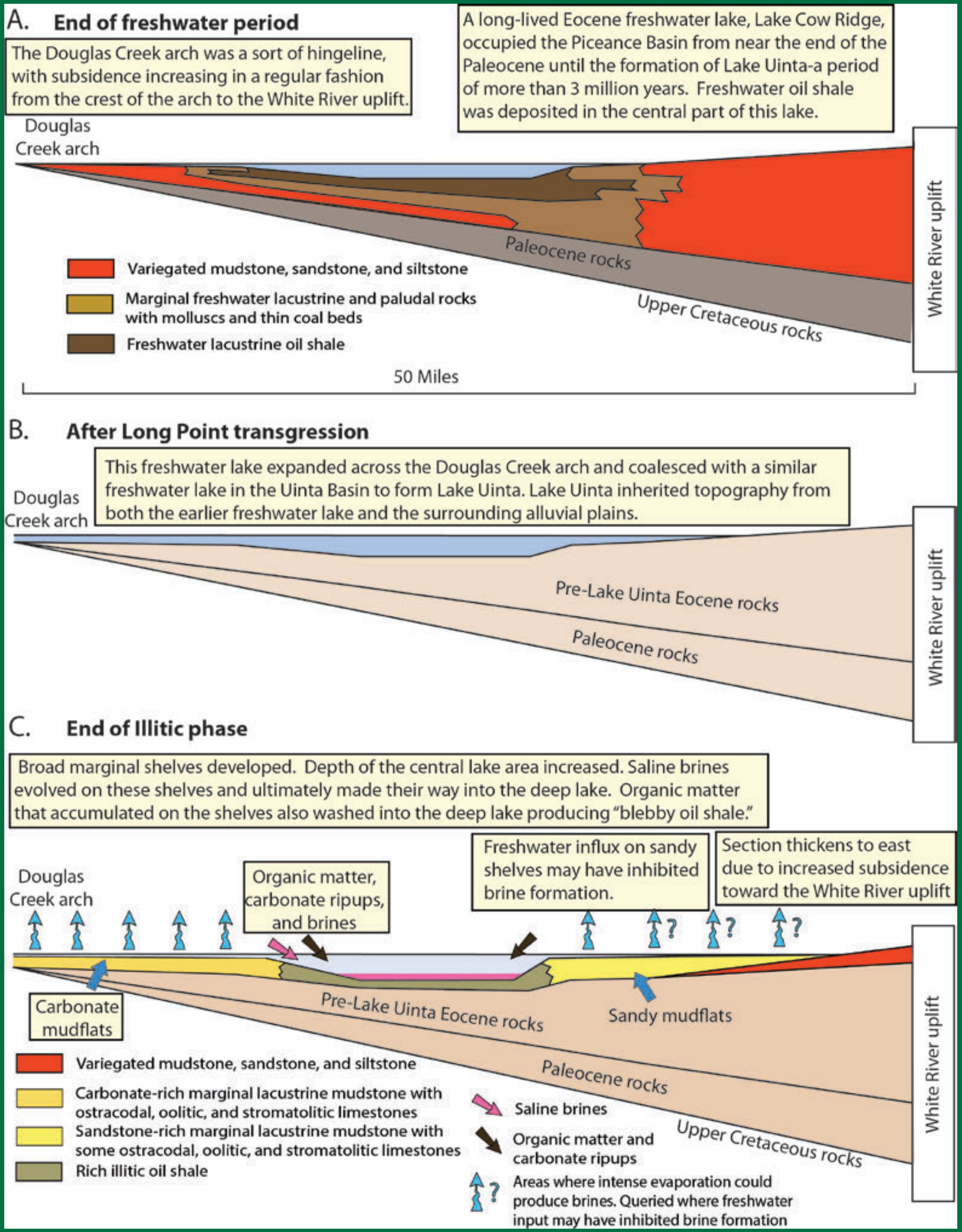
Illitic Phase Summary

At the time of the Long Point transgression, a freshwater lake had occupied the central part of the Piceance Basin for more than 3 million years. There is no evidence that this lake ever filled in, and it is likely that it was relatively deep.

Lake Uinta transgressed across the marginal shelves and alluvial plains during the Long Point transgression depositing low-grade oil shale over a wide area.

Infilling began, producing broad marginal shelves that ultimately reached the deep central part of Lake Uinta before halting.

The shelf edge and slope were subject to failure with mass-movement deposits accumulating at the base of the slope.



From Johnson and Brownfield (2015)

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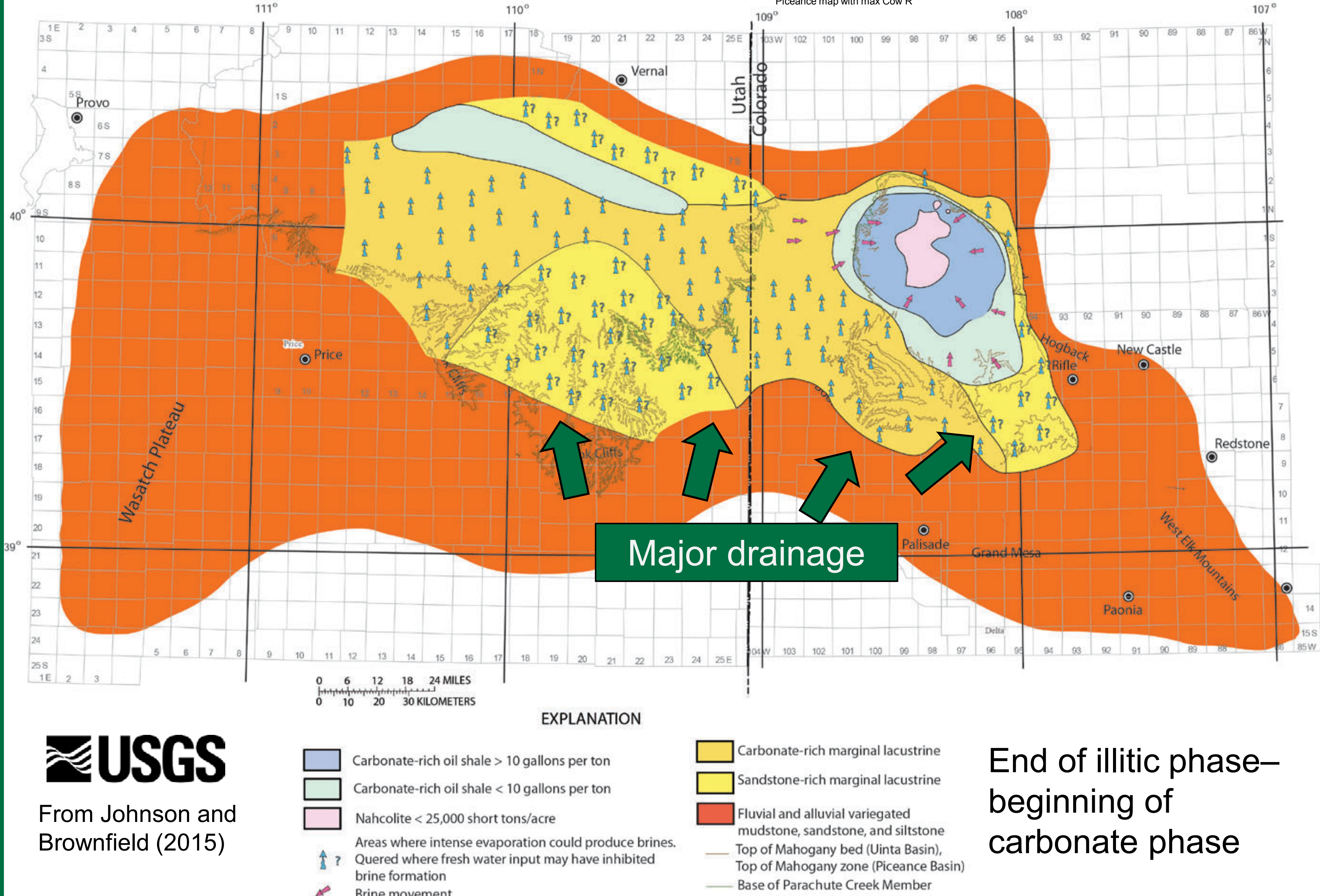
AAPG talk 14, also Leached zone figs. After review fig. 17 Uinta and Piceance at beginning R-2 also 2ed layer in Uinta-Piceance map with max Cow R

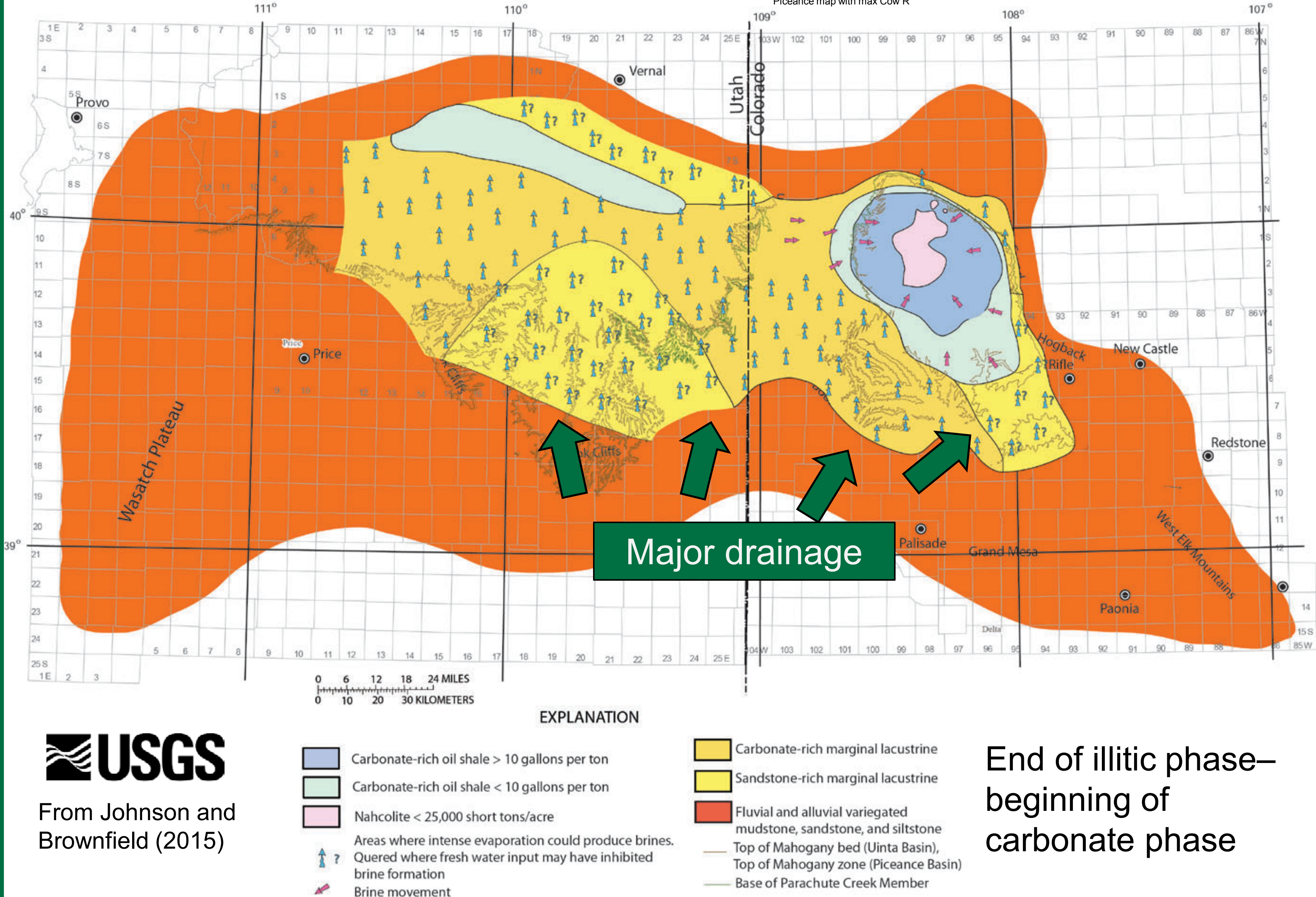


From Johnson and Brownfield (2015)

End of illitic phase–beginning of carbonate phase

By the end of the illitic phase, offshore oil-shale deposition had been replaced by shallow-water shelf deposition throughout all but the deep trough of the Uinta Basin. Sediments from the southern Uinta Basin spilled over to create an expanding shelf along the southwest margin of the Piceance Basin.

AAPG talk 14, also Leached zone figs. After review fig. 17 Uinta and Piceance at beginning R-2 also 2ed layer in Uinta-Piceance map with max Cow R



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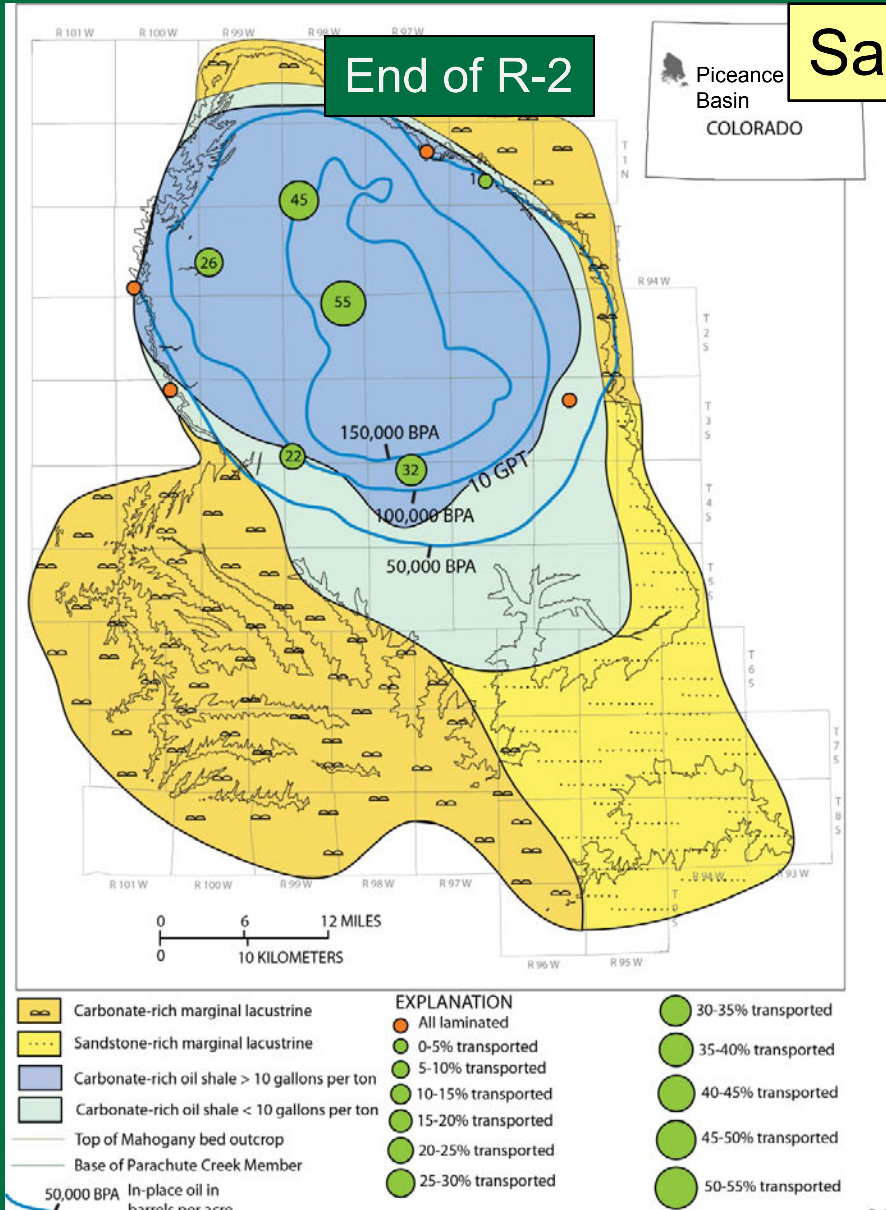
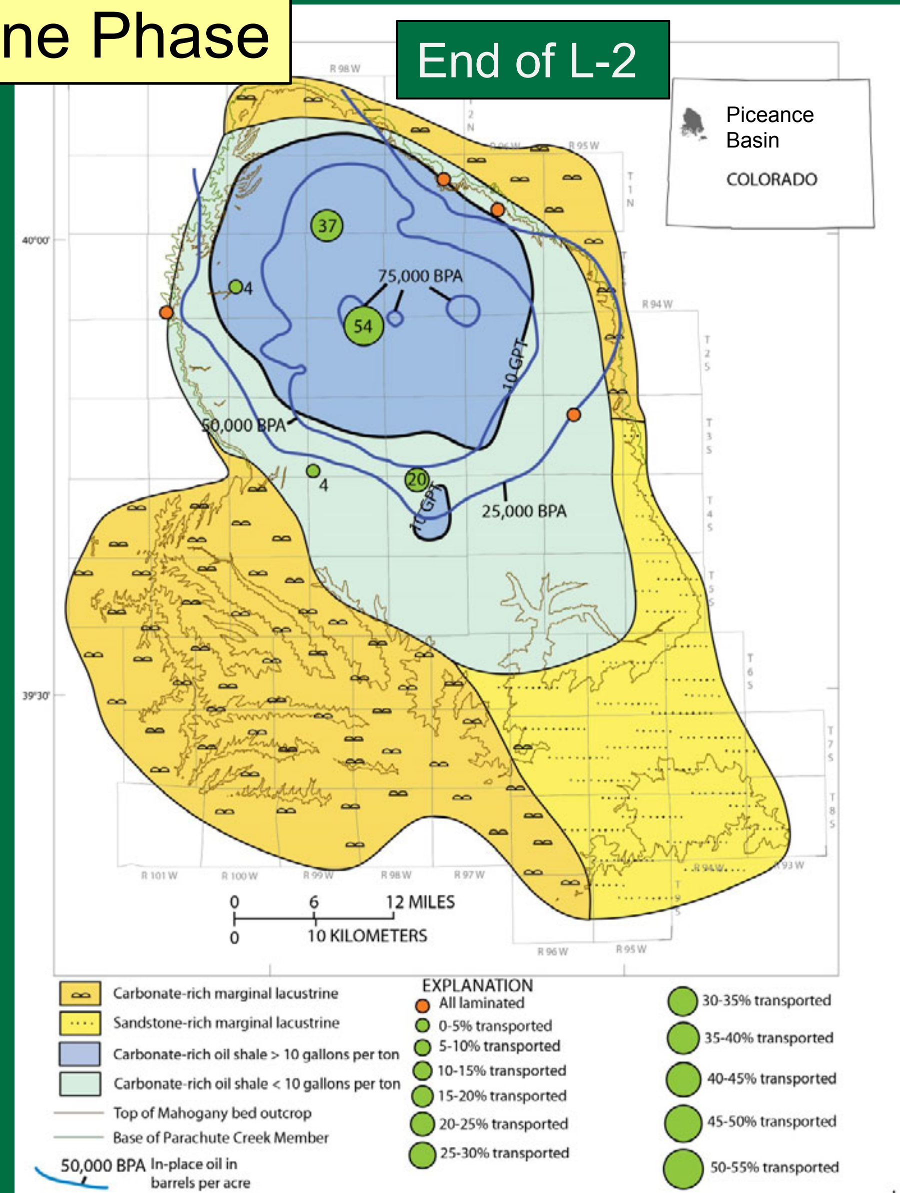
From Johnson and Brownfield (2015)

End of illitic phase–beginning of carbonate phase

Many authors have stressed the importance of evaporation on lake-margin mud flats in producing concentrated brines (Smith, 1974, p. 77; Ryder and others, 1976; Eugster and Hardie, 1978; Surdam and Stanley, 1979; Johnson, 1985; Remy and Ferrell, 1989).

Saline Phase





By the beginning of the carbonate and saline mineral phase of the lake (Parachute Creek Member, R-2 oil shale zone), shelf building had slowed. Mass-movement deposits now accumulated mainly in the central part of the lake.

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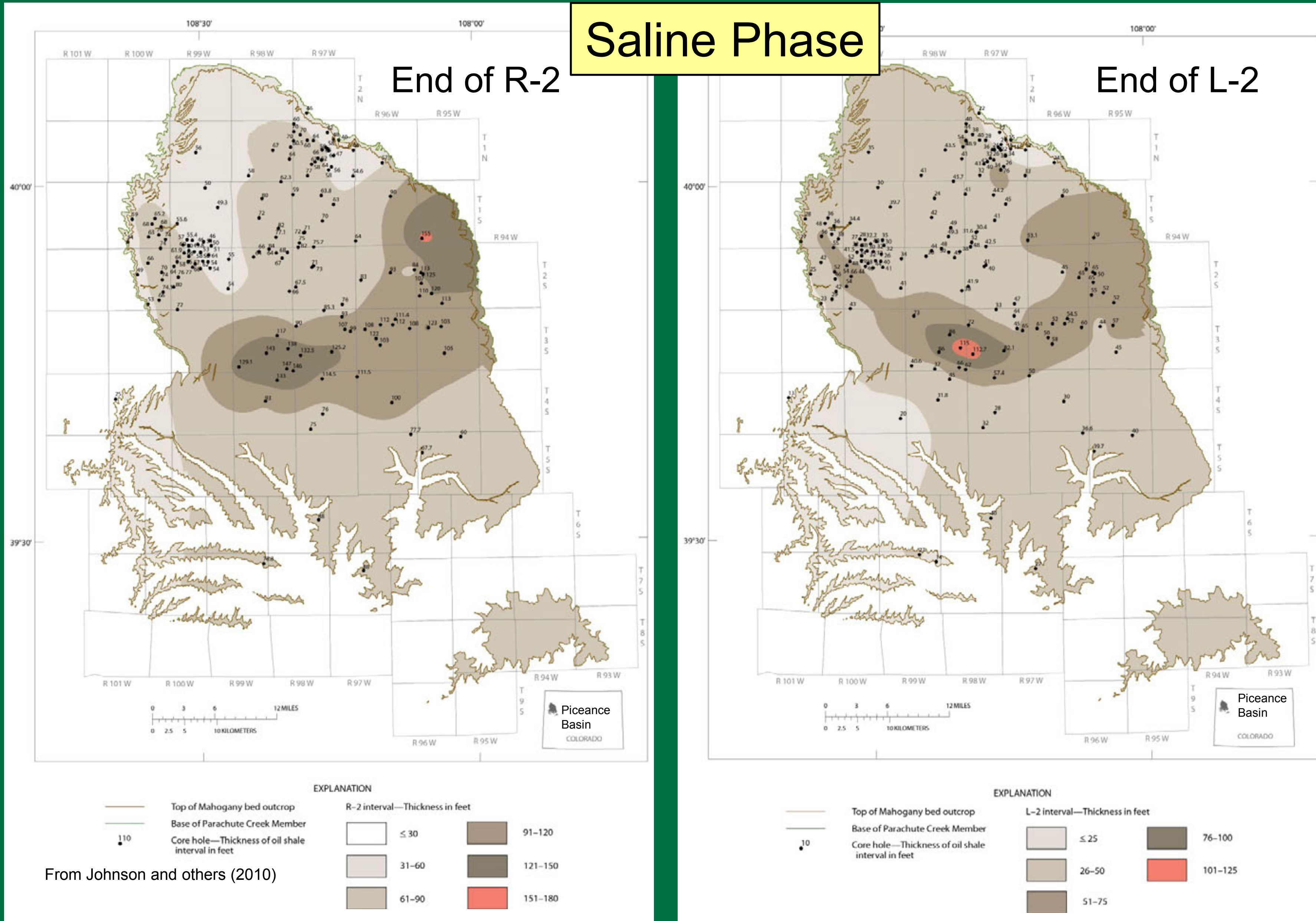
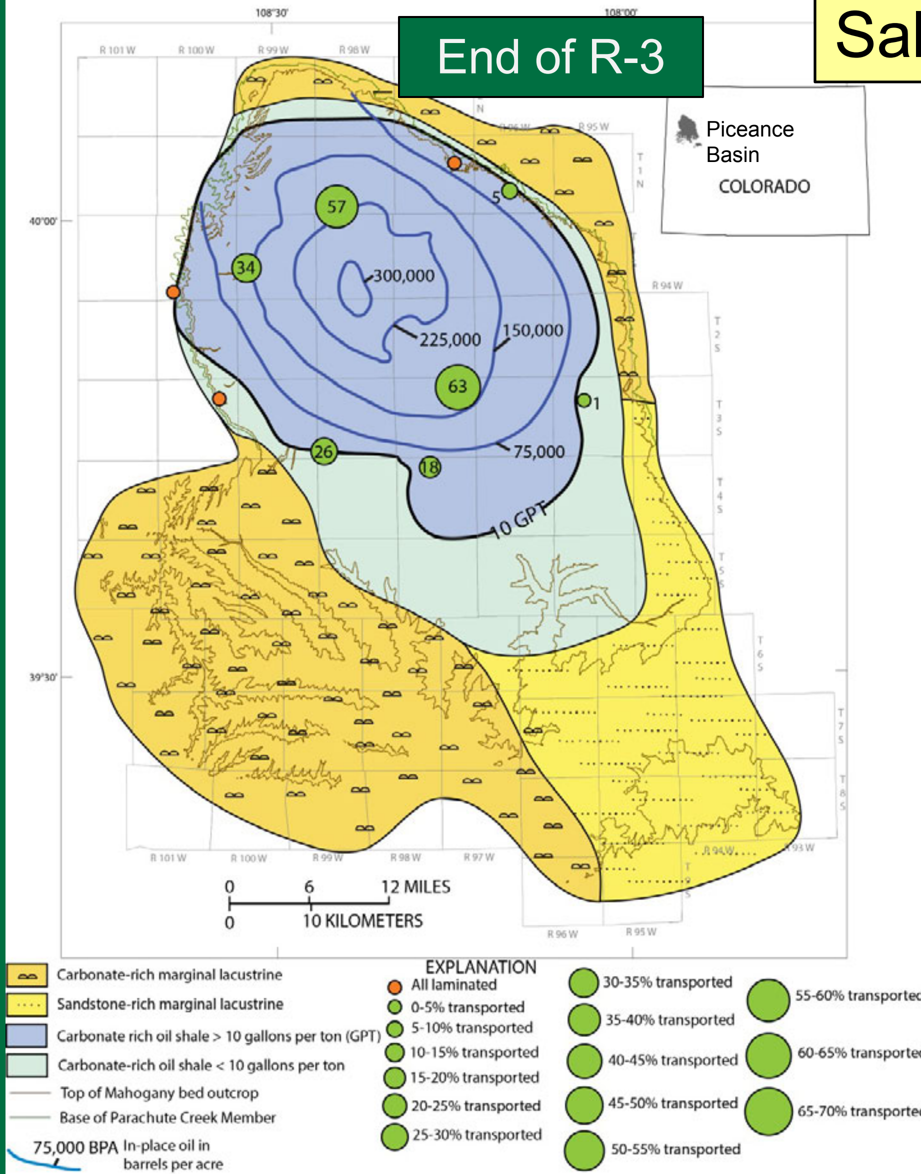
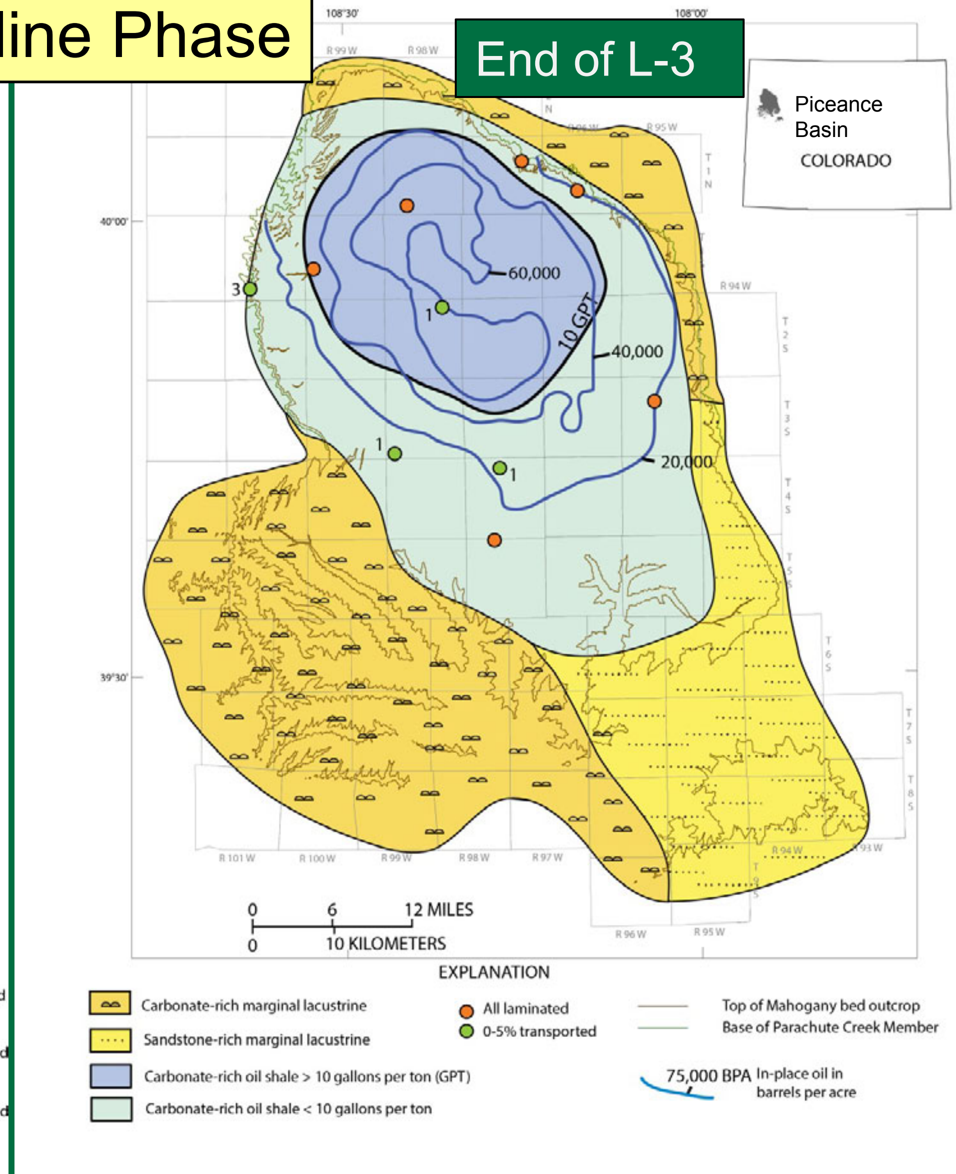


Some shelf building continued during the early carbonate phase.
The R-2 and L-2 zones are thickest at the base of the shelf.

Saline Phase





The R-3 zone is predominantly composed of mass-movement deposits in the center of the lake, whereas the overlying L-3 zone contains almost no mass-movement deposits.

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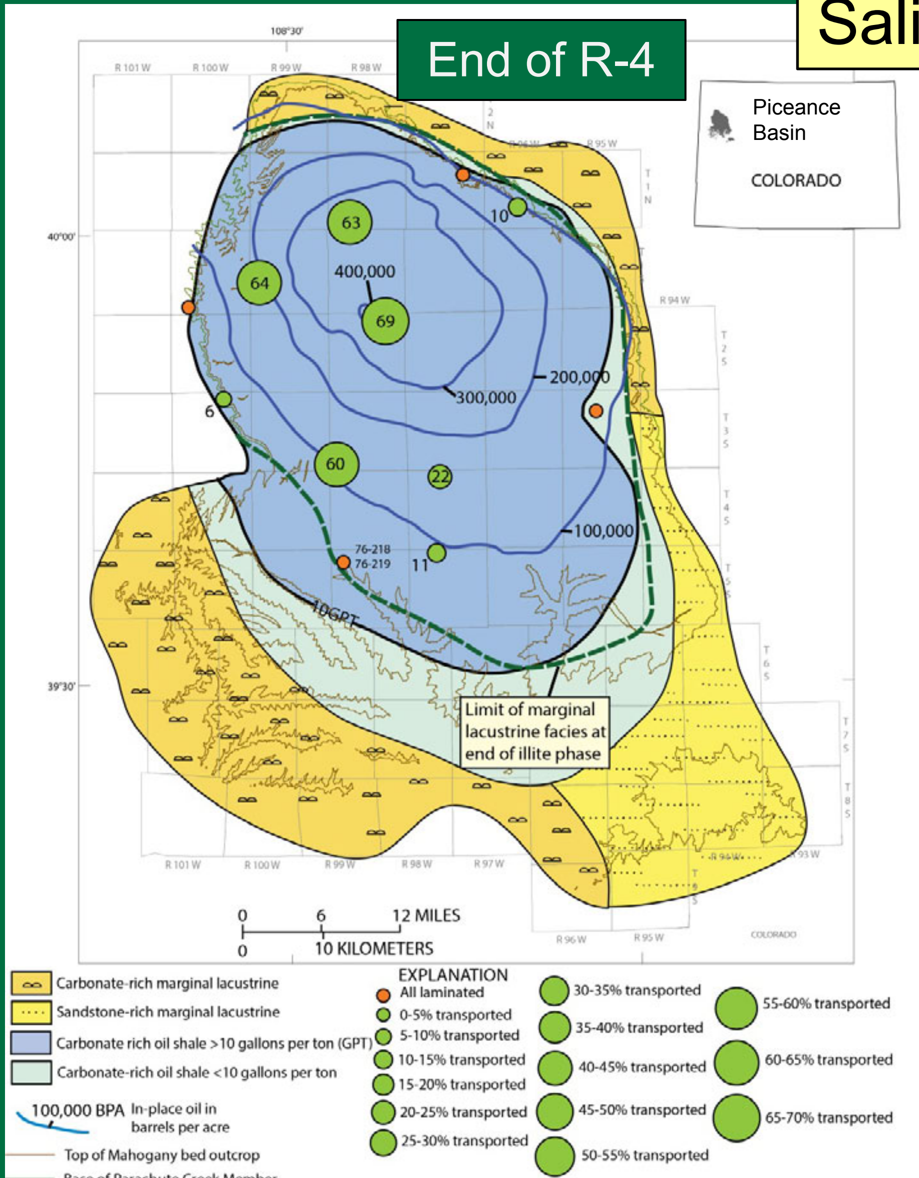
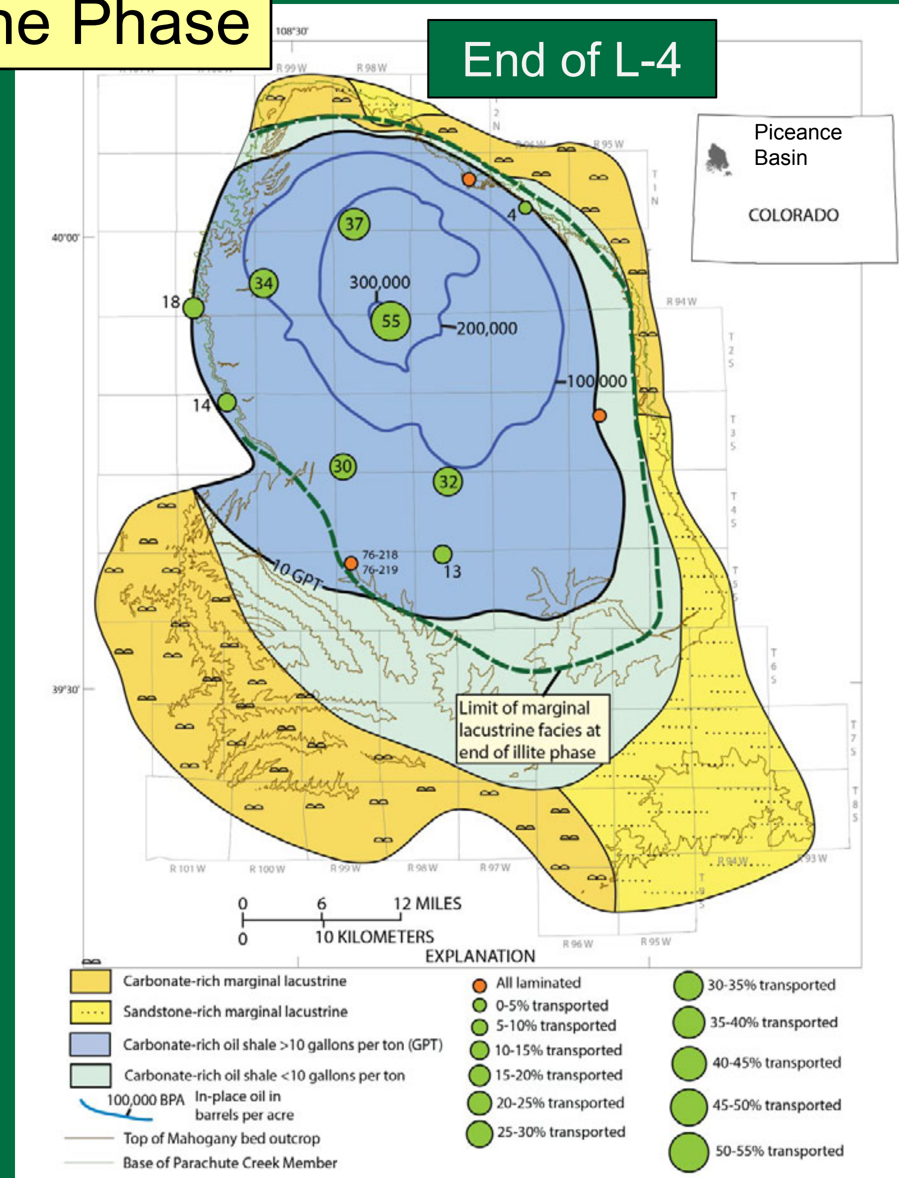
Saline Phase





The lake began to expand over the marginal shelves in R-4 time. The rich R-4 zone is mainly composed of mass-movement deposits in the center of the lake, whereas mass-movement deposits are somewhat less in the overlying leaner L-4 zone.

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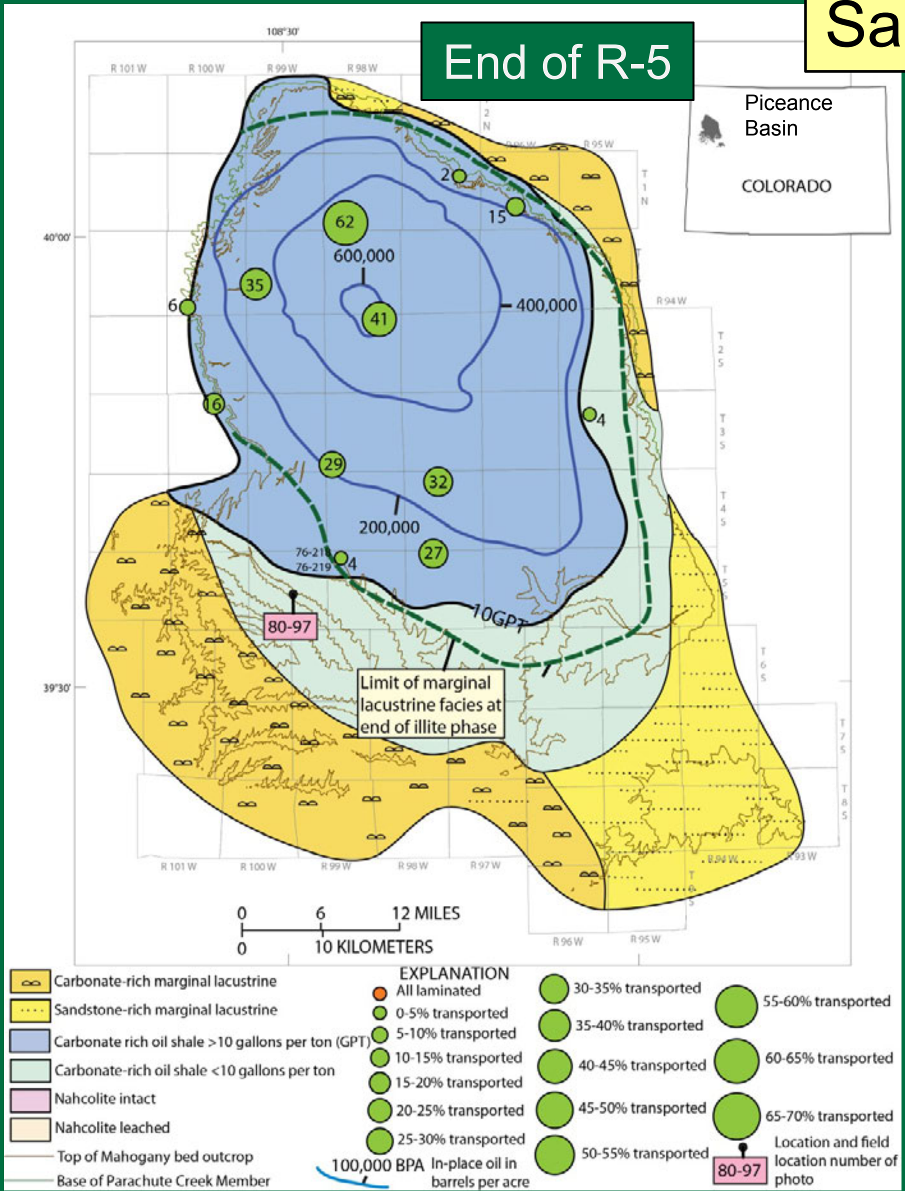
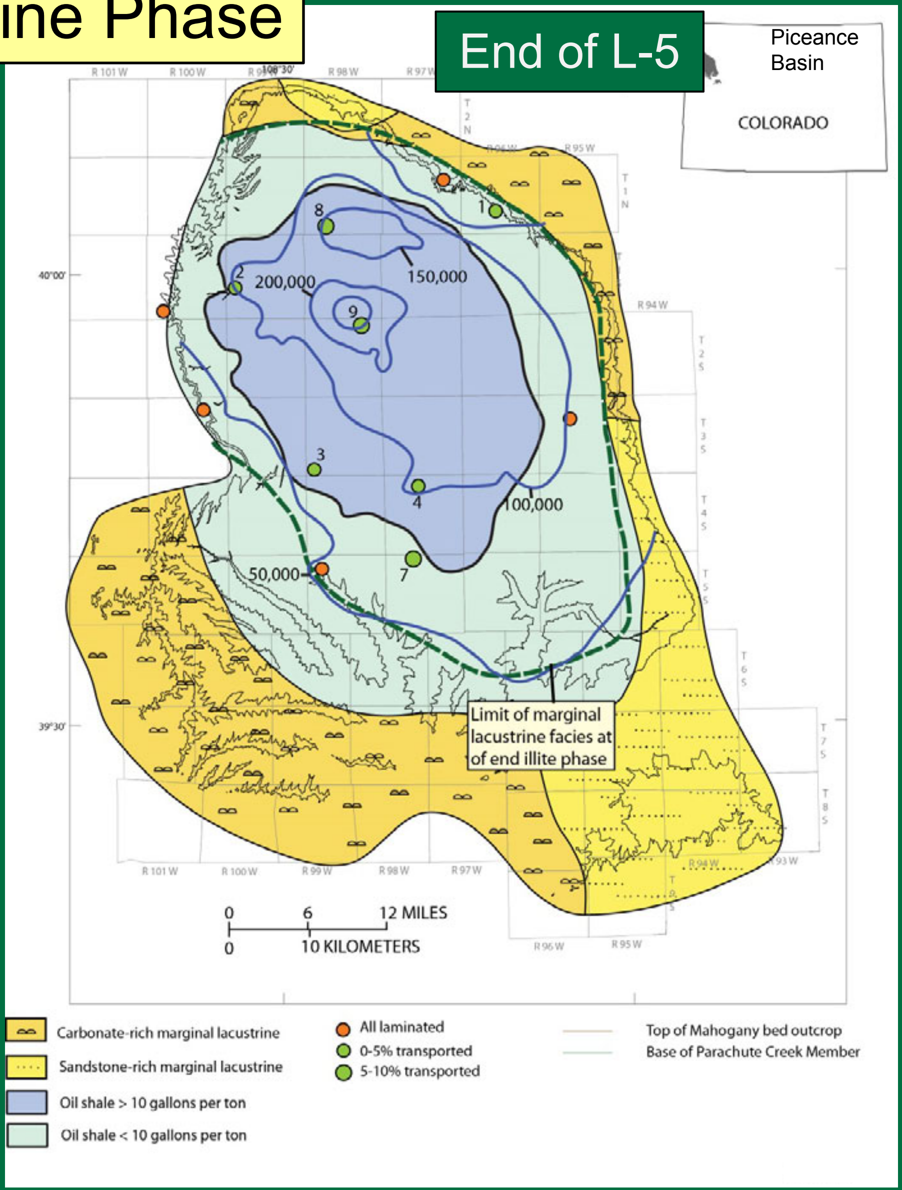
Saline Phase





The R-5 zone contains abundant mass-movement deposits, whereas mass-movement deposits are rare in the overlying leaner L-5 zone.

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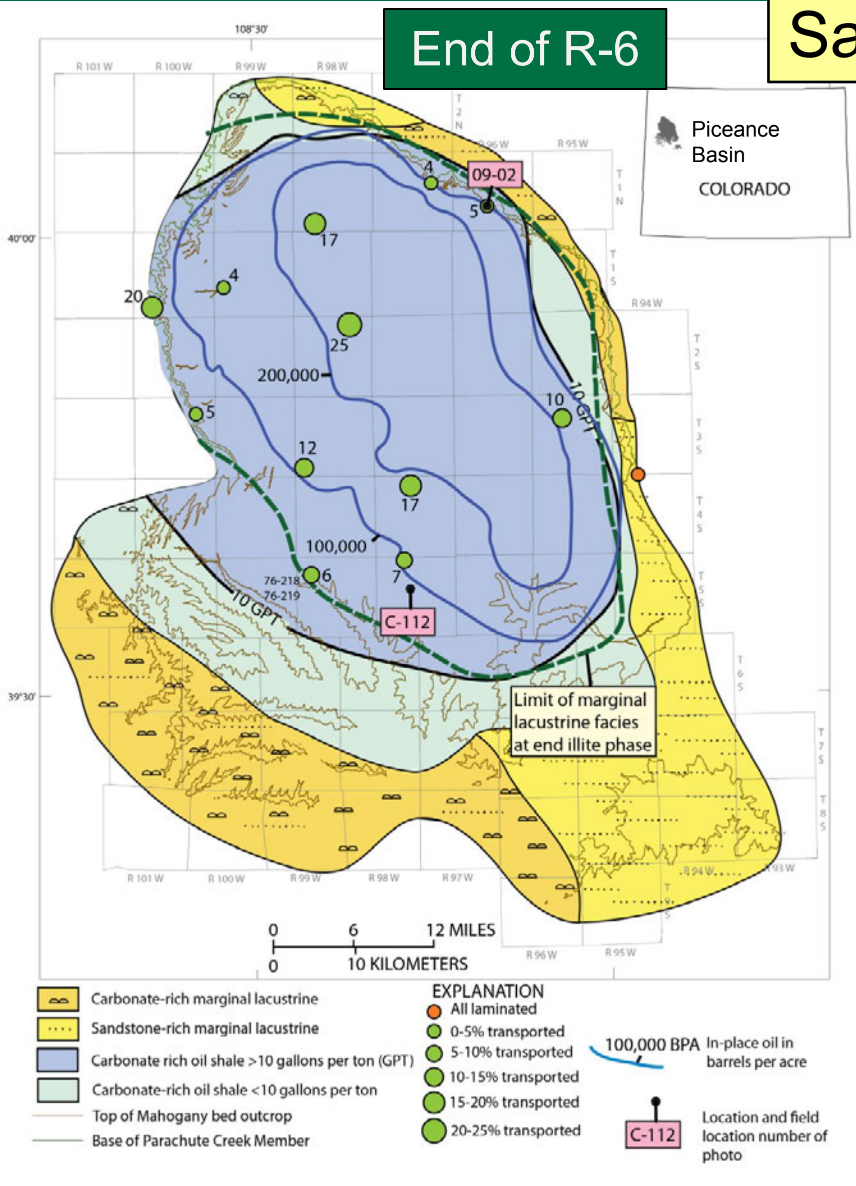
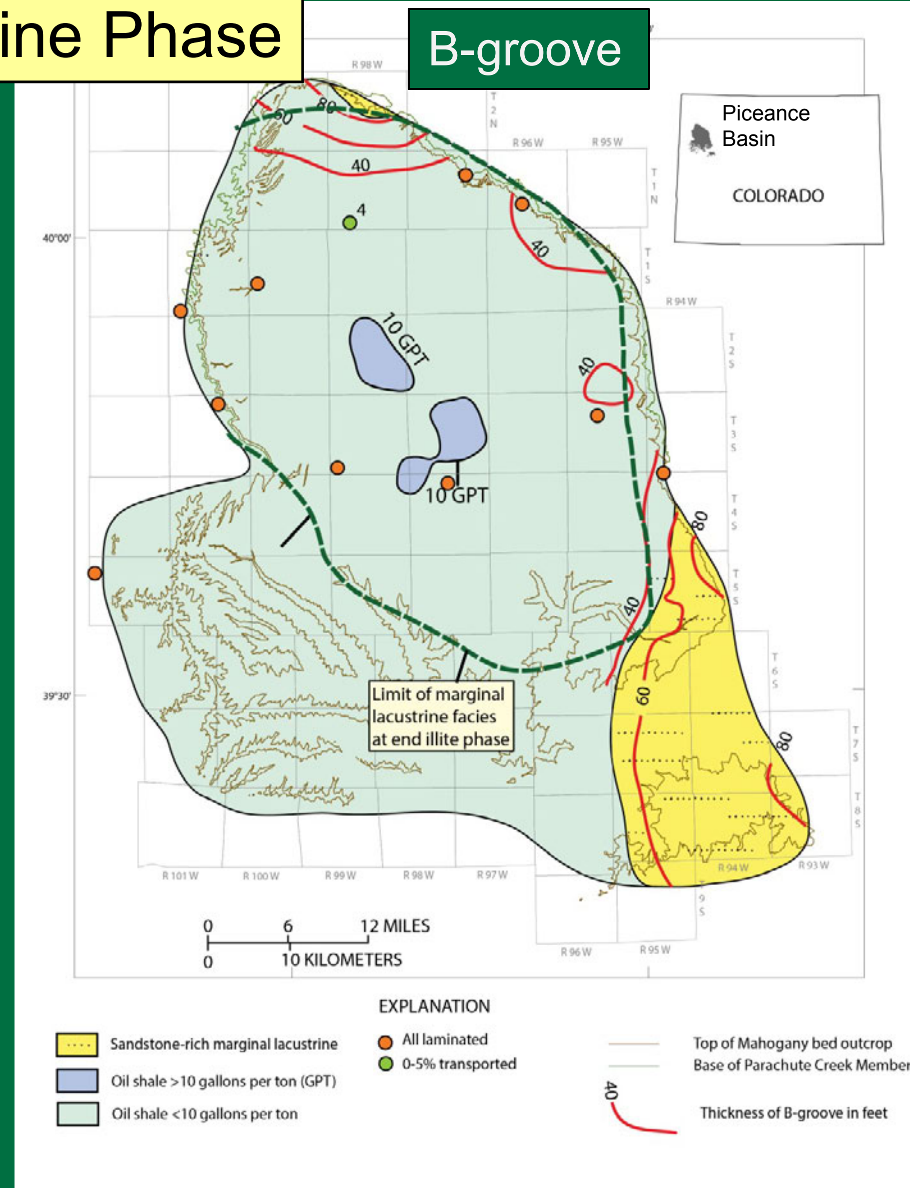
Saline Phase





The percentage of mass-movement deposits progressively decreased as deep-water conditions continued to encroach on the marginal shelf during R-6 time. The overlying lean B-groove contains almost no mass-movement deposits.

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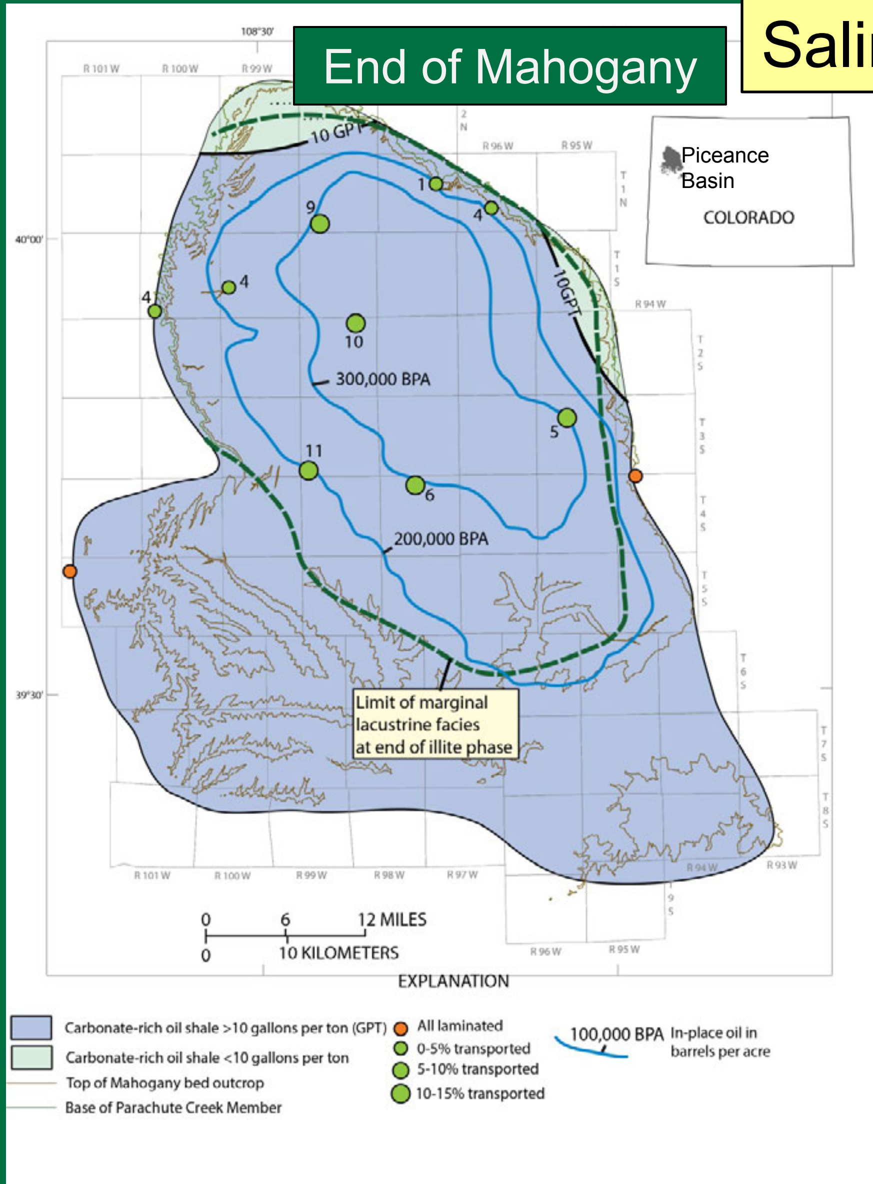
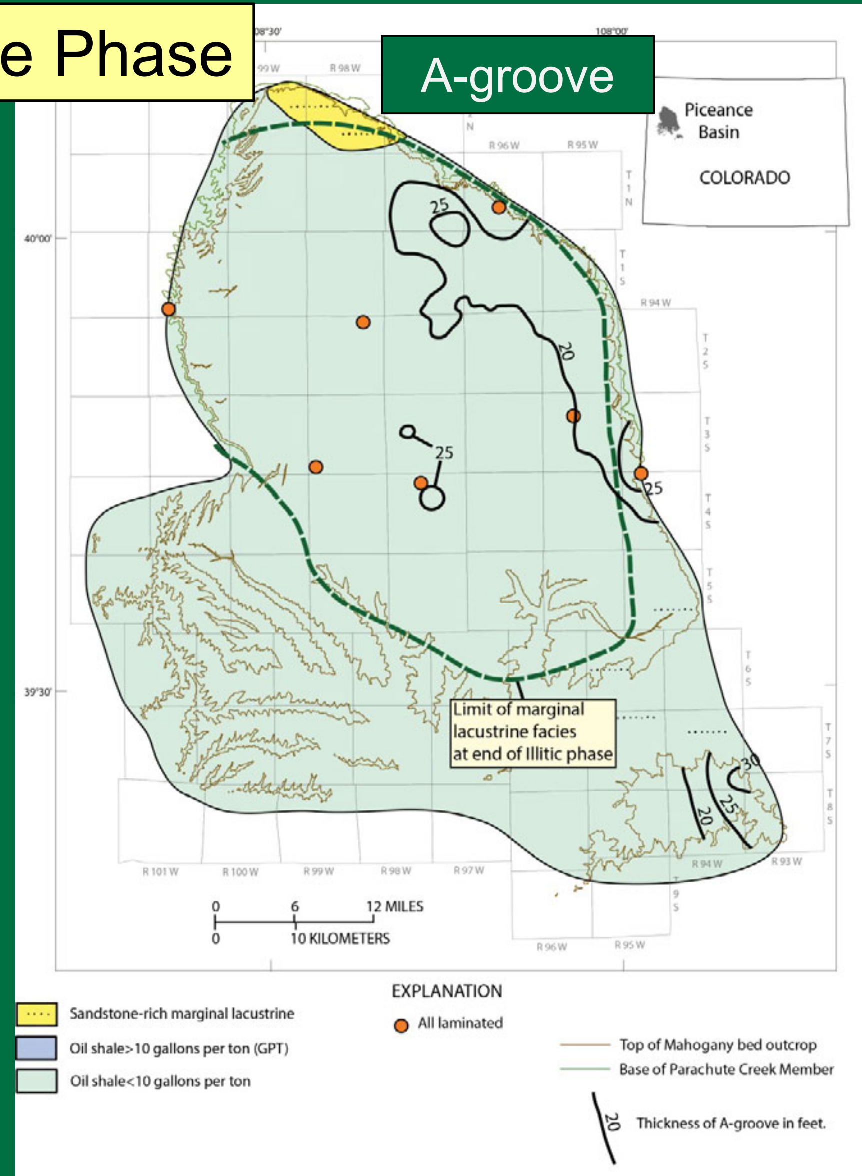
Saline Phase





Deep-water conditions were dominant over the former marginal shelves during deposition of the Mahogany zone. Mass-movement deposits are rare in the Mahogany and absent in the overlying lean A-groove.

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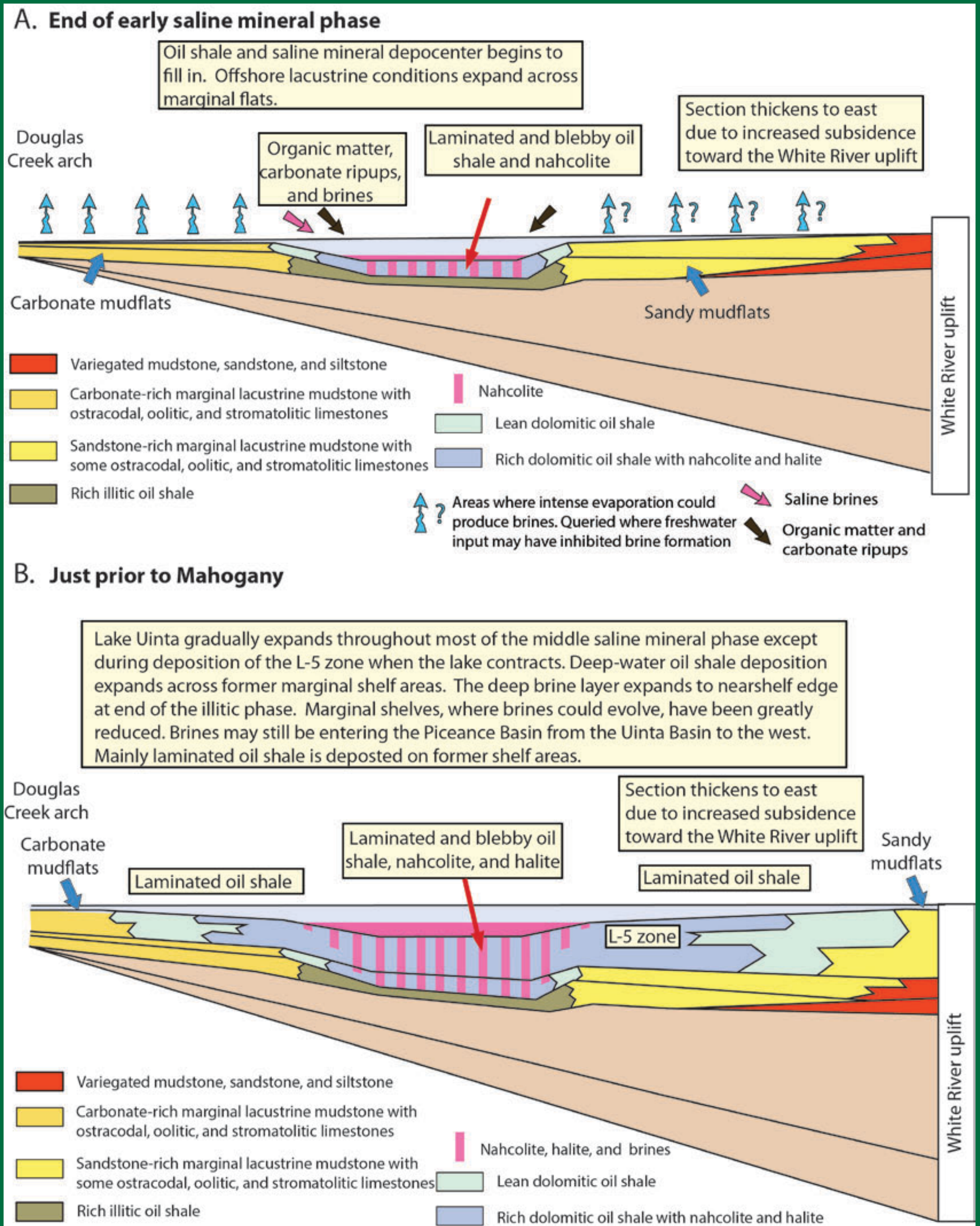
Saline Phase Summary

During the early stages of the saline mineral phase (Parachute Creek Member), Lake Uinta repeatedly transgressed and regressed across the marginal shelves, providing opportunities for sediments and organic matter to be exhumed and transported to the central part of the lake.

As Lake Uinta expanded and deepened, mass-movement deposits diminished.



From Johnson and Brownfield (2015).

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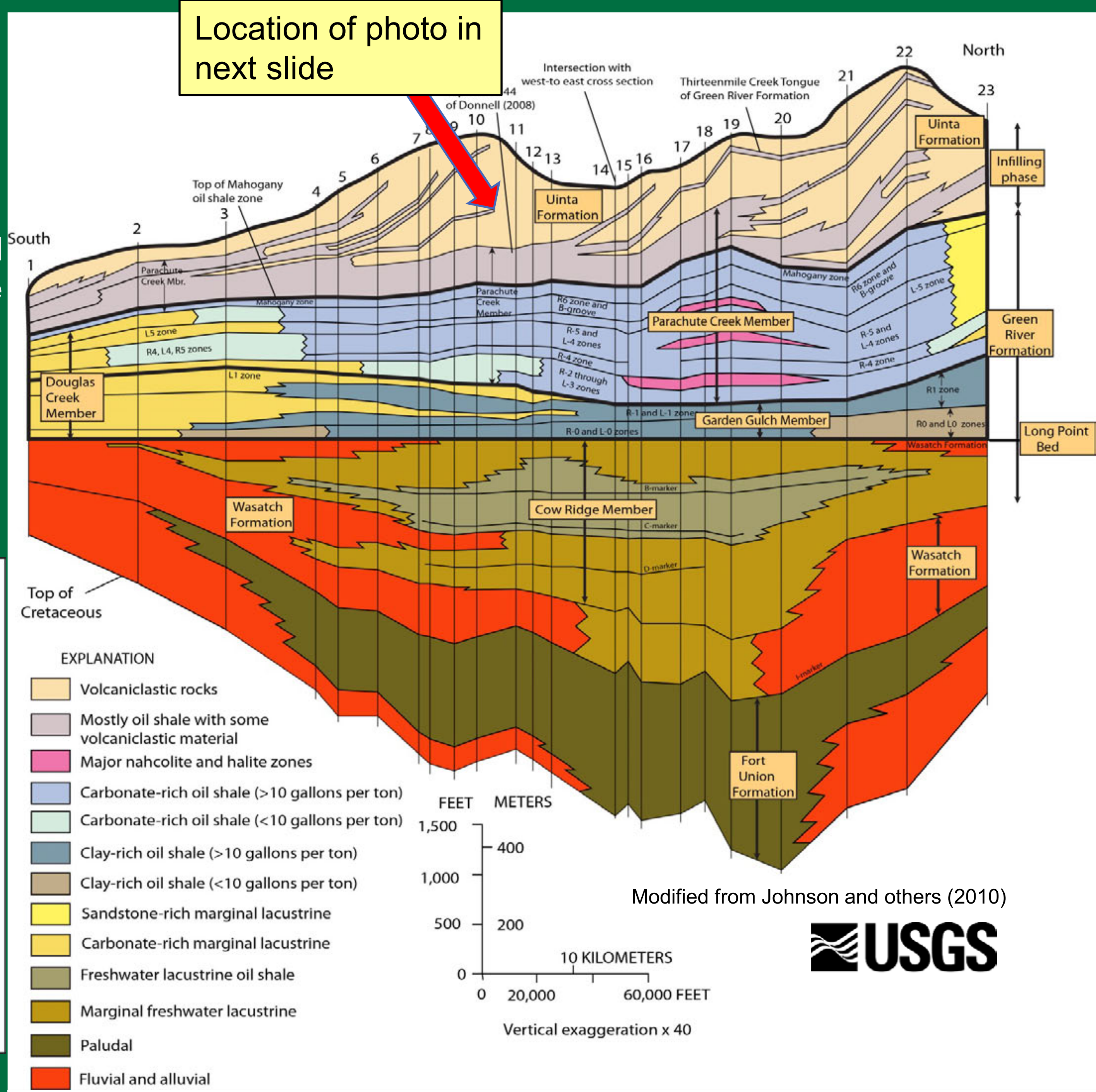
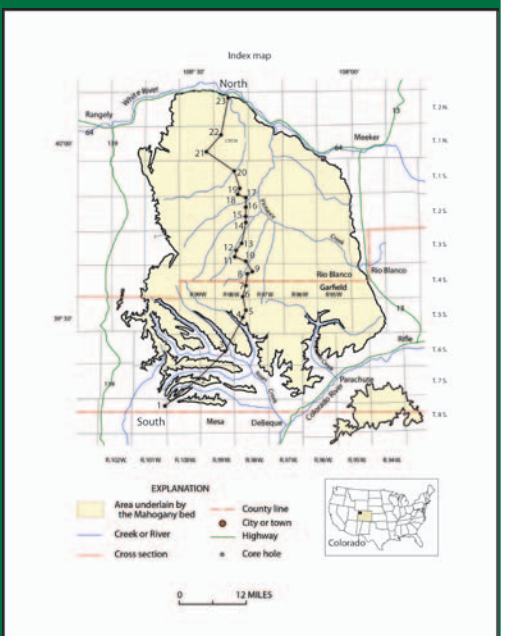
Infilling Phase

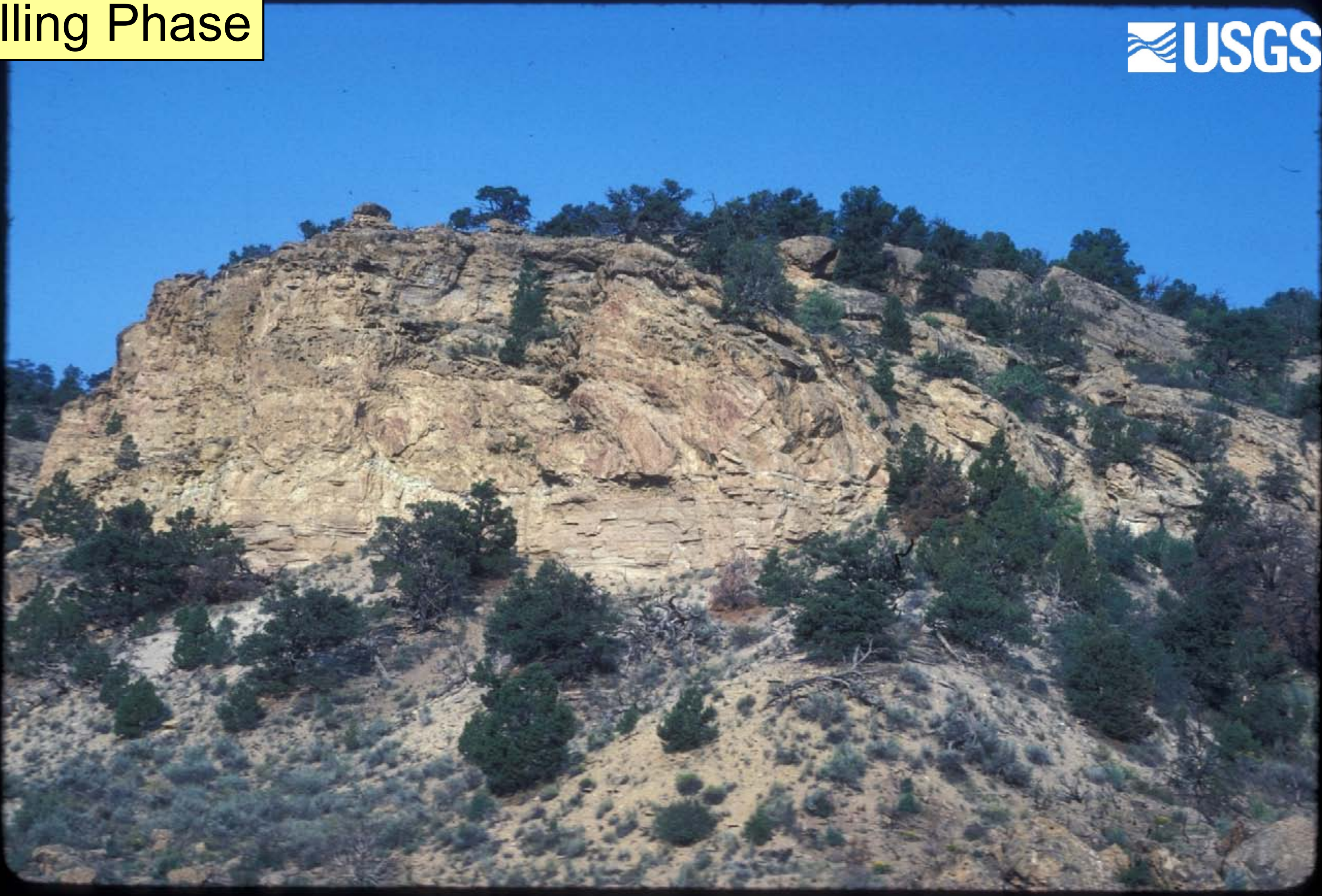
Huge slumps and mass-movement deposits of all sorts occurred during the infilling stage of Lake Uinta.



Modified from Johnson and others (2010)



Infilling Phase



Following deposition of the Mahogany zone, Lake Uinta began to fill in from north to south. Slumps during the infilling stage of the lake can be several hundred feet thick, cover several square miles, and can be underlain and overlain by laminated marl and oil shale. This slump extends along a valley wall for 2.1 miles.

Conclusions

- Mass-movement deposits during the illitic phase of Lake Uinta contain fewer clasts than the carbonate phase of the lake suggesting that the source area was mostly unlithified.
- Mass-movement deposits during the carbonate phase of the lake (Parachute Creek Member) contain abundant clasts indicating early lithification of sediments in marginal areas. These flows are most abundant in the central part of the depocenter.
- Mass-movement deposits accumulated at the base of the prograding shelves until the shelves reached the deep central part of the lake when progradation slowed. Mass-movement deposits then reached the central deep part of the lake.

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Conclusions (continued)

- Large amounts of organic matter were included in mass-movement deposits.
- Highly saline brines that evolved on the marginal shelves may have been incorporated into the mass-movement deposits.
- Lean zones tend to include less mass-movement deposits than adjacent rich zones, possibly because organic-rich sediments were more prone to failure.

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