Petroleum Generation and Migration from the Oil Shale Interval of the Eocene Green River Formation, Uinta Basin, Utah*

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Abstract

An examination of the current distribution of oil shale resources, combined with paleogeographic reconstructions of the lacustrine oil shale interval in the northwestern depocenter of the Uinta Basin, indicates that oil shale source rocks in the area originally contained significantly greater organic richness. Thermal maturation in this deeply buried part of the basin has led to the loss or depletion of a substantial portion of the original petroleum-generating potential of these source rocks. Some of this loss of potential has led to the presence of unconventional petroleum resources, including tar sands and solid bitumens like gilsonite, in the Uinta Basin. In-place oil shale resources of the Eocene Green River Formation were compiled and reported in the recent U.S. Geological Survey assessment. These results have been used to define areas within the oil shale interval along the deep structural trough of the basin that appear to be depleted in terms of Fischer assay oil yields (gallons of oil per ton of rock) and in-place oil shale resource (barrels of oil per acre). The oil shale interval has also been established as the most likely source for gilsonite deposits in the basin and much of the tar sands resource. Petroleum expulsion may have occurred at unusually low degrees of thermal stress due to the very high organic carbon content and hydrogen-richness of the Type I kerogen present in Green River oil shale.

In order to examine the possible sources and migration pathways for the tar sands and gilsonite deposits, paleogeographic reconstructions of several oil shale zones in the basin were created. Applying oil yields from core and cuttings samples collected near the edge of the defined 'depleted area', we estimate that the reduction in petroleum-generating potential is slightly more

than 500 billion barrels. This loss represents nearly 40% of the original oil shale resource and is more than 20 times greater than all of the tar sands (~12 billion barrels) and gilsonite (~10 billion barrels of oil equivalent) deposits in the basin sourced primarily from the oil shale interval. Analysis to develop a first-approximation of the amount of actual generated and expelled petroleum was conducted, leading to estimates ranging from 15 to 50 billion barrels. No attempt was made to estimate the amount of oil lost to leakage, erosion and biodegradation, but based on our current understanding of the history of the Uinta Basin, it is expected that such losses could account for much of the discrepancy between the known deposits and estimates of generated oil. Late Eocene uplift of the Uinta Basin exposed the marginal areas of the Green River Formation around much of the basin. Exposure of persistent marginal lacustrine sandstone and stacked fluvial sandstones that connect to the depleted oil shale area may have allowed most of the generated and expelled petroleum to escape. The tar sands deposits around the present-day basin margins can be thought of as erosional remnants of migration pathways that allowed oil to reach the surface.

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A manuscript on this subject was published in 2016:

Johnson R.C., Birdwell J.E., Mercier T.J., 2016, Generation and migration of bitumen and oil from the oil shale interval of the Eocene Green River Formation, Uinta Basin, Utah, chap. 13 *of* Dolan M.P., Higley D.H., and Lillis P.G., eds., Hydrocarbon source rocks in unconventional plays, Rocky Mountain Region: Denver, Colo., Rocky Mountain Association of Geologists. [Also available at http://www.rmag.org/hydrocarbon-source-rocks.]

Overview

- Using the results of a 2010 oil shale assessment of the Green River Formation in the Uinta Basin, we interpret the oil shale interval in the structurally deepest part of the basin to be depleted of some of its petroleum-generating potential due to thermal maturation.

- Thermal maturities for the oil shale interval are generally consistent with a range of vitrinite reflectance (Ro) values from 0.5 to 0.9%.

We made general estimates of:

(1)   the amount of depletion

(2)   the total amount of petroleum generated.

Due to the limited or inconclusive data available (for some parameters) and assumptions required, these are essentially order of magnitude estimates.

It should be noted that the efficiency of kerogen conversion to petroleum in natural systems is overestimated by pyrolysis experiments.
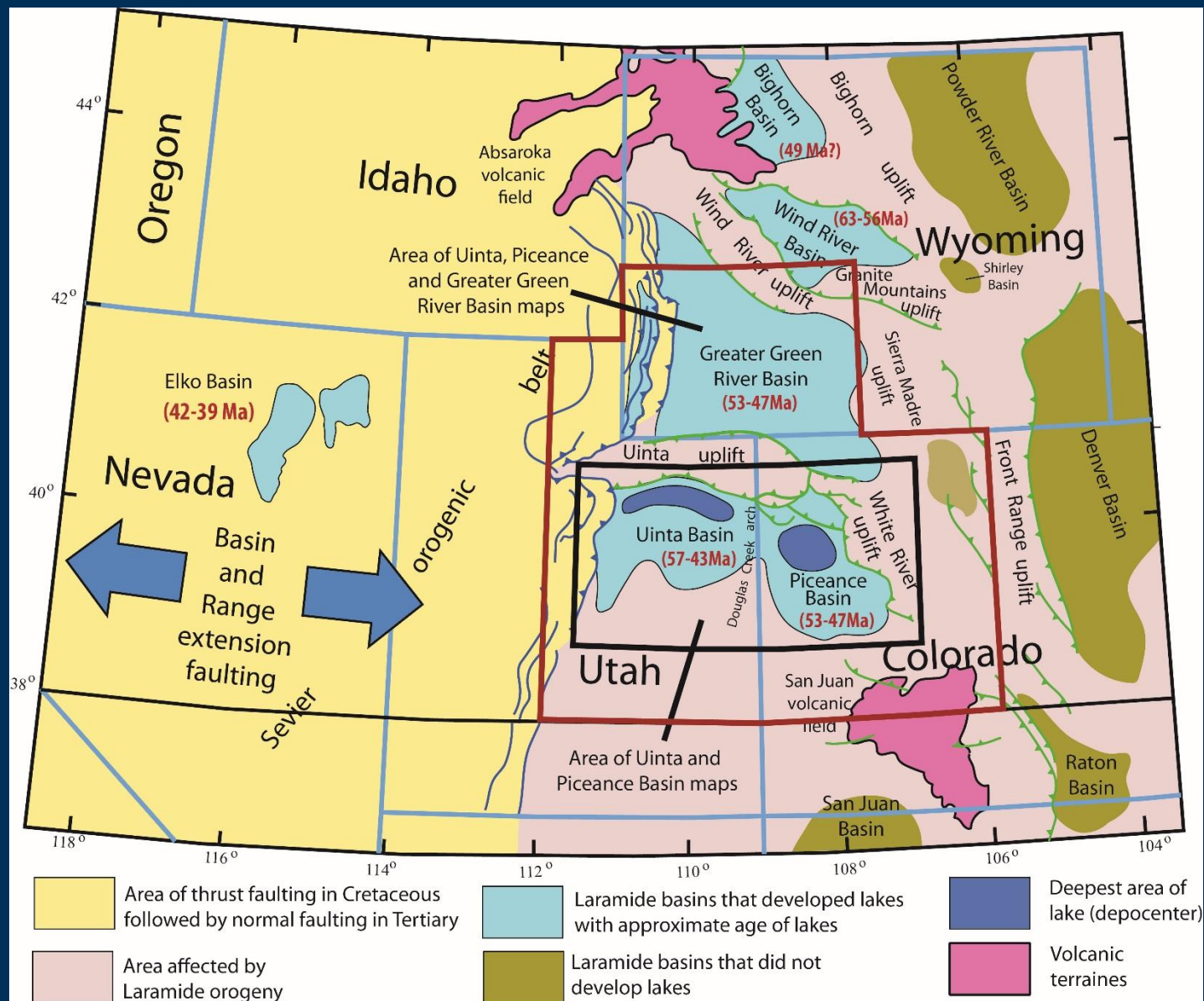
Map of central Rocky Mountain region. Modified from King (1969). Approximate ages of lacustrine intervals in each basin shown in red text and millions of years (Ma). Area of Uinta and Piceance Basin maps outlined in black. Area of Uinta, Piceane, and Greater Green River Basin maps outlined in dark red. Major faults are shown as green lines (Paleogene) and as blue lines (Jurassic through Paleogene).

Deep lake depocenters were established in the Uinta and Piceance Basins very early in the Eocene. Variations in subsidence rates and sediment supply determined where the deep lake areas developed.

It is important, but not critical, to our hypothesis that, once established, these deep depocenters did not shift very much through time.

Extent of Ramsey Ranch Member of Wasatch Formation in the Greater Green River Basin modified from Roehler (1993, fig. 45). Extent of Flagstaff Member of the Green River Formation in the Uinta Basin modified from Ryder and others (1976, fig. 15). Extent of the Cow Ridge Member of the Green River Formation in the Piceance Basin modified from Johnson and others (2016). Isopach map from the top of the Cretaceous to the base of the Long Point Bed of the Green River Formation in the Uinta Basin from Johnson and Roberts (2003, fig. 8) and in the Piceance Basin from Johnson and Finn (1986, fig. 9). Isopach map from the top of the Cretaceous to the top of the Tipton Shale Member from Johnson and others (2016, fig. 41).
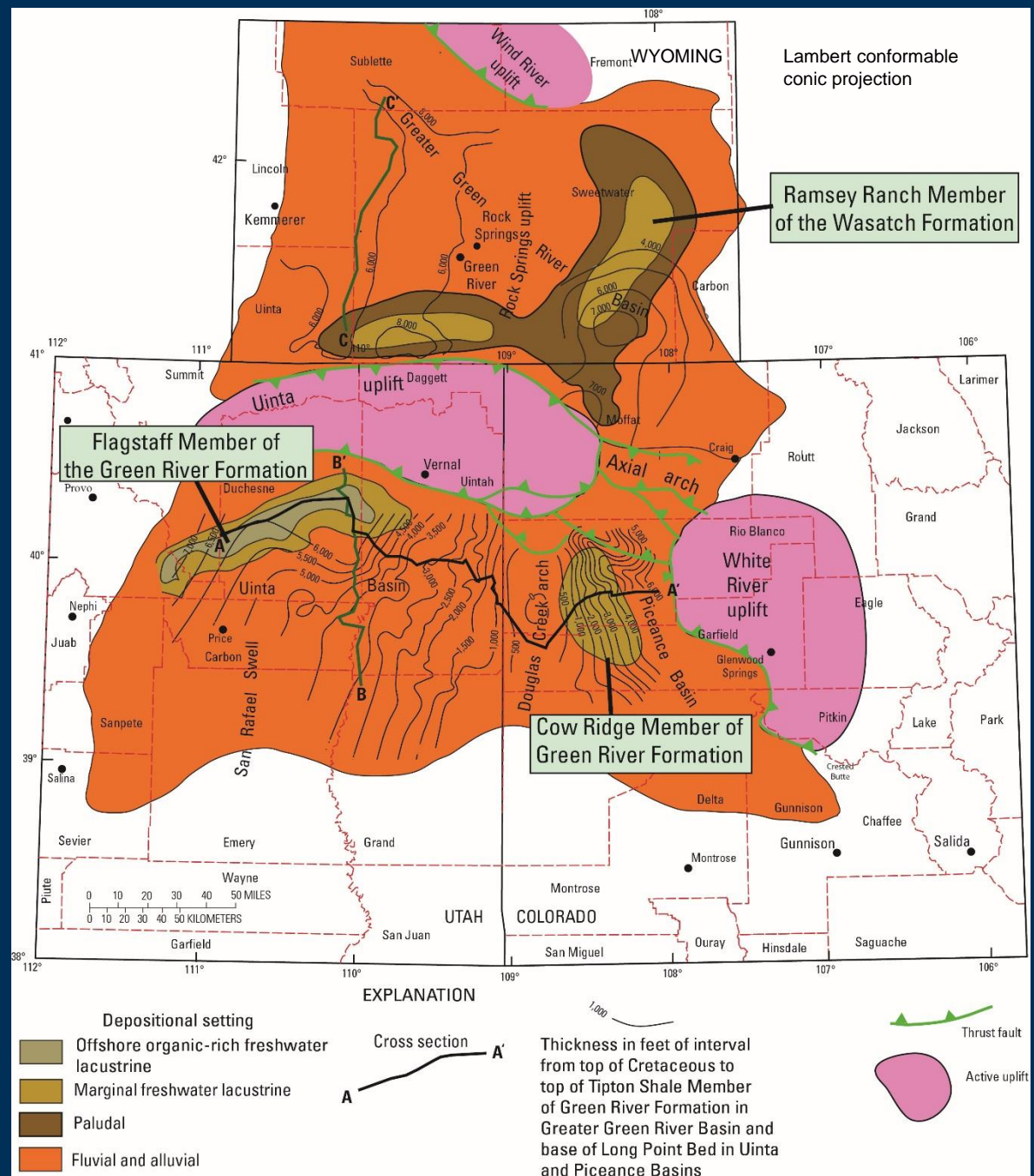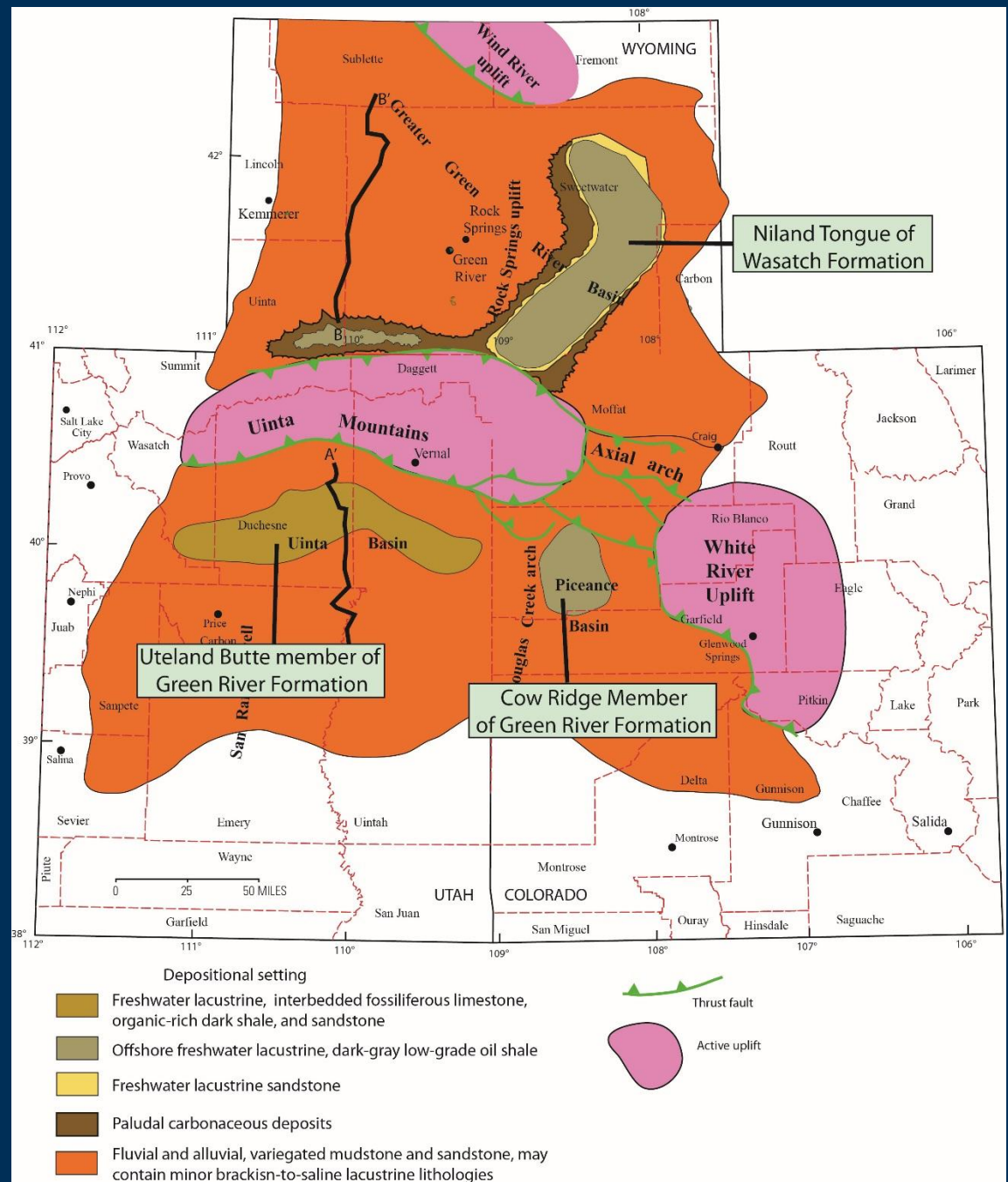
During high lake levels, the lakes expanded to cover large areas of the Uinta, Piceance, and Greater Green River Basins.
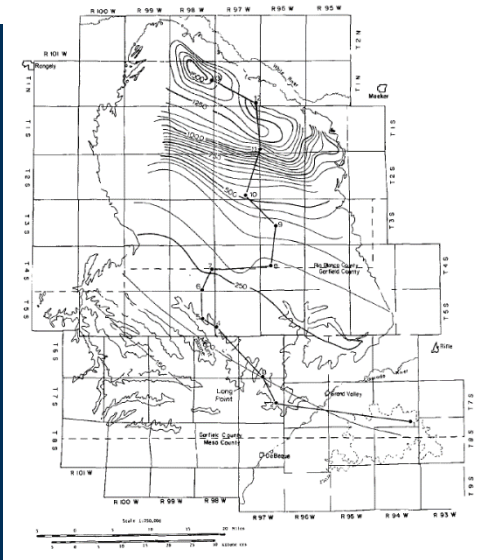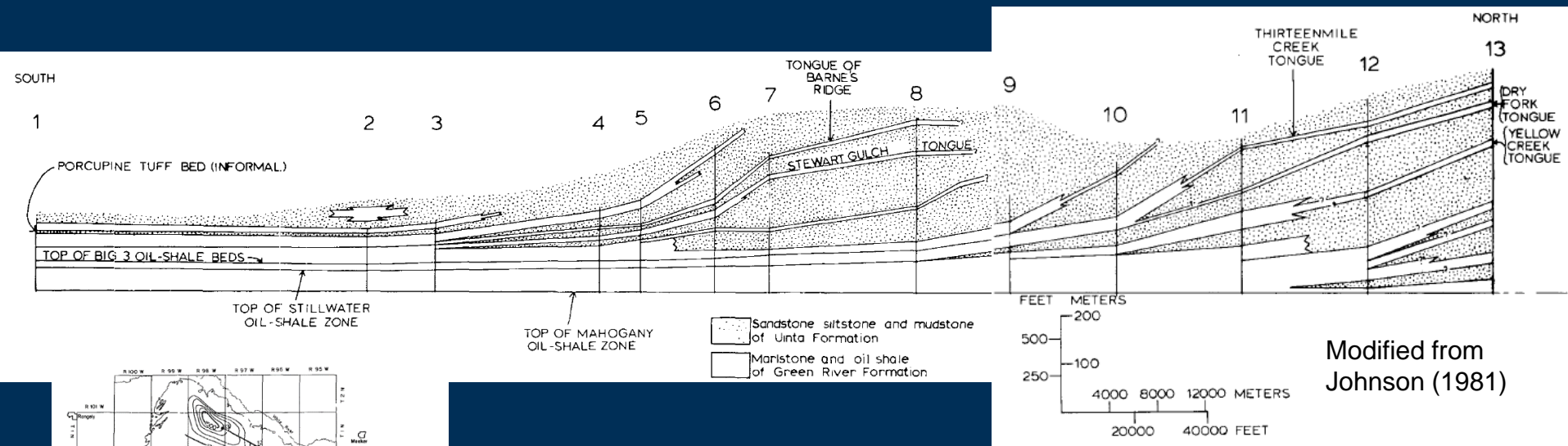
Extent of Luman Tongue of the Green River Formation in the Greater Green River Basin modified from Roehler (1993, fig. 46). Extent of Uteland Butte member of the Green River Formation and Cow Ridge Member of the Green River Formation modified from Johnson and others (2016, fig, 24). Isopach map of the Luman Tongue from Roehler (1992). Isopach map from the top of the Cretaceous to the base of the Long Point Bed of the Green River Formation in the Uinta Basin from Johnson and Roberts (2003, fig. 8) and in the Piceance Basin from Johnson and Finn (1986, fig. 9).
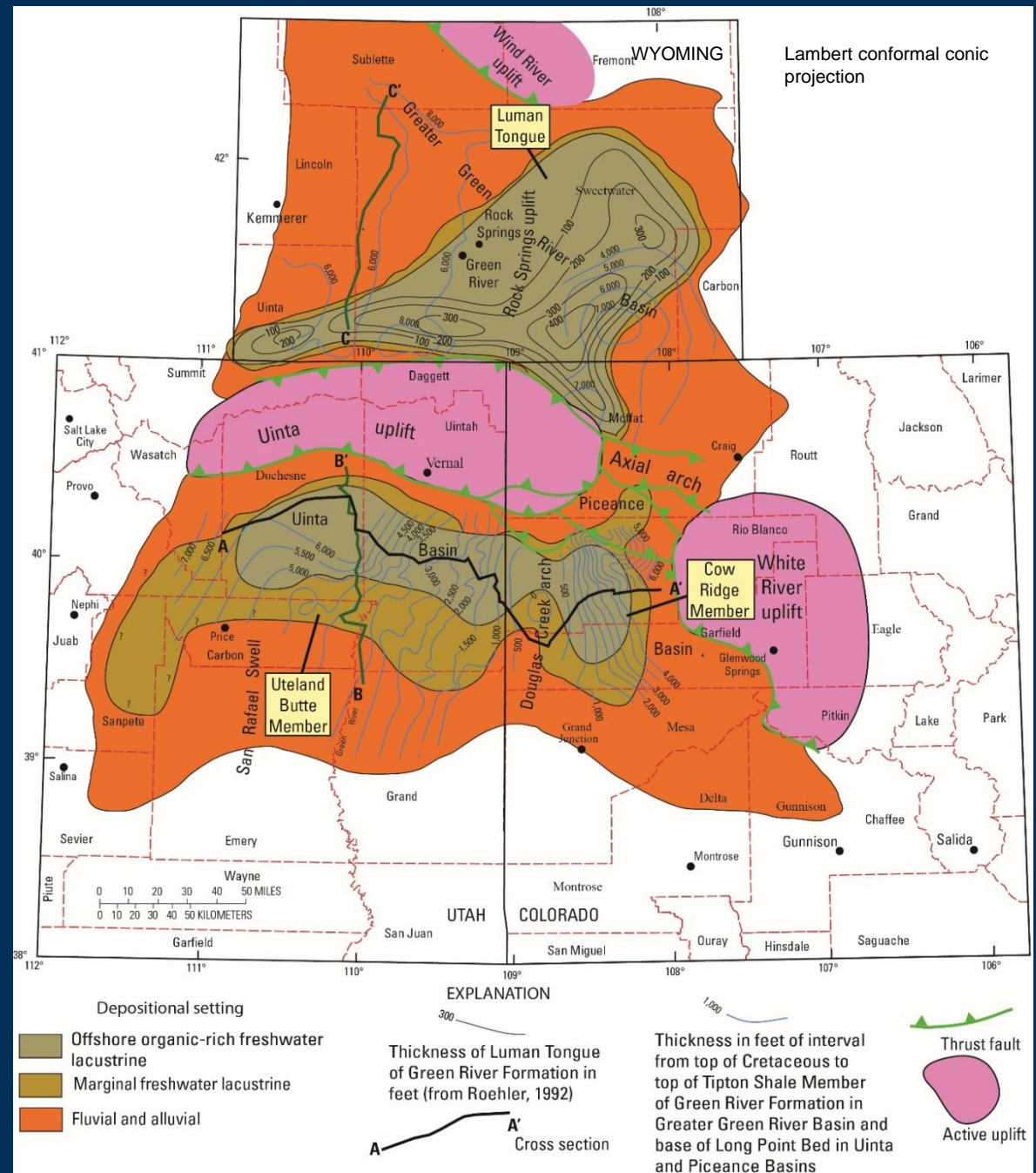
However, during low lake levels, the lakes always retreated into about the same deep lake depocenter areas. This map shows the positions of the lakes just prior to major transgressions that marked the onset of brackish water conditions about 52 million years ago.

Extent of the Niland Tongue of the Wasatch Formation in the Greater Green River Basin modified from Roehler (1993, fig. 49). Extent of Uteland Butte member of the Green River Formation in the Uinta Basin and Cow Ridge Member of the Green River Formation in the Piceance Basin from Johnson and others (2016, fig. 41).

Depositional setting

Freshwater lacustrine, interbedded fossiliferous limestone, organic-rich dark shale, and sandstone

Offshore freshwater lacustrine, dark-gray low-grade oil shale

Freshwater lacustrine sandstone

Paludal carbonaceous deposits

Fluvial and alluvial, variegated mudstone and sandstone, may contain minor brackisn-to-saline lacustrine lithologies

Thrust fault

Active uplift

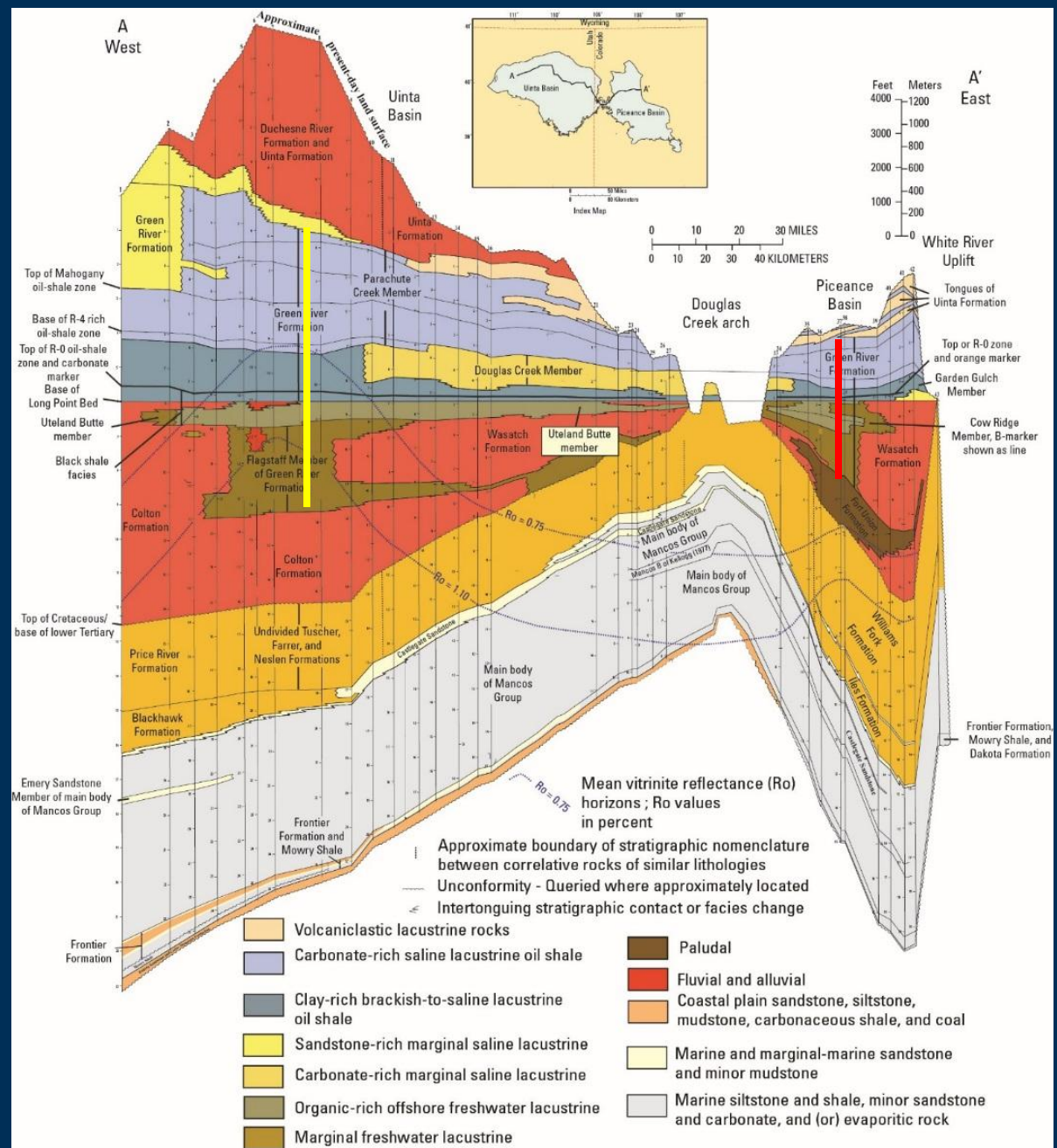Modified from Johnson (1981)

When the Piceance Basin part of Lake Uinta was filled in, a delta formed with foresets as high as 1,350 feet. The lake in the Piceance Basin depocenter was thus very deep, and it is likely that the Uinta depocenter was deep as well.

A deep depocenter is much less likely to shift position through time than is a shallow depocenter that could be easily filled in by relatively minor shifts in subsidence and (or) sediment supply.

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.

In the heart of the Uinta Basin depocenter, there are more than 9,500 feet of continuous, mostly fine grained, offshore lacustrine rock (yellow line). Much, if not most, of this interval was probably organic-rich prior to hydrocarbon generation. The maximum thickness of offshore lacustrine rock in the Piceance Basin depocenter is about 4,000 feet (red line).

The two deep depocenters were separated by shallow water conditions over the Douglas Creek arch.

Cross section modified from Johnson (1989)

The lower clay-rich part of the Green River Formation in the Uinta Basin is informally known as the "black shale facies" (black arrows). It generated large amounts of hydrocarbons in the structurally deepest part of the basin, charging many of the oil fields including the Altamont-Bluebell field (Anders and Gerrild, 1984; Ruble and others, 2001).

We are proposing that, based on apparent lower organic matter content (for example, depletion of oil-generating potential), oil shale in the overlying carbonate-rich Parachute Creek Member (blue arrows) also generated large amounts of hydrocarbons.
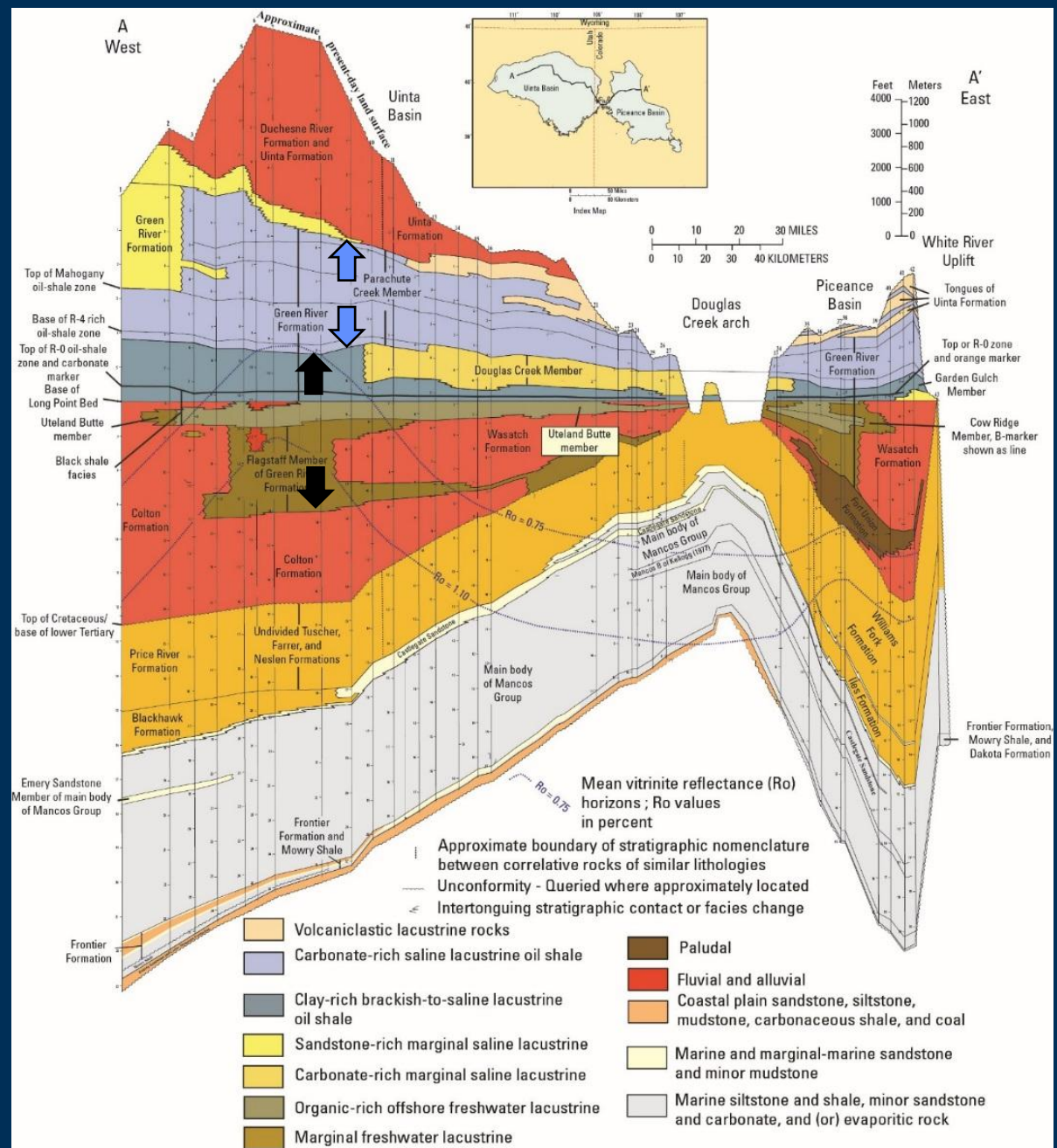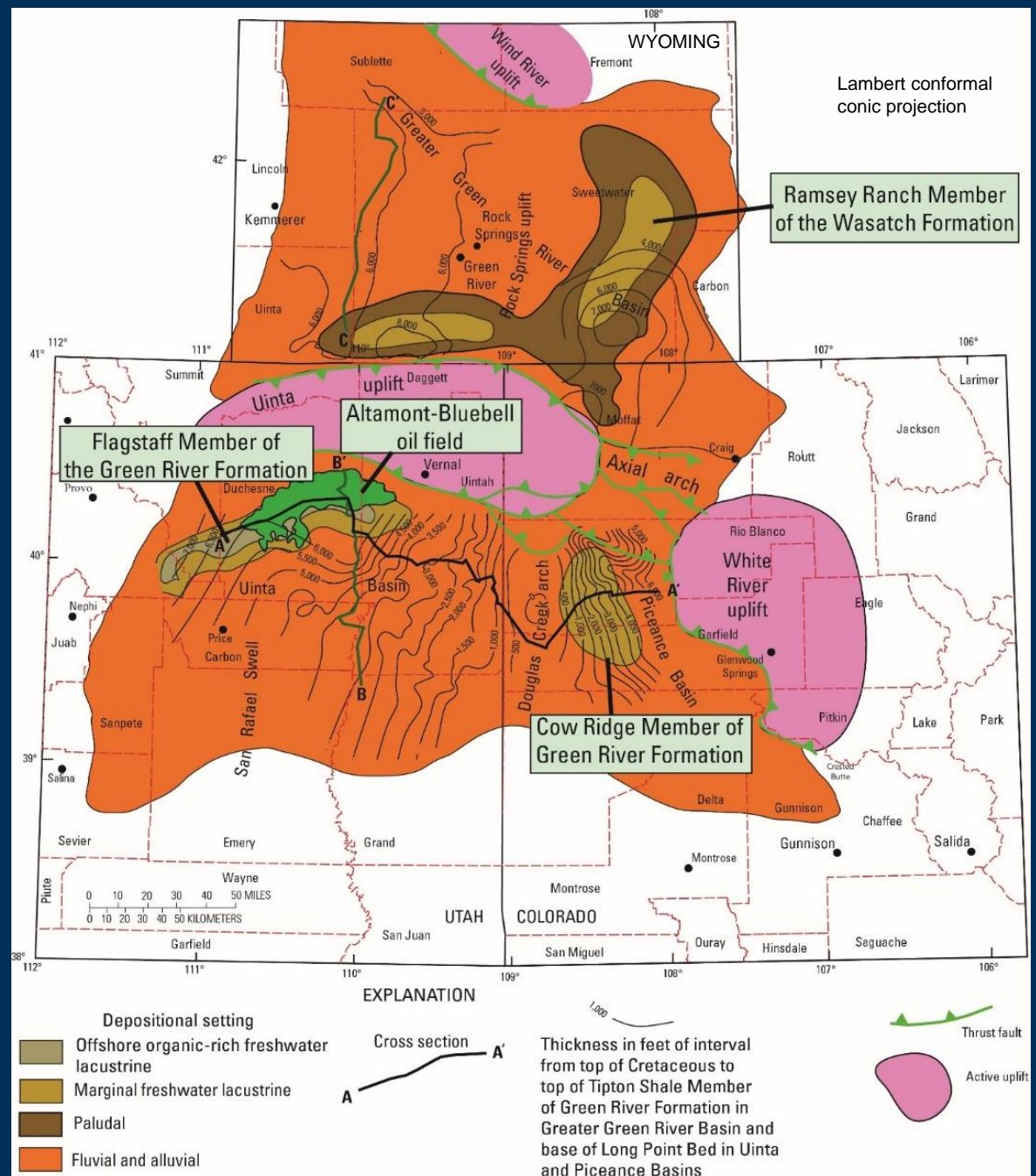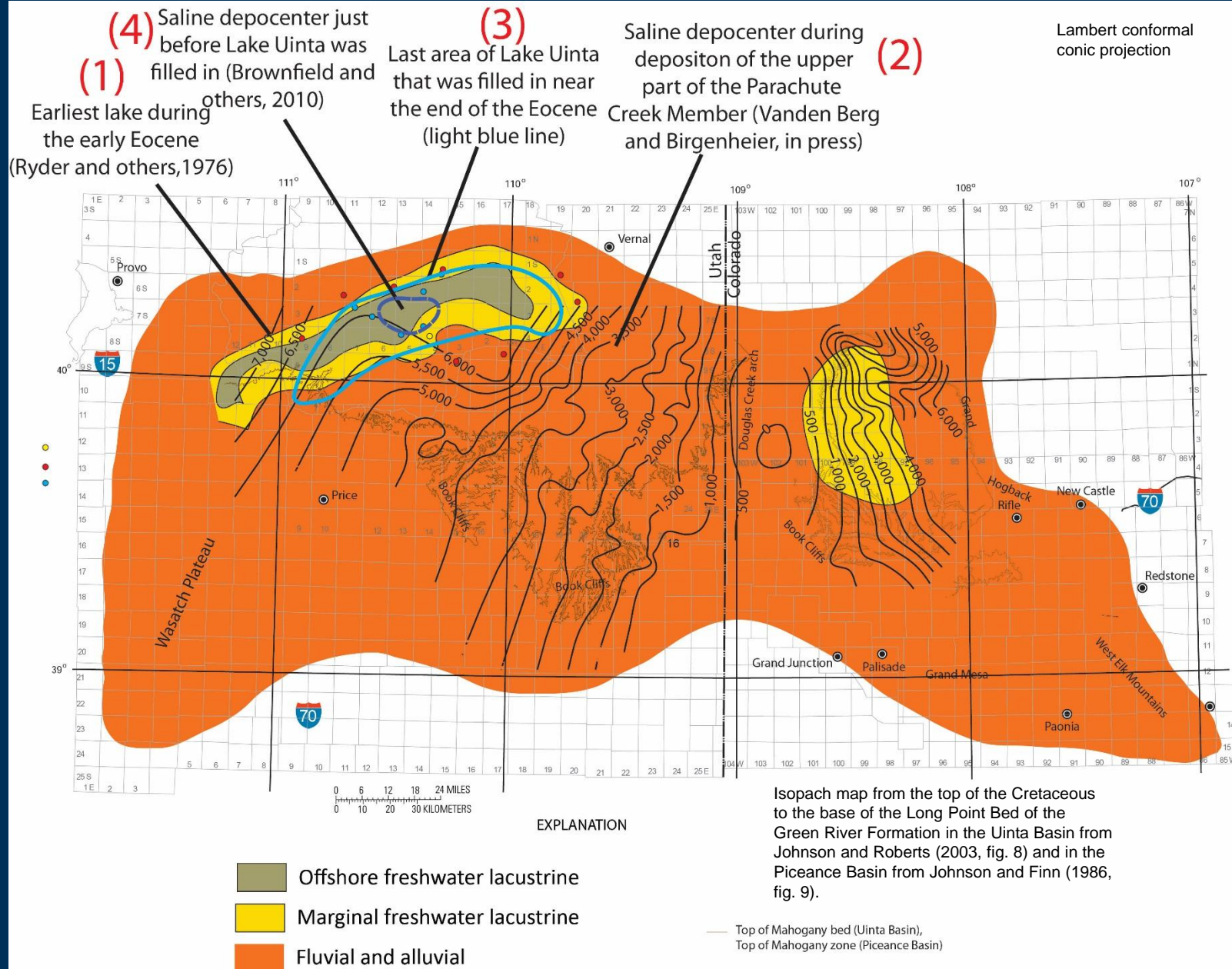
Cross section modified from Johnson (1989)

The Altamont-Bluebell oil field produces Green River-sourced oil from marginal lacustrine and fluvial sandstones adjacent to organic-rich, thermally mature offshore lacustrine rocks of the "black shale facies."

Organic-rich rocks in the Piceance Basin depocenter were never buried deeply enough to have generated significant hydrocarbon volumes (Nuccio and Roberts, 2003).

Extent of the earliest lakes in the Uinta, Piceance, and Greater Green River Basins. Extent of Ramsey Ranch Member of Wasatch Formation in the Greater Green River Basin modified from Roehler (1993, fig. 45). Extent of Flagstaff Member of the Green River Formation in the Uinta Basin modified from Ryder and others (1976, fig, 15). Extent of the Cow Ridge Member of the Green River Formation in the Piceance Basin modified from Johnson and others (2016).
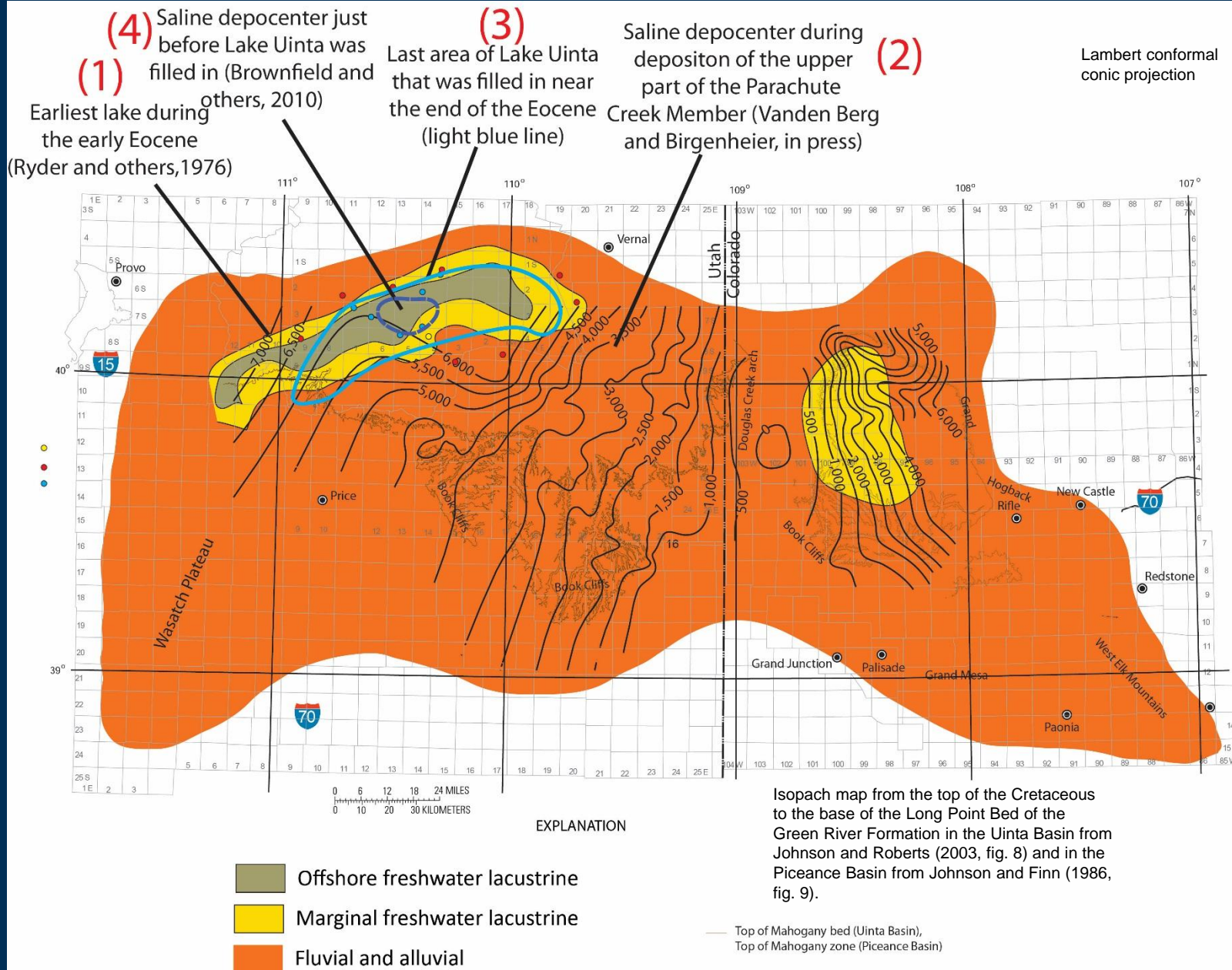
(4) Saline depocenter just before Lake Uinta was filled in (Brownfield and others, 2010)

(3) Last area of Lake Uinta that was filled in near the end of the Eocene (light blue line)

(1) Earliest lake during the early Eocene (Ryder and others, 1976)

(2) Saline depocenter during depositon of the upper part of the Parachute Creek Member (Vanden Berg and Birgenheier, in press)

Lambert conformal conic projection

Isopach map from the top of the Cretaceous to the base of the Long Point Bed of the Green River Formation in the Uinta Basin from Johnson and Roberts (2003, fig. 8) and in the Piceance Basin from Johnson and Finn (1986, fig. 9).

EXPLANATION

Offshore freshwater lacustrine

Marginal freshwater lacustrine

Fluvial and alluvial

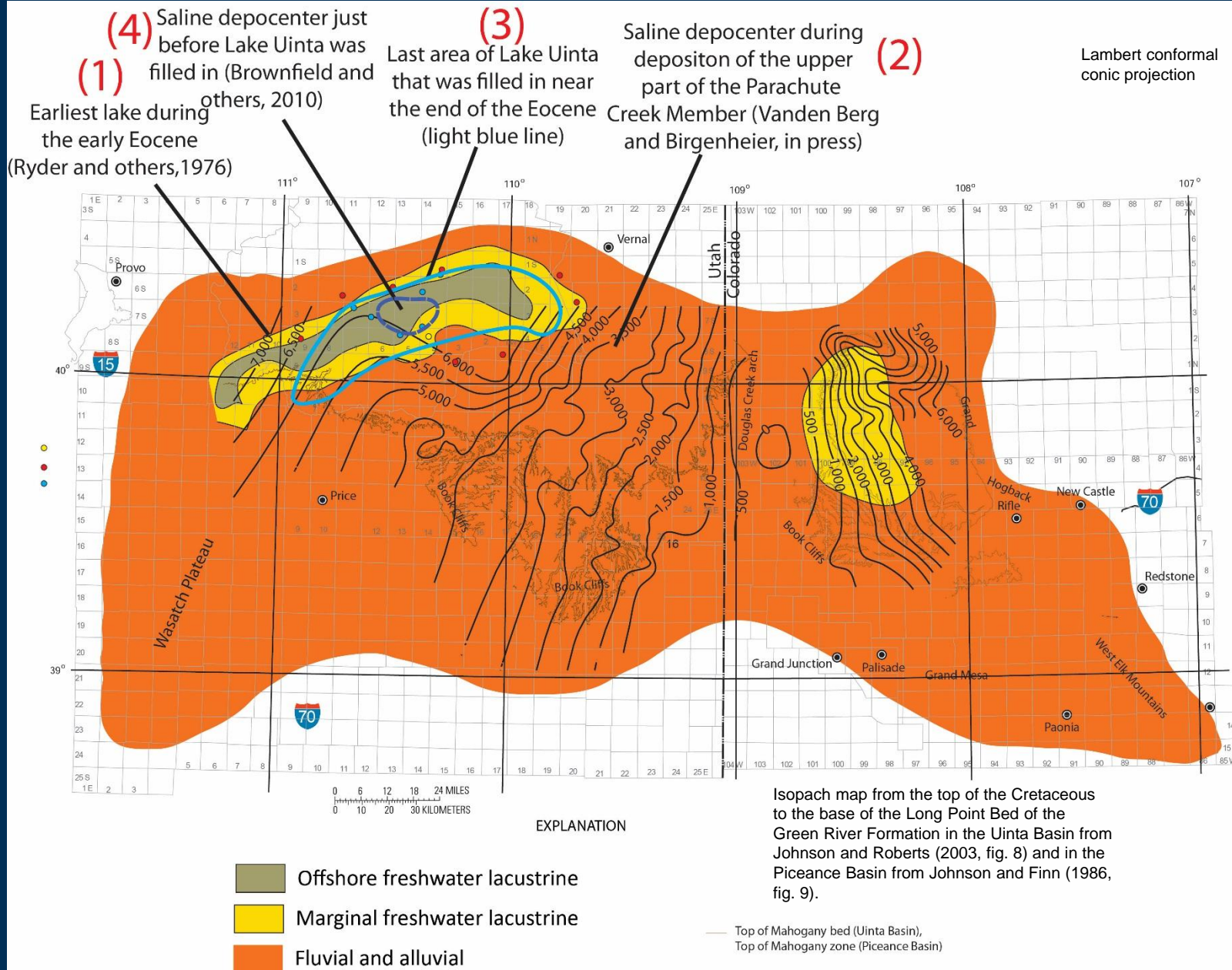Top of Mahogany bed (Uinta Basin), Top of Mahogany zone (Piceance Basin)

The very last lake to occupy the Uinta Basin near the end of the Eocene occupied almost the same area as the very first lake, suggesting that the position of the deepest part of the lake did not change much through time..

(1) Earliest lake during the early Eocene (Ryder and others, 1976)

(4) Saline depocenter just before Lake Uinta was filled in (Brownfield and others, 2010)

(3) Last area of Lake Uinta that was filled in near the end of the Eocene (light blue line)

(2) Saline depocenter during deposition of the upper part of the Parachute Creek Member (Vanden Berg and Birgenheier, in press)

Lambert conformal conic projection

EXPLANATION

Offshore freshwater lacustrine

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Isopach map from the top of the Cretaceous to the base of the Long Point Bed of the Green River Formation in the Uinta Basin from Johnson and Roberts (2003, fig. 8) and in the Piceance Basin from Johnson and Finn (1986, fig. 9).

Top of Mahogany bed (Uinta Basin), Top of Mahogany zone (Piceance Basin)

The saline mineral nahcolite in the Parachute Creek Member today is confined to the eastern part of the basin (2), whereas saline minerals in the uppermost part of the Green River Formation are much further west (3). This suggests that the depocenter shifted back and forth through time.

(4) Saline depocenter just before Lake Uinta was filled in (Brownfield and others, 2010)

(1) Earliest lake during the early Eocene (Ryder and others, 1976)

(3) Last area of Lake Uinta that was filled in near the end of the Eocene (light blue line)

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EXPLANATION

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Isopach map from the top of the Cretaceous to the base of the Long Point Bed of the Green River Formation in the Uinta Basin from Johnson and Roberts (2003, fig. 8) and in the Piceance Basin from Johnson and Finn (1986, fig. 9).

Top of Mahogany bed (Uinta Basin), Top of Mahogany zone (Piceance Basin)

We propose instead that saline minerals were once present in the Parachute Creek Member throughout the Uinta Basin depocenter, but in the structurally deepest part, these minerals may have dissolved out or decomposed during thermal maturation (which also led to petroleum generation) at the time of maximum burial.

Modified from Dyni (1987)
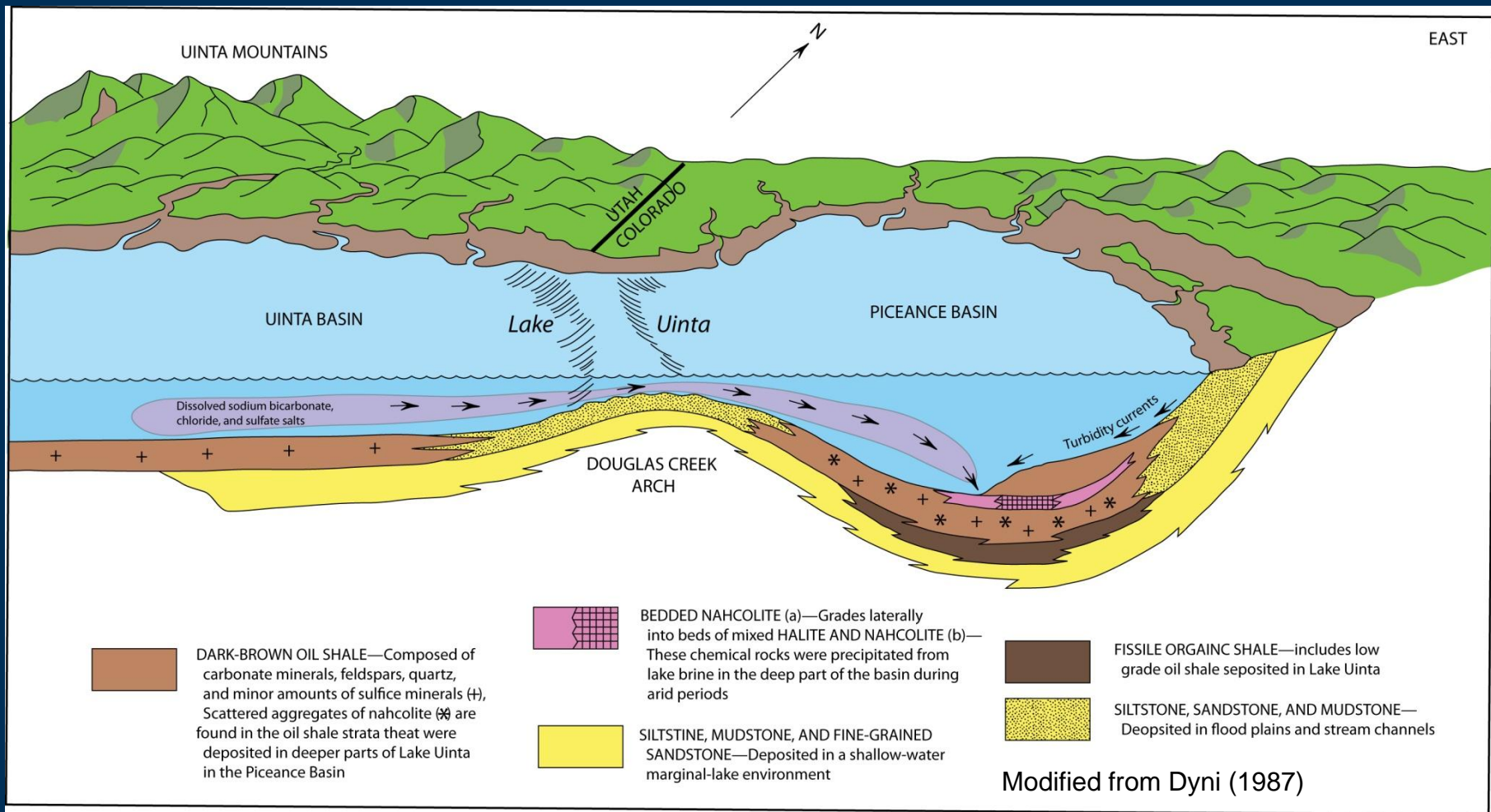
Dyni (1987) noted that saline minerals were concentrated in the eastern part of the Uinta Basin depocenter, and proposed that a net flow of water from the Uinta to the Piceance Basin concentrated the saline brines to the eastern part of the Uinta Basin depocenter. We propose instead that the entire deep depocenter in the Uinta Basin once contained saline minerals, such as nahcolite and possibly halite. Nahcolite would have thermally decomposed in the high heat during maximum burial, and decomposition products of nahcolite (for example, sodium carbonate) and any halite present could have been dissolved and removed by groundwater.
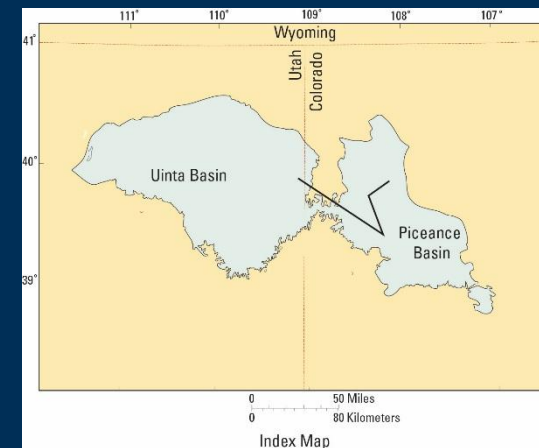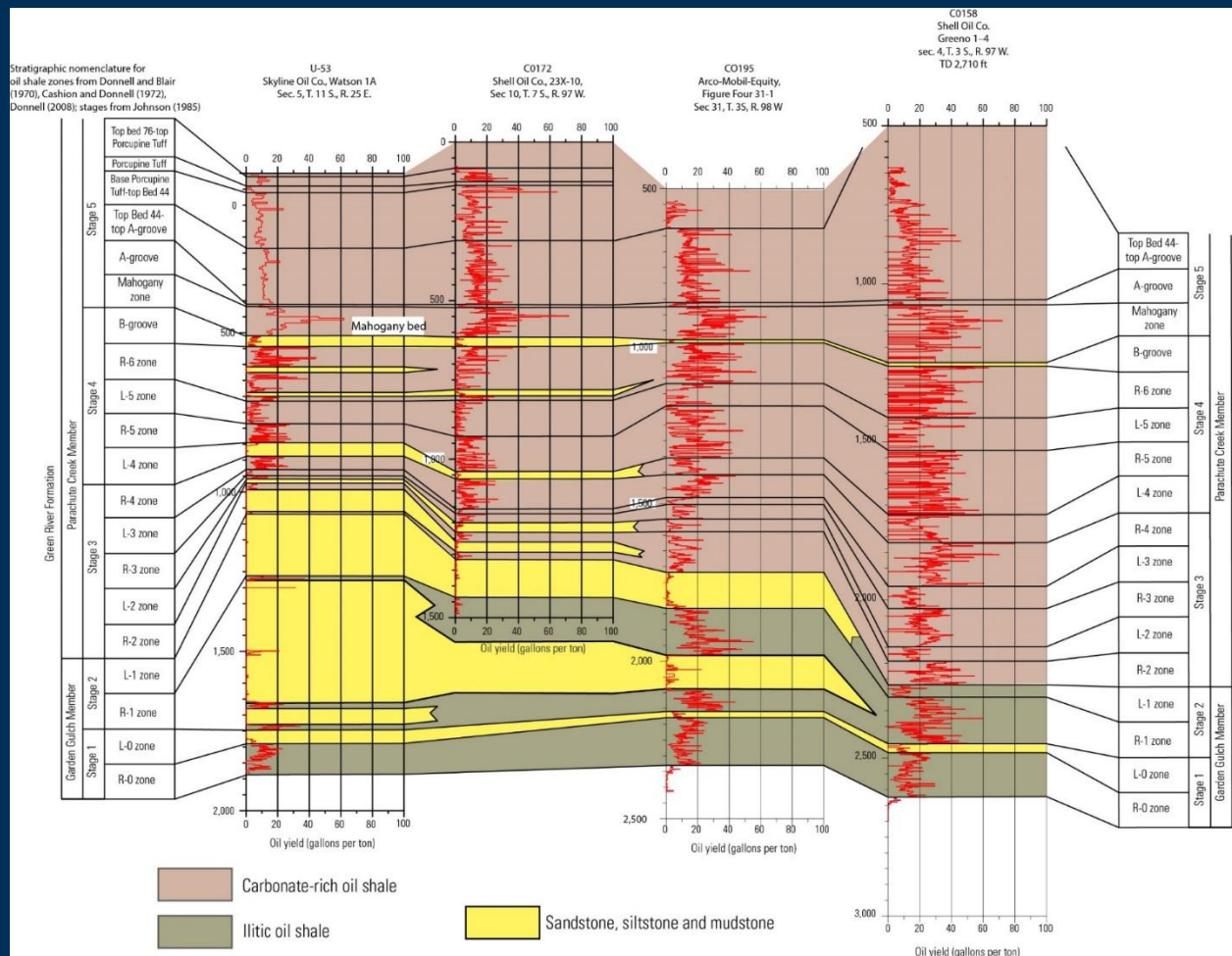
The oil-shale interval in the Uinta and Piceance Basin was subdivided by Cashion and Donnell (1972) into laterally persistent, time-stratigraphic rich and lean zones. This is a powerful tool for studying the evolution of Lake Uinta.
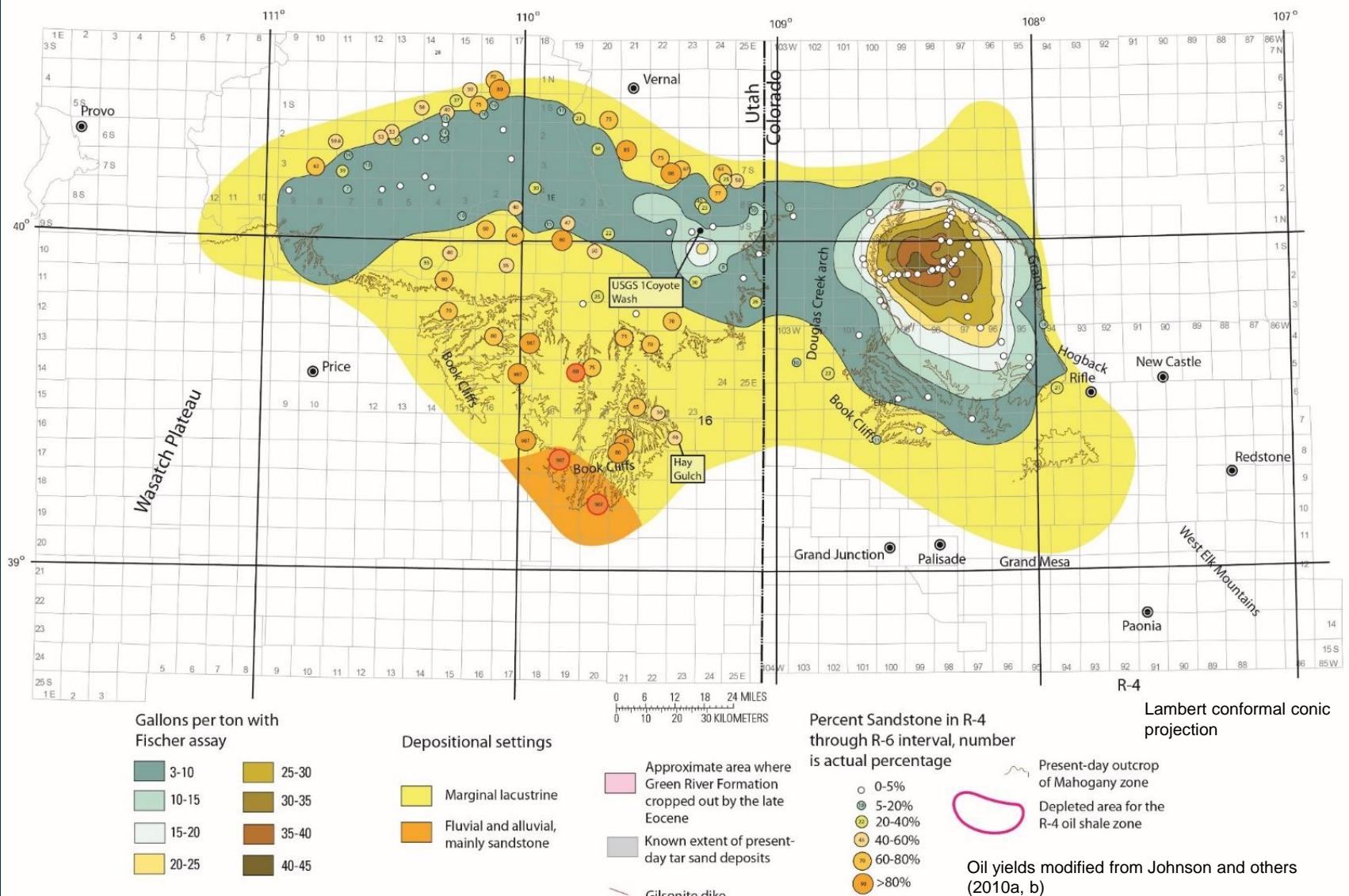
For this study, the percentage sandstone from Amstrat logs and surface sections was added to the oil yield maps for each oil shale zone from the USGS oil shale assessments (Johnson and others, 2010a, b). The two depocenters are the areas that contain very little sandstone.
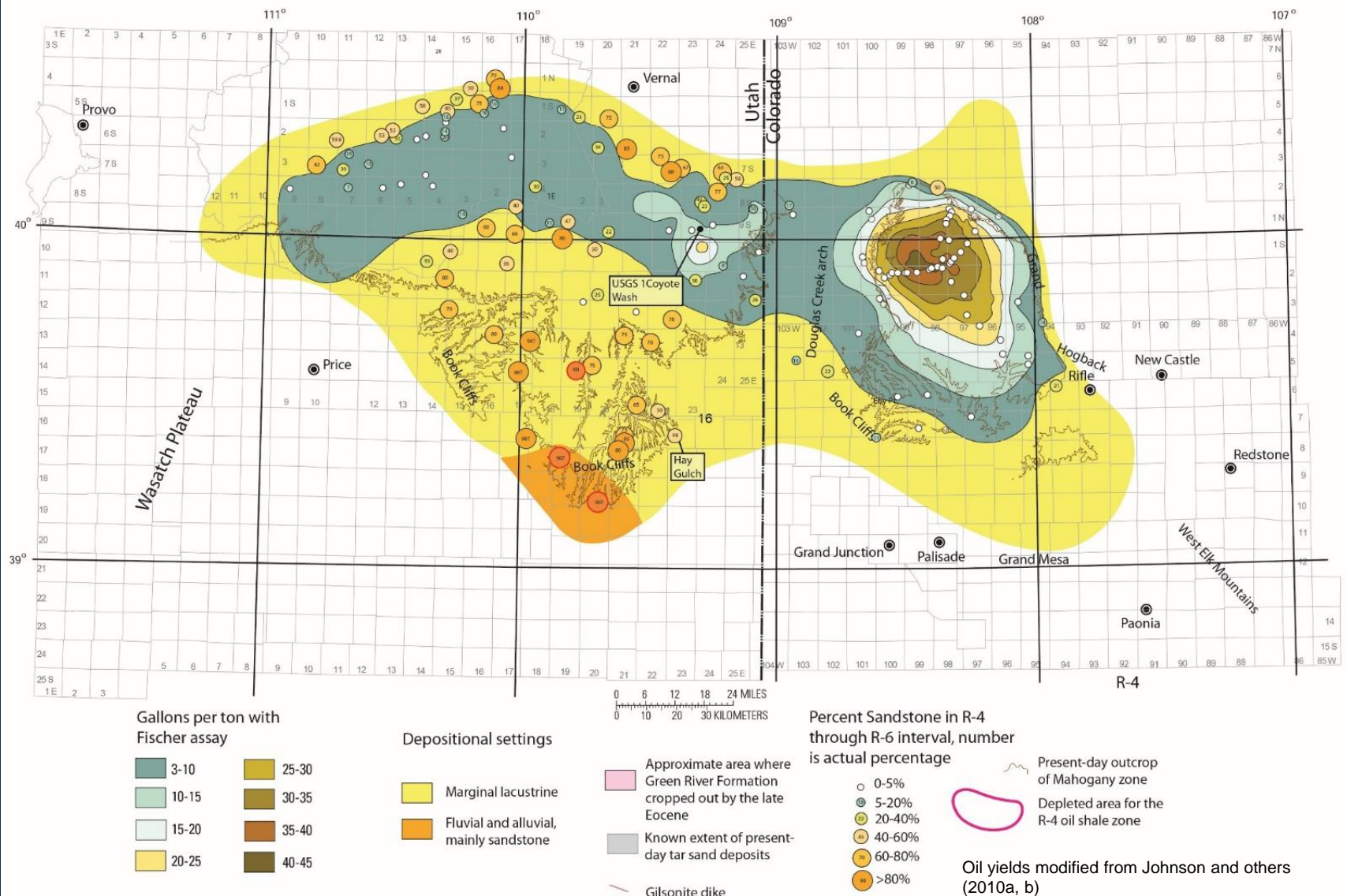
Note that oil yields increase markedly toward the central part of the Piceance Basin depocenter. In contrast, oil yields in the Uinta Basin are high in the eastern part of the depocenter but decrease markedly toward the west.
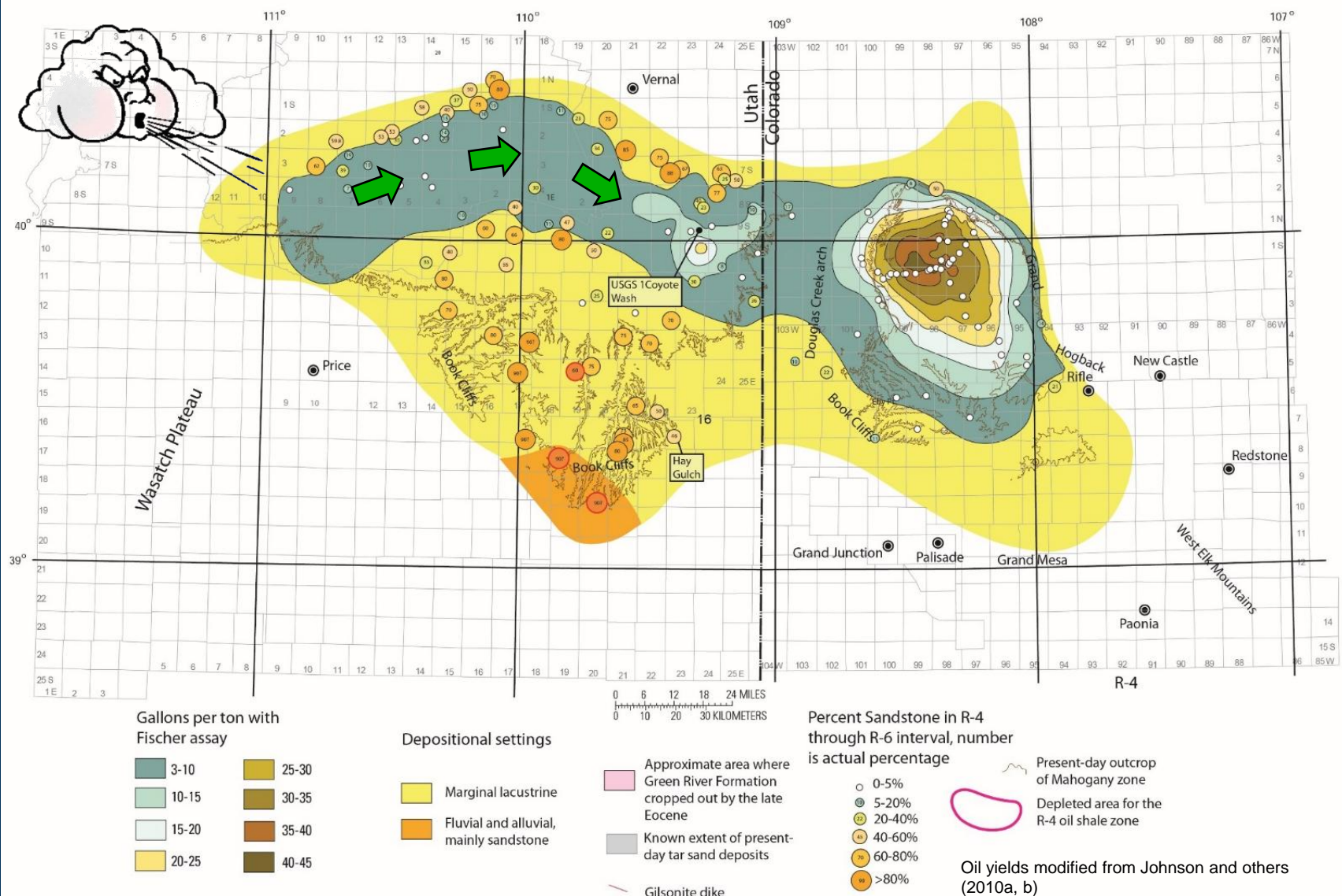
Wind-driven currents perhaps led to movement of organic matter toward the eastern part of the Uinta Basin depocenter. However, no eastward organic matter concentration gradient is apparent in the Piceance Basin depocenter. In addition, much of the organic matter in the Piceance Basin depocenter was brought in by mass-movement processes from marginal areas (Dyni and Hawkins, 1981). These deposits would not have been affected by winds.

End of early saline mineral phase

Oil shale and saline mineral depocenter begins to fill in. Offshore lacustrine conditions expand across marginal flats.

Douglas Creek arch

Organic matter, carbonate ripups, and brines

Laminated and blebby oil shale and nahcolite

Section thickens to east due to increased subsidence toward the White River uplift

Carbonate mudflats

Sandy mudflats

White River uplift

Variegated mudstone, sandstone, and siltstone

Carbonate-rich marginal lacustrine mudstone with ostracodal, oolitic, and stromatolitic limestones

Sandstone-rich marginal lacustrine mudstone with some ostracodal, oolitic, and stromatolitic limestones

Rich illitic oil shale

Nahcolite

Lean dolomitic oil shale

Rich dolomitic oil shale with nahcolite and halite

Areas where intense evaporation could produce brines. Queried where freshwater input may have inhibited brine formation

Saline brines

Organic matter and carbonate ripups

Modified from Johnson and Brownfield (2015)

Lake Uinta was probably a stratified lake with a highly saline lower layer and a fresher upper layer (Bradley, 1963; Bradley and Eugster, 1969). Salt crusts formed on the broad shallow flats surrounding the lake (Smith, 1974). During high lake levels the salt would have redissolved forming dense brines that migrated to the deep part of the lake (Smith, 1974). The brines likely picked up organic matter and carbonate ripups as they moved forming the "blebby" oil shale intervals in the Piceance Basin depocenter (Dyni, 1981; Dyni and Hawkins, 1981; Johnson and Brownfield, 2015; Johnson and others, 2015).

Mass-movement deposits are common in the oil shale depocenter in the Piceance Basin. Dyni (1981) and Dyni and Hawkins (1981) studied those deposits in core and attributed some of them to deep-water turbidity currents.

Dyni (1981) and Dyni and Hawkins (1981) estimated 40-50% of the lower part of the Parachute Creek Member in the central part of the basin consisted of what they referred to as "blebby" oil shale.

In the upper right image, note the grading in the blebby oil shale bed from abundant large marlstone fragments at the base to kerogen in a very-fine grained matrix at the top.
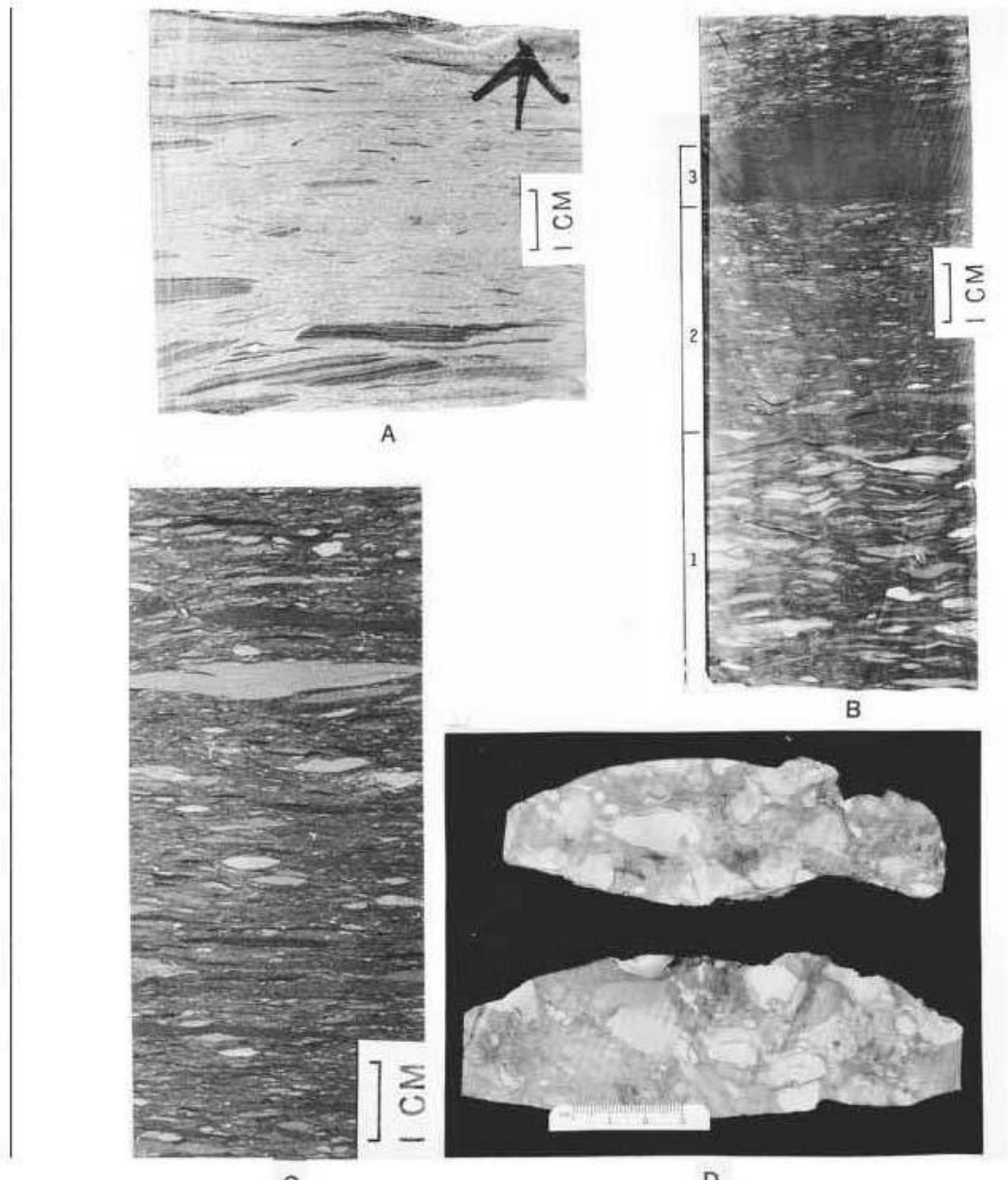
Examples of "blebby" oil shale from the central part of Lake Uinta, Piceance Basin. (From Dyni, 1981)
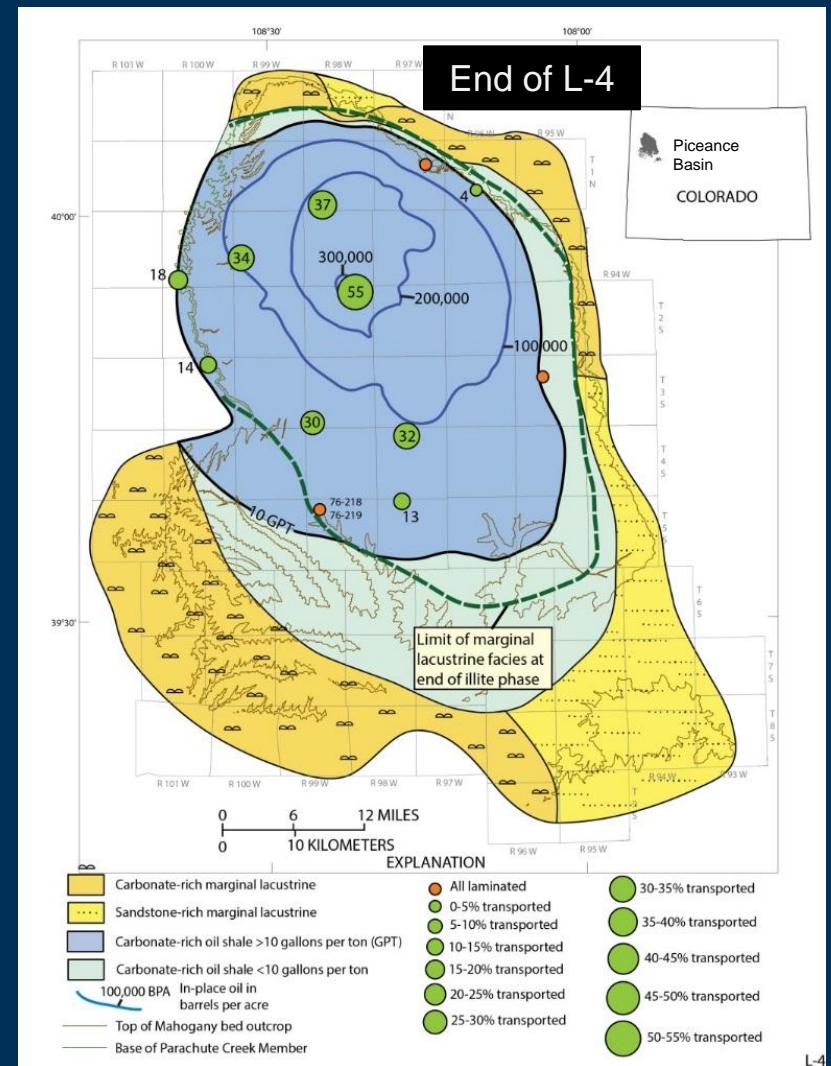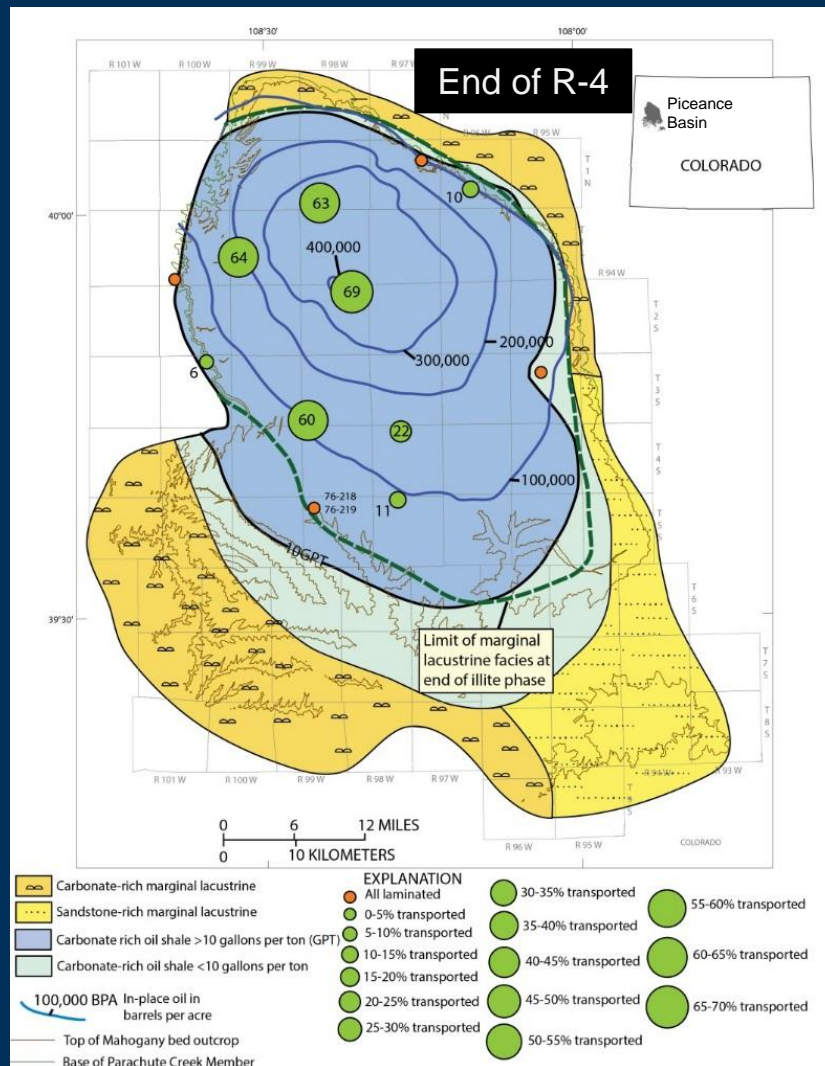
Modified from Johnson and others (2015)

Mass-movement deposits comprise the majority of many of the oil shale zones in the Piceance Basin depocenter. It is likely that they also comprise a significant portion of the interval in the Uinta Basin depocenter. Once buried in the deep part of the lake, these organic-rich sediments would not have moved.

Mass-movement deposits are present in the oil shale interval in the Uinta Basin suggesting that, similar to the Piceance Basin, much of the oil shale deposited along the deep depocenter of the Uinta Basin may have been brought in from more marginal areas. We believe that this is further evidence that wind was not the major factor determining organic matter distribution in the Uinta Basin.

Blebby oil shale in Mahogany zone in EOG Resources Pete's Wash U 13-06 GR hole in Sec. 6, T. 10 S., R. 16 E.
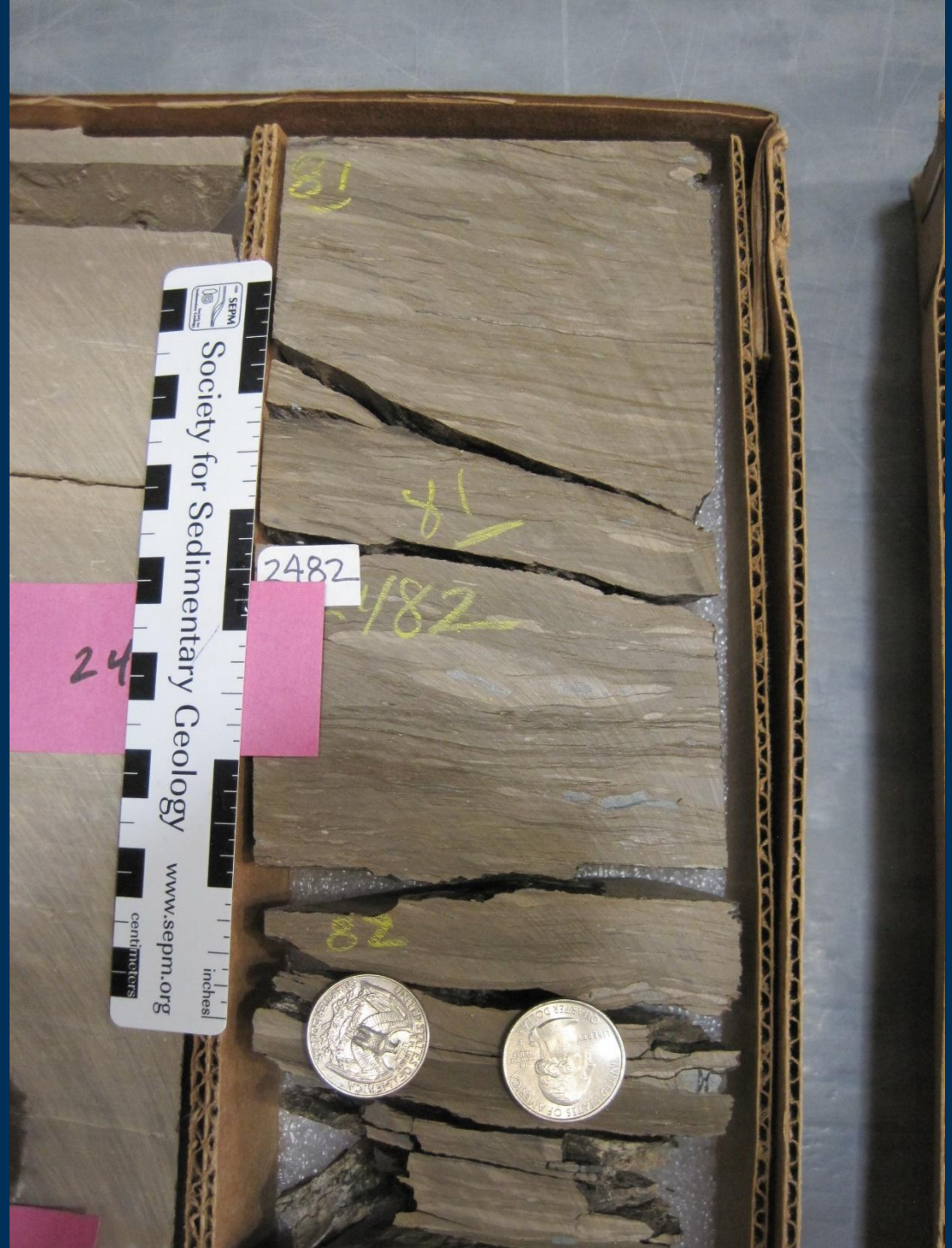
We propose that the decrease in organic richness toward the deep part of the Uinta Basin is due largely to petroleum generation and migration.
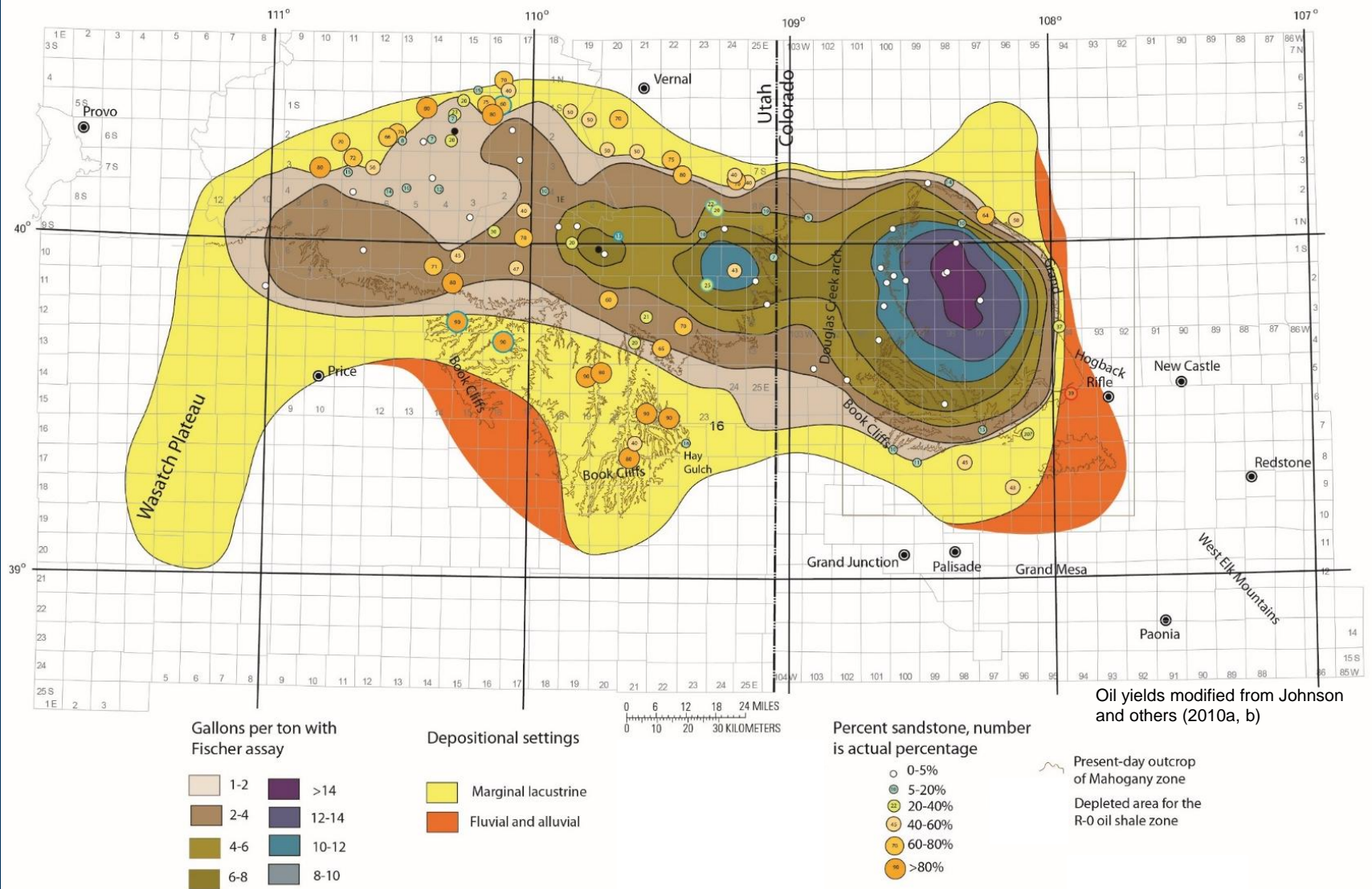
Oil yield map for the R-0 zone, the oldest oil shale zone assessed in the recent oil shale assessment (Johnson and others, 2010b). Note the two depocenters are defined by the lack of sandstone and that oil yields decrease toward the western part of the Uinta Basin depocenter..
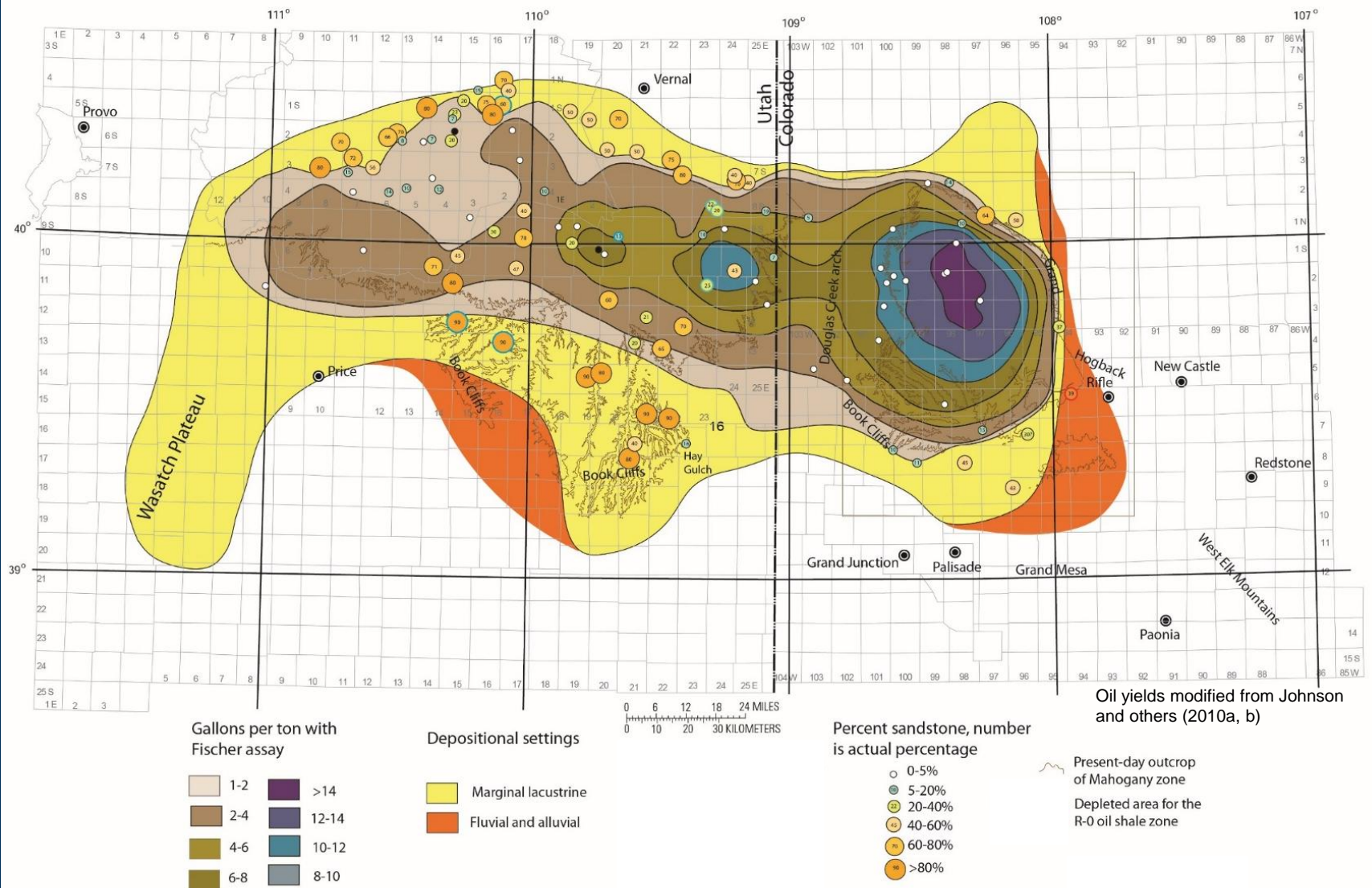
The R-0 zone is a clay-rich interval in the middle of the "black shale facies" that is known to have generated large amounts of hydrocarbons along the deep basin trough (see, for example, Ruble and others, 2001).

Oil yields modified from Johnson and others (2010a, b)
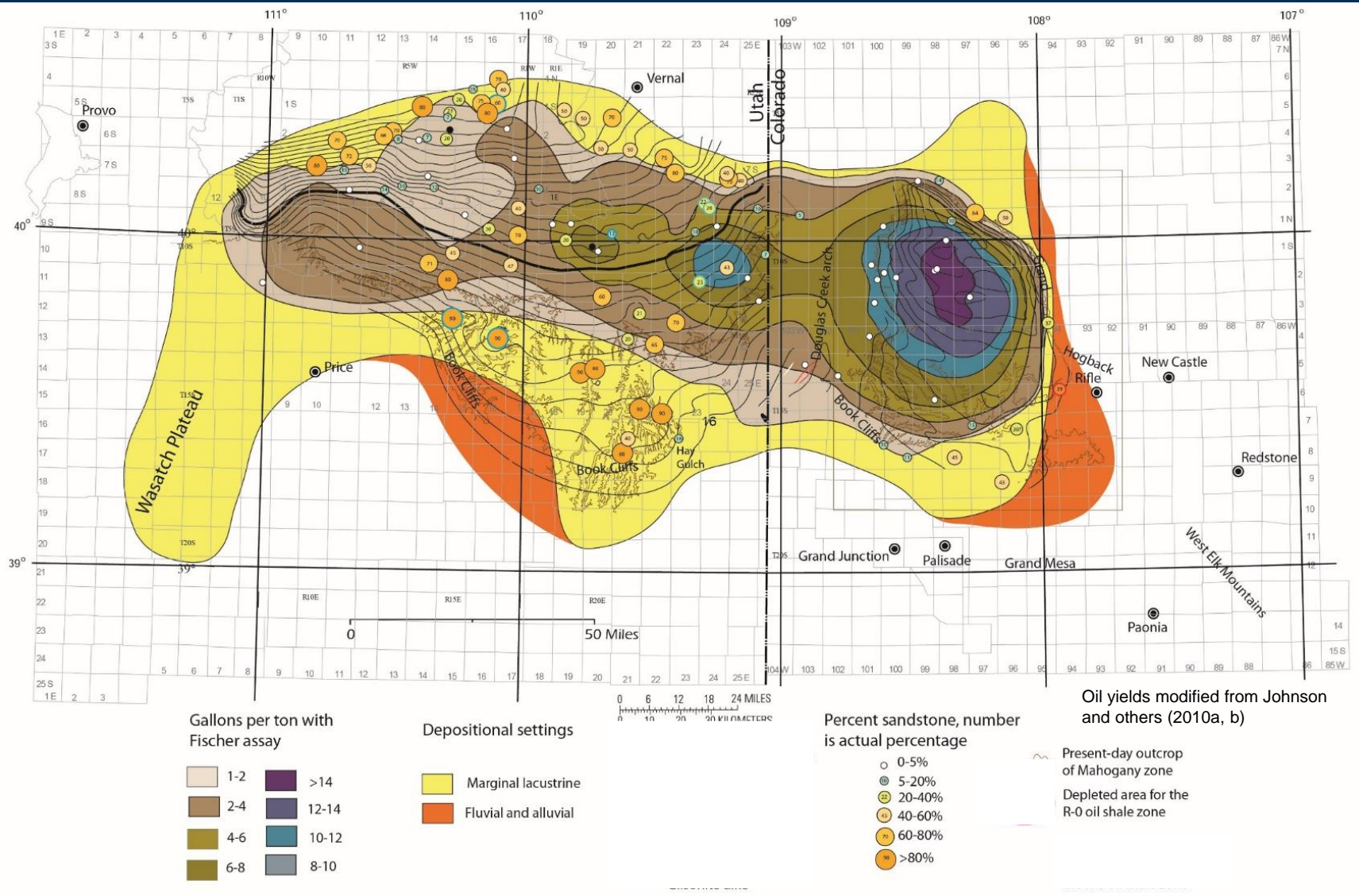
Combining a structure contour map of the Long Point bed, which forms the base of the R-0 zone, and the previous map shows that oil yields appear to decrease along a particular contour line (shown in bold). This indicates that oil yields decrease when maximum overburden prior to uplift and erosion reaches a certain thickness.
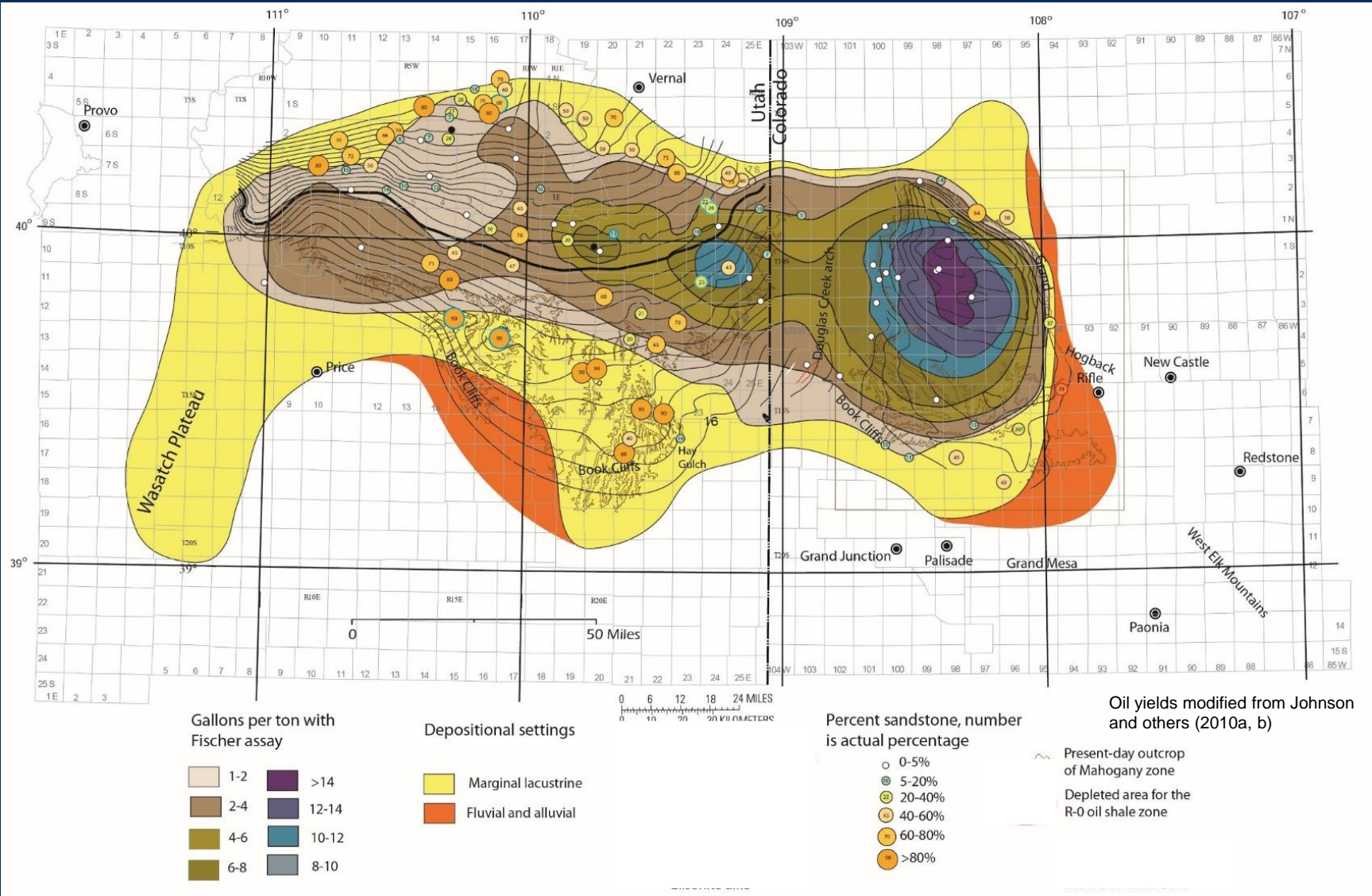
Rock-evaluation pyrolysis (Rock-Eval) studies of samples from two drillholes within the area outlined in black (black dots) indicate that the R-0 zone has generated hydrocarbons (Anders and Gerrild, 1984; Anders and others, 1992).
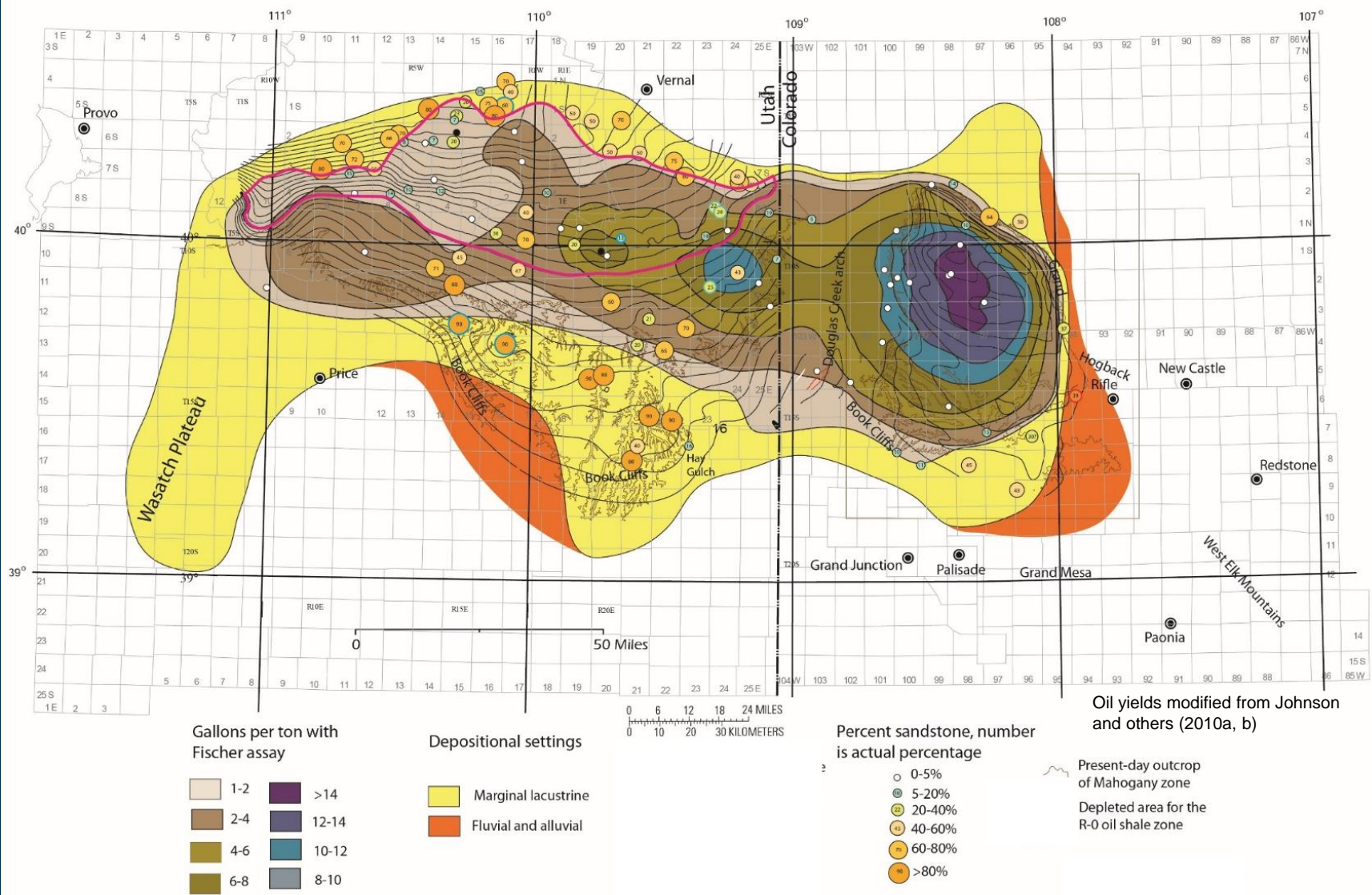
The decrease in oil yields toward the deep trough of the Uinta Basin, as defined by Fischer assay and the structure contour map on the base of the R-0 zone, can be used to approximate the area where the R-0 zone has generated hydrocarbons (red line).
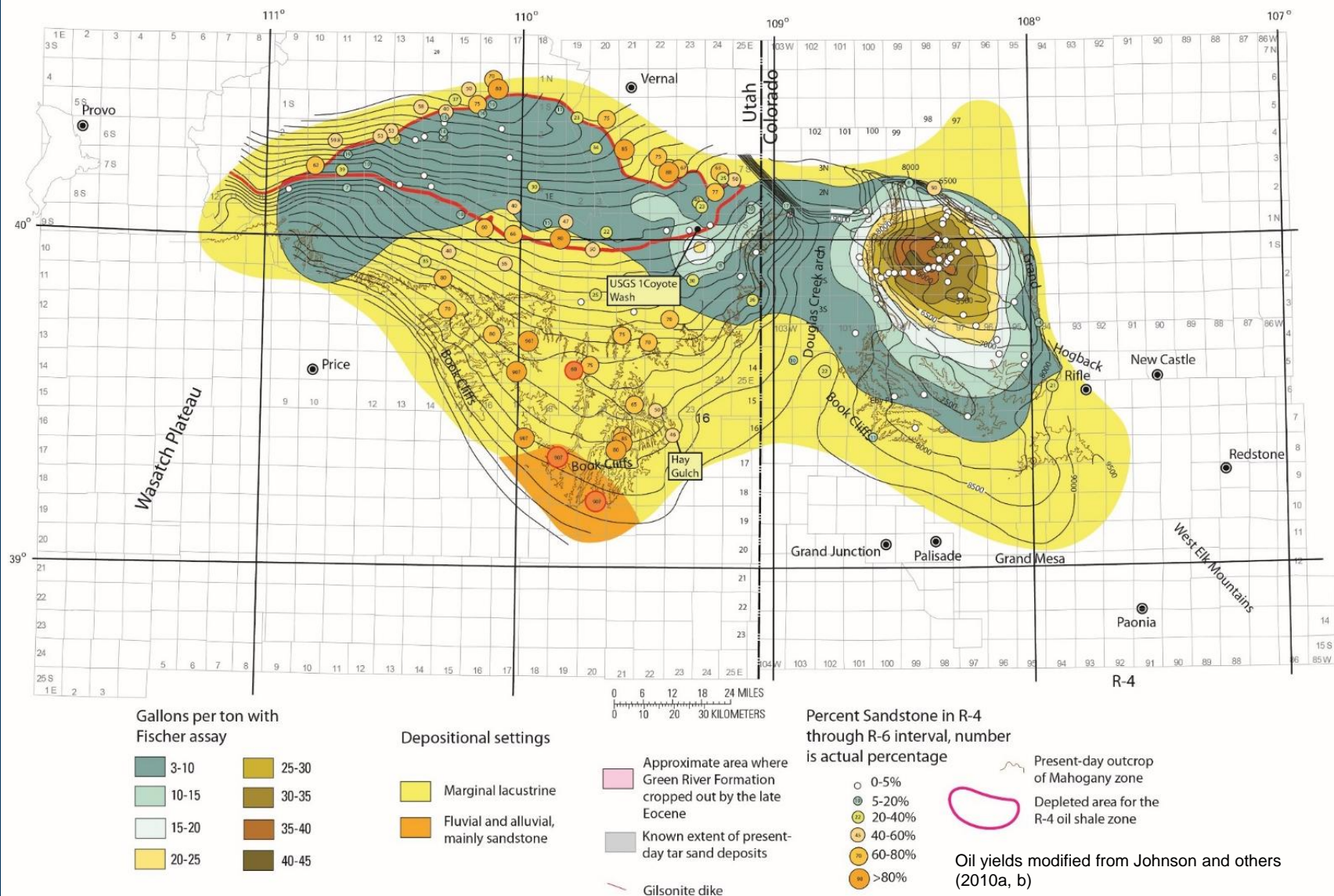
Similar decreases in oil yield toward the structural trough of the basin combined with structure contour maps (here, the top of the Mahogany oil shale zone) were used to define "depleted areas" for all other assessed oil shale zones. Shown are variations in oil yield for the R-4 oil shale zone and hypothesized area of depleted petroleum-generating potential based on Fischer assay yields (red line).
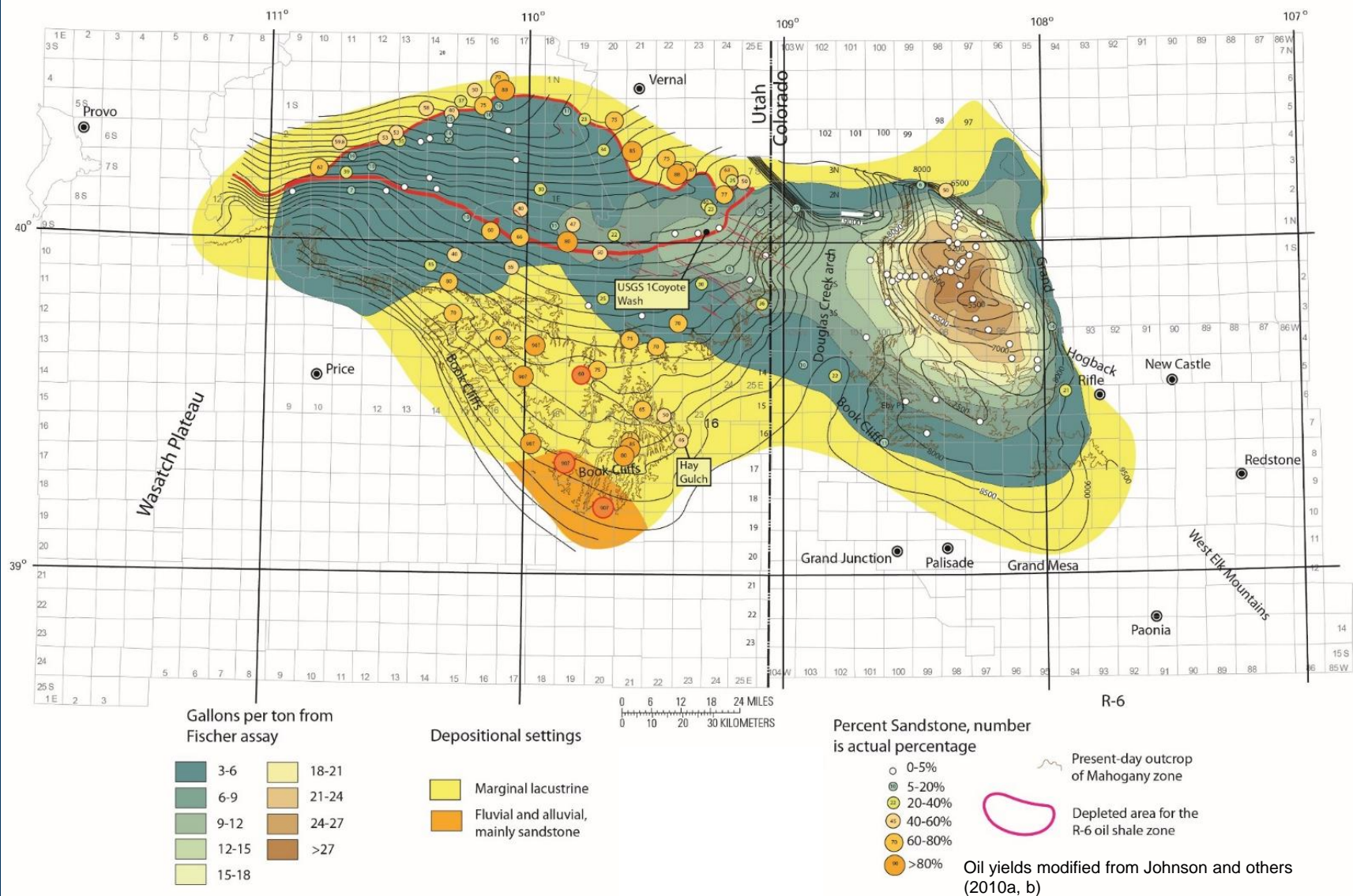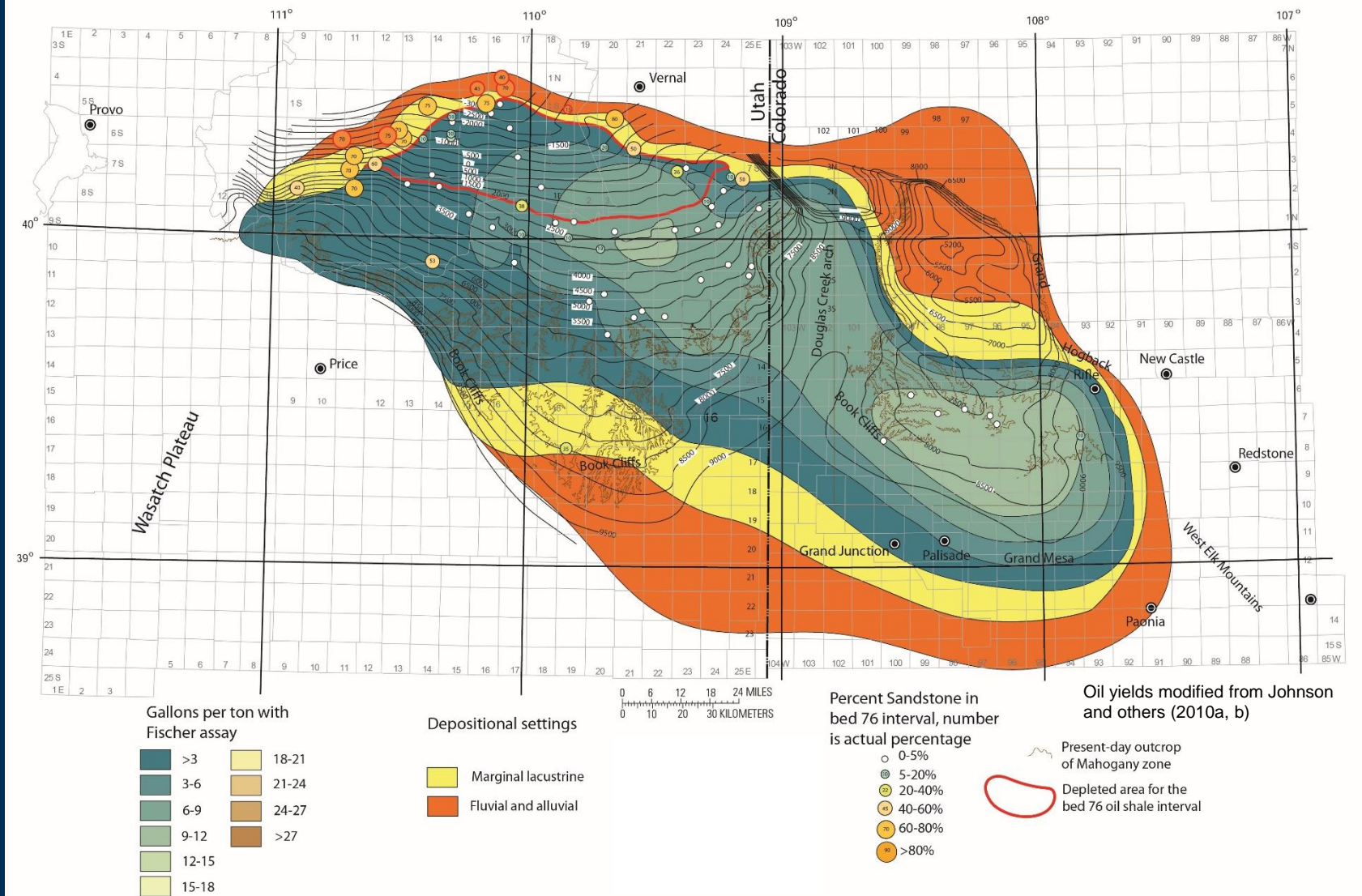
Variations in oil yield for the R-6 oil shale zone and hypothesized area where petroleum-generating potential is depleted based on Fischer assay yields (outlined in red). The structure contour lines are on the top of the Mahogany oil shale zone.
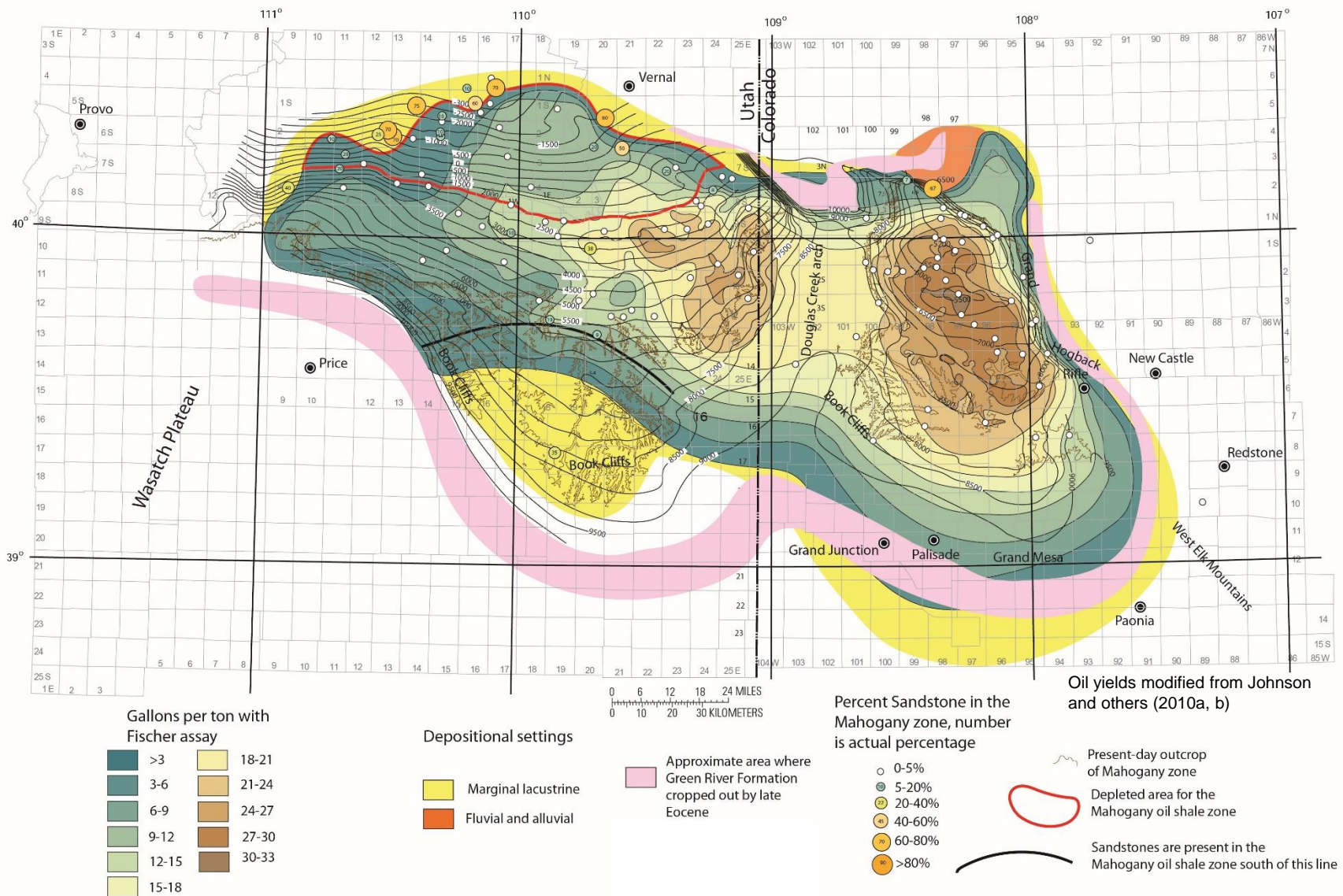
Variations in oil yield for the Mahogany oil shale zone and hypothesized area where petroleum-generating potential is depleted based on Fischer assay yields (red line). The structure contour lines are on the top of the Mahogany oil shale zone.
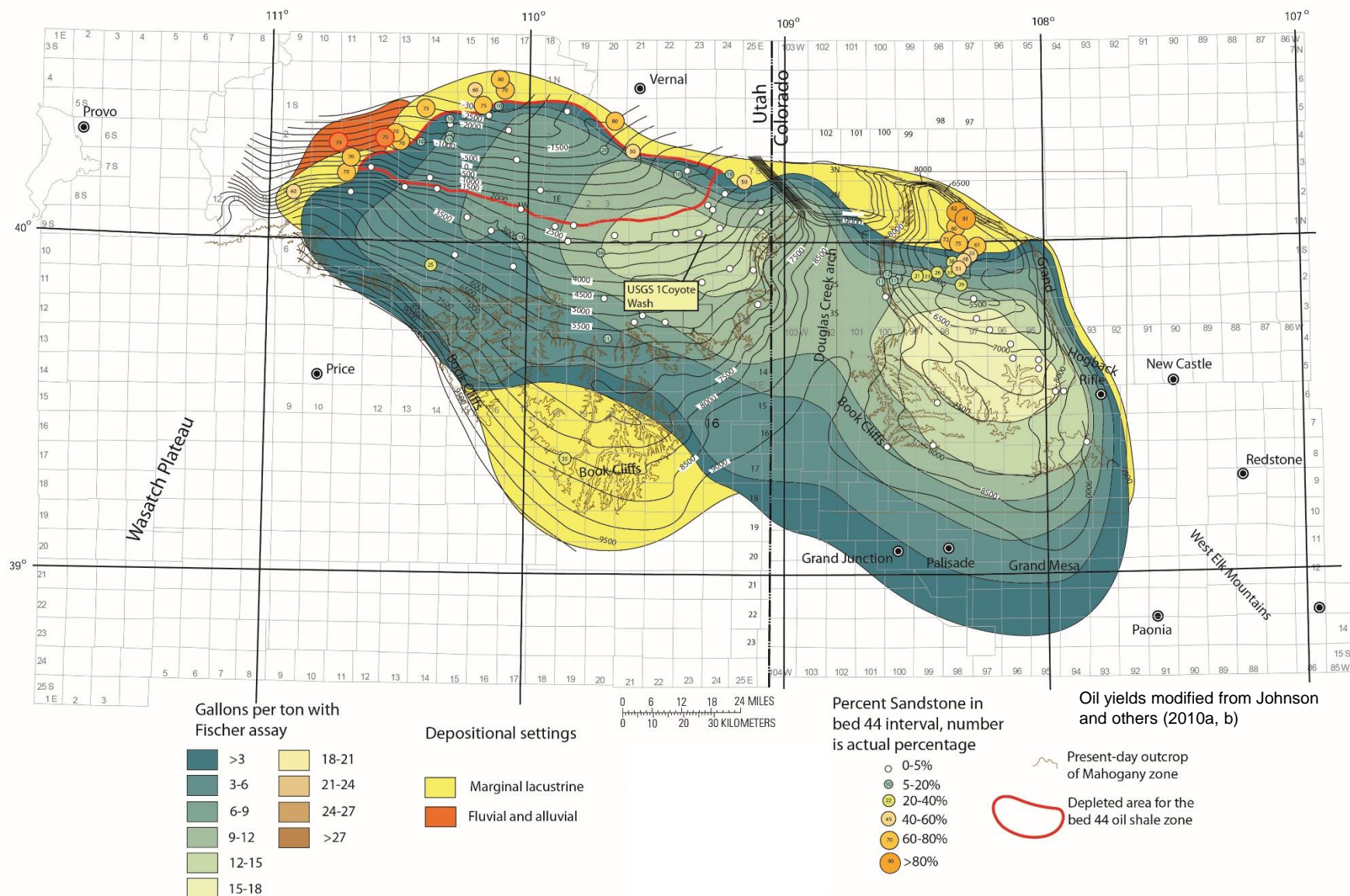
Variations in oil yield for the Bed 44 oil shale zone and hypothesized area where petroleum-generating potential is depleted based on Fischer assay yields (red line). The structure contour lines are on the top of the Mahogany oil shale zone.

Variations in oil yield for the Bed 76 oil shale zone and hypothesized area where petroleum-generating potential is depleted based on Fischer assay yields (red line). The structure contour lines are on the top of the Mahogany oil shale zone.

Where Did the Bitumen and Oil Go?

Migration pathways?

- Workers in the past noted that many of the tar sand deposits in the Uinta Basin occur in marginal lacustrine equivalents of the oil shale interval, which implies that the oil shale interval may be a source for some of the tar (see, for example, Cashion, 1967; Calkin, 1980; Schamel, 2013).

- Here, we have generally placed the tar sand intervals along the south margin of the basin into the rich and lean zone stratigraphy defined by Cashion and Donnell (1972).
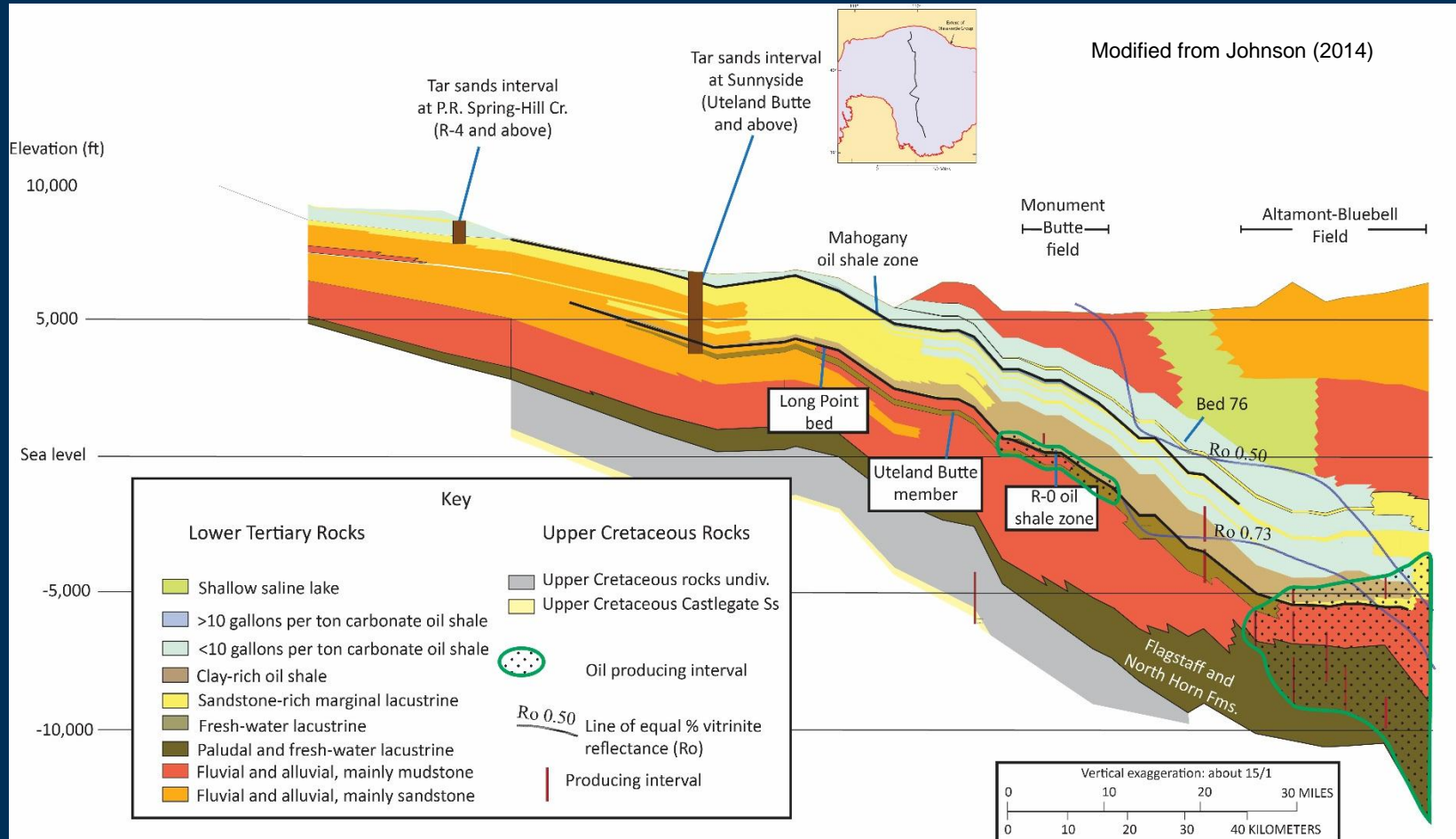
Tar sands at P.R. Spring-Hill Creek extend from the base of the R-4 zone to above the Mahogany zone (main carbonate oil shale interval). Tar sands at Sunnyside extend from the Uteland Butte to above the Mahogany zone. (%, percentage; ft, foot; Ro, vitrinite reflectance)
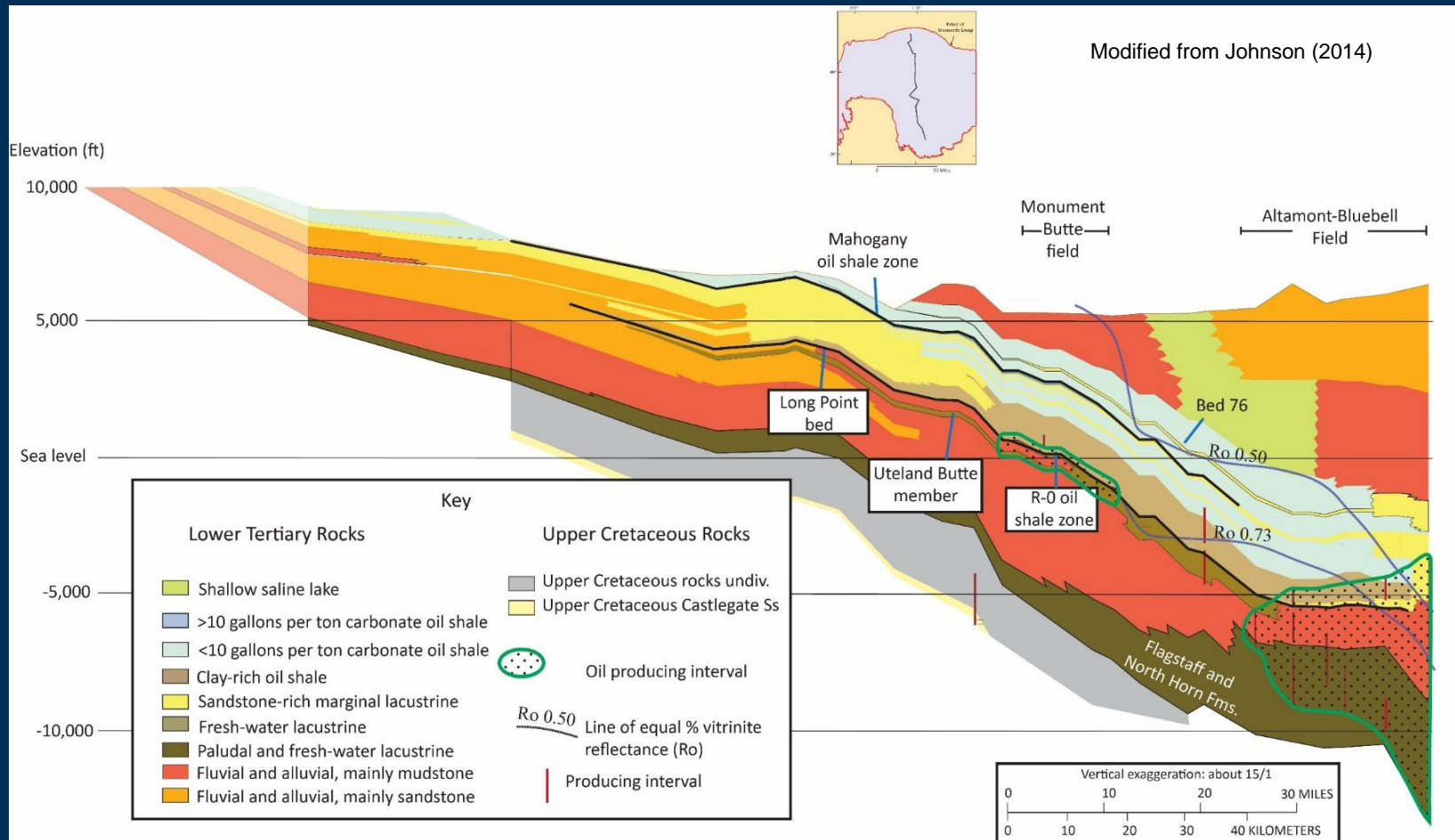
The cross section was then extrapolated to the present day, 10,000-foot level representing the approximate surface of the basin at the end of the Laramide orogeny based on preserved remnants in the southwestern part of the Piceance Basin to the east. (%, percentage; ft, foot; Ro, vitrinite reflectance)
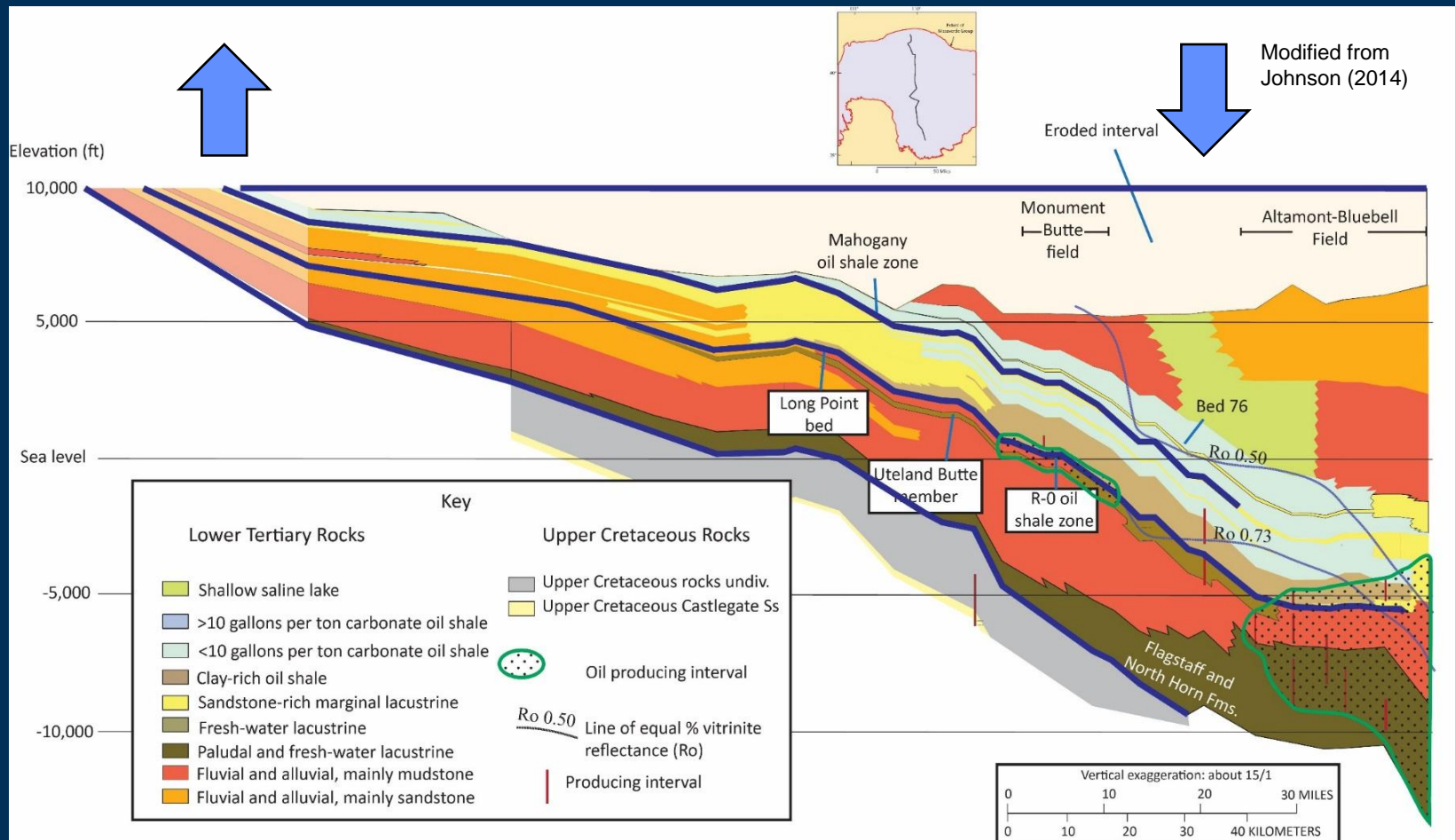
Paleogene subsidence rates prior to deposition of the Mahogany zone increased gradually toward the trough of the Uinta Basin. After deposition of the Mahogany zone (48.8 millions of years ago), subsidence rates increased markedly toward the trough of the Uinta Basin while, at the same time, the south margins of the basin were uplifted (indicated by blue arrows). (%, percentage; ft, foot; Ro, vitrinite reflectance)
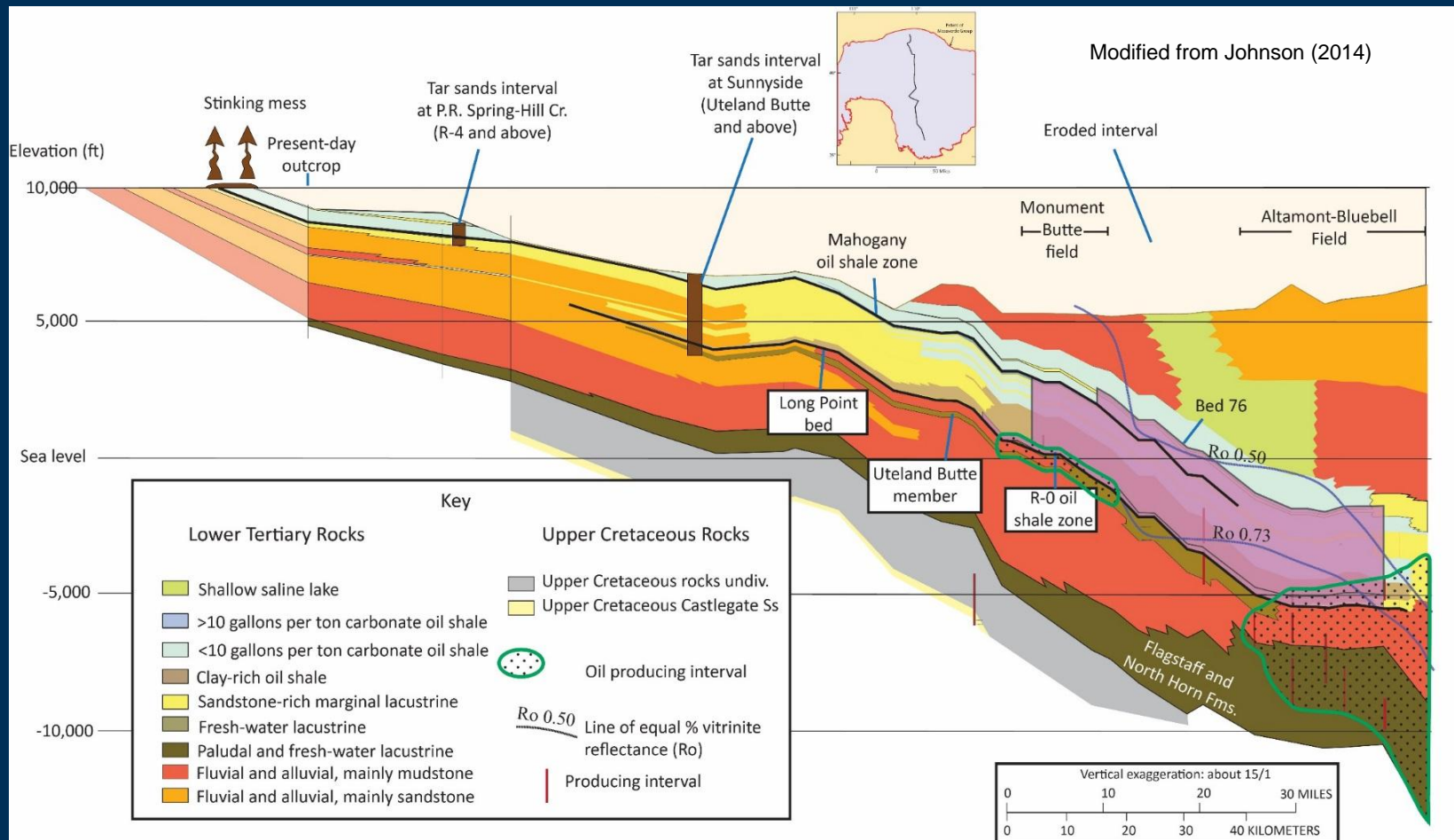
Depleted oil shale intervals are shown in purple, tar sand intervals are shown in brown, and the eroded section is shown in beige. Depletion begins at a vitrinite reflectance of about 0.5%. Oil and bitumen migrated through the present-day tar sand deposits to the surface where it was eroded away. (%, percentage; ft, foot; Ro, vitrinite reflectance)
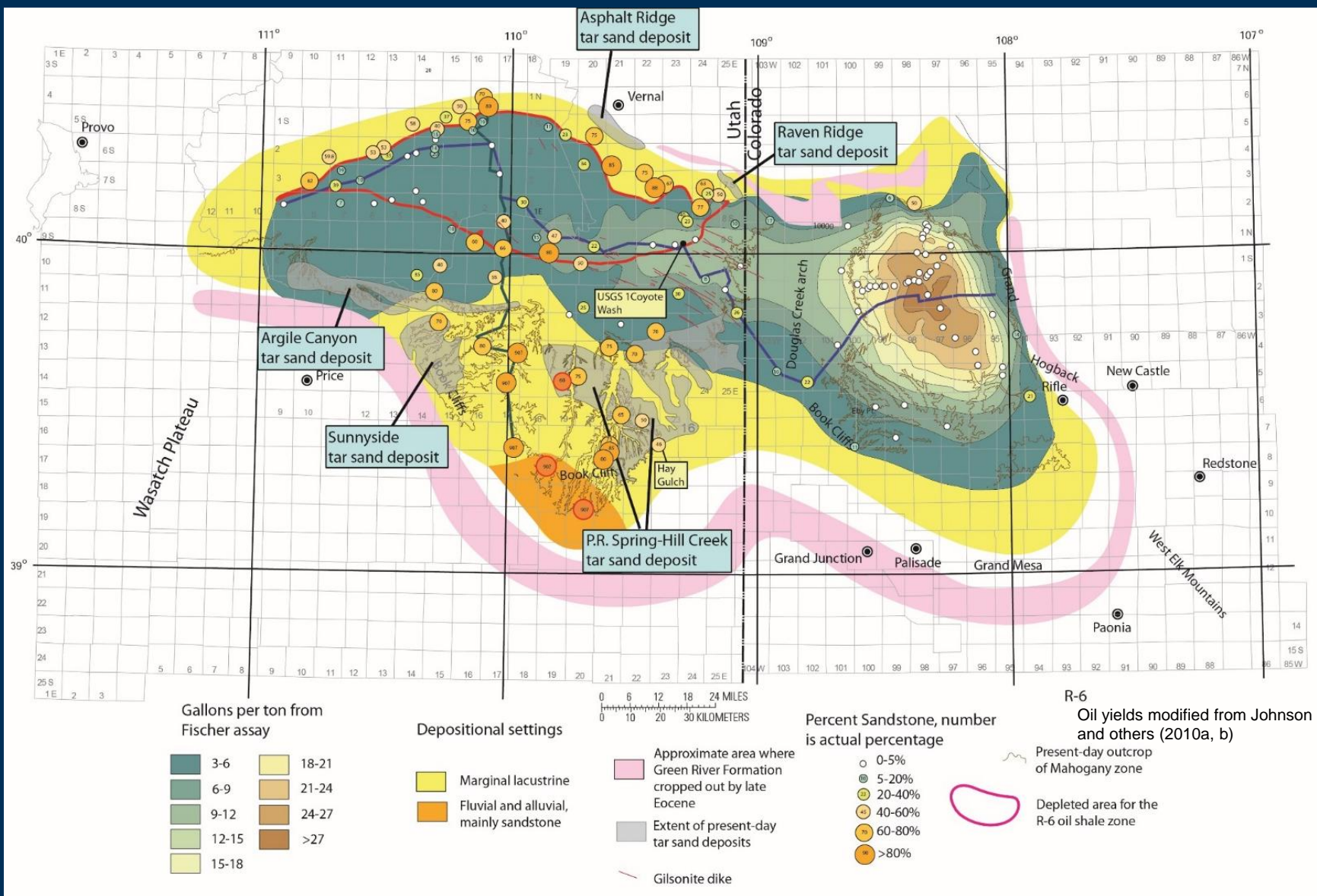
The present day tar sand deposits are shown in gray. Areas where the Green River Formation cropped out by late Eocene time are in pink. The Sunnyside deposit is very close to late Eocene outcrops. The P.R. Spring-Hill Creek deposit is much further from late Eocene outcrops. (%, percentage)
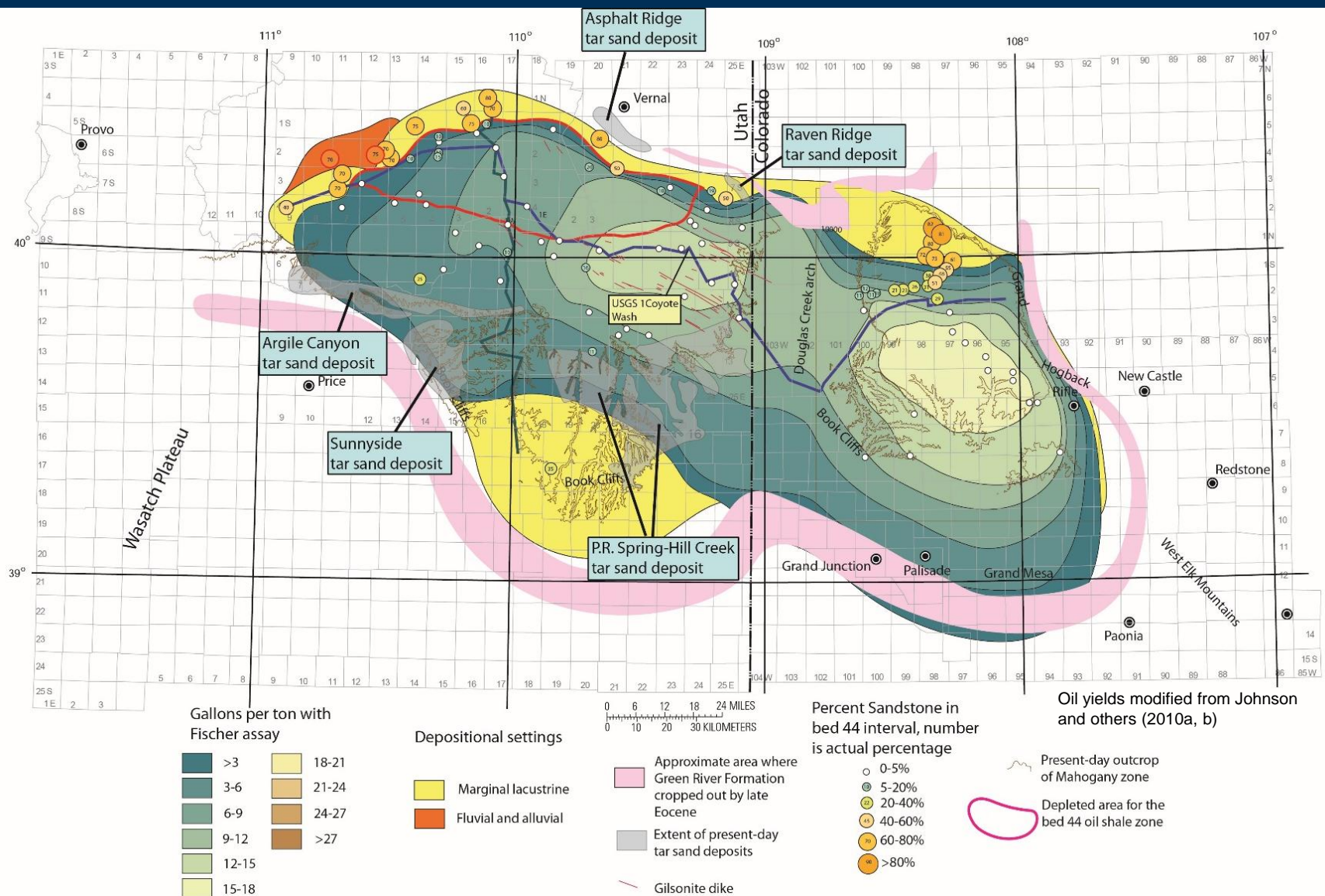
The gilsonite dikes shown in red may have been sourced by the oil shale interval above the Mahogany zone. This is consistent with work by Verbeek and Grout (1992) that suggests a southeast transport direction for the gilsonite. (%, percentage)
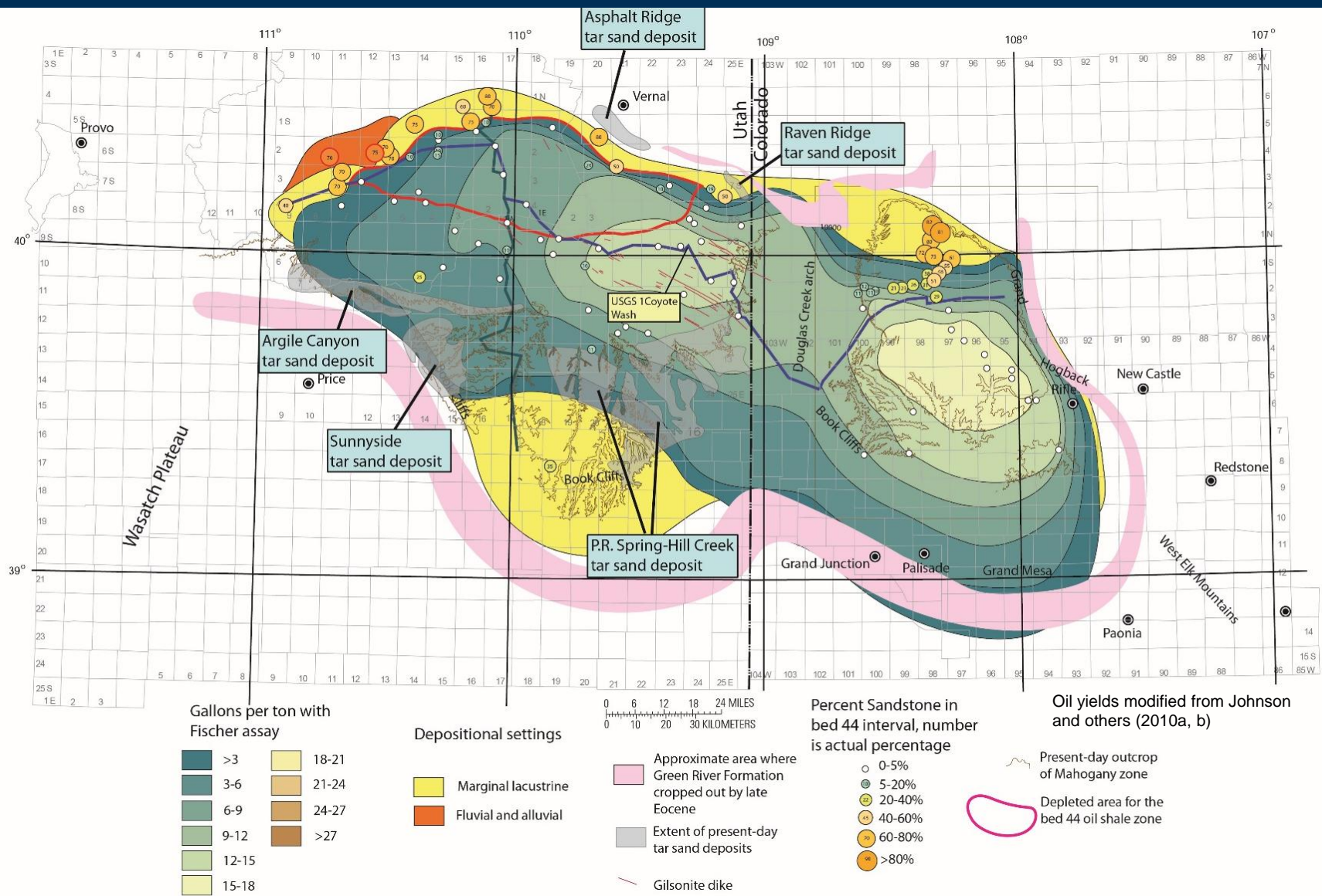
The lack of marginal lacustrine sandstones in contact with the depleted area in the Mahogany zone and overlying interval may have caused the generated bitumen to fill fractures in overlying strata forming the dikes. Lines of section presented in slide 40 is north-south line shown in blue. (%, percentage)

We estimated how much petroleum-generating potential is missing from the depleted area based on Fischer assay data.

- There is virtually no core available for the depleted area largely because it is too deep to be considered a potential oil shale resource and it is not a major oil producer. Fischer assay data from cuttings were used in a 2010 oil shale assessment (Johnson and others, 2010b) to determine gallons per ton and barrels per acre for this area along the deep basin trough that lacked core data.

- Gallons per ton and barrels per acre values from coreholes located closest to the depleted area were applied to the entire depleted area for each oil shale zone.

- As these coreholes are from the margins of the depocenter, they probably represent minimum values of the original organic richness prior to depletion.

- Gallons per ton and barrels per acre values from the 2010 assessment were subtracted from these corehole values to estimate how much petroleum-generating potential is now missing.
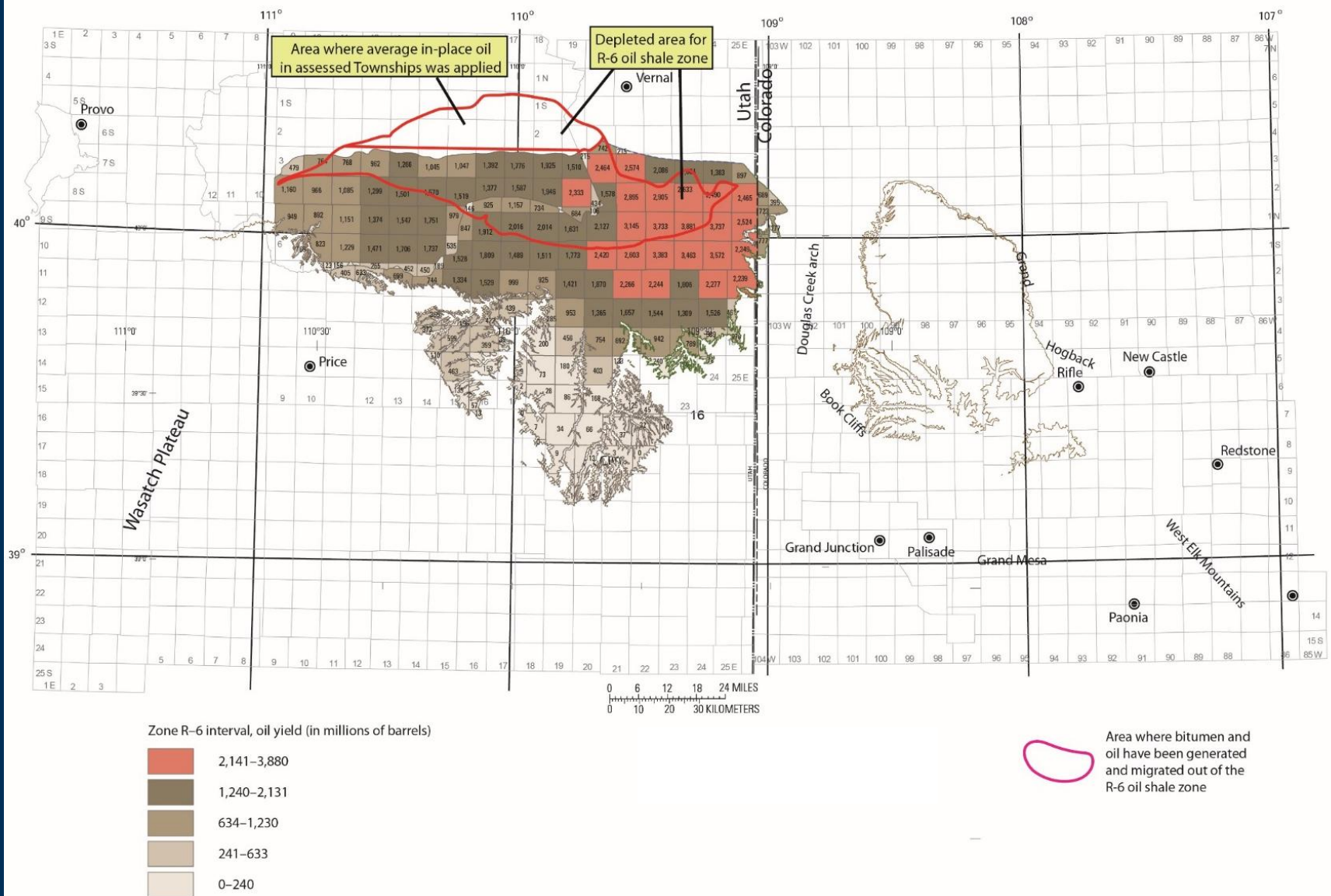
This map shows barrels of oil per township based on Fischer assay in each township in the Uinta Basin. (From Johnson and others, 2010b) These maps were used to determine total present-day oil in place for the depleted area for each oil shale zone.

Missing oil shale resource

- The total amount of missing petroleum-generating potential based on Fischer assay is **509 billion barrels.**

- ***This is not the amount of bitumen and oil generated!!!***

- Only a small percentage is likely to have been generated as mobile petroleum.

- Much of the generated oil and bitumen migrated through marginal lacustrine and alluvial sandstones and fractures to the surface and were lost.

Calculating the Amount of Bitumen and Oil Generated

U.S. Department of the Interior
U.S. Geological Survey

Approach

- Ranges of values for geologic, geochemical, and expulsion-related parameters were used in a probabilistic analysis of potential generated oil.

- Expulsion factors were estimated using values from Sandvik and others (1992) that were modified by a pyrolysis yield-to-nature correction factor from Lewan and others (2002).

- Transformation ratios, or fractional conversions, were estimated from studies of the thermal history of the oil shale interval in the Uinta Basin combined with information from hydrous pyrolysis experiments (Lewan and Ruble, 2002).

Expulsion factors

Fischer assay values were used to estimate immature TOC (FA oil yield = 2 × TOC).

An original HI of 700 mg/g was assumed (minimum for Type I kerogen).

Values from this graph were multiplied by 0.59 based on guidance in Lewan and others (2002) to get estimate of maximum expelled oil.

Type I window

HI = 700 mg/g
TOC = 7%
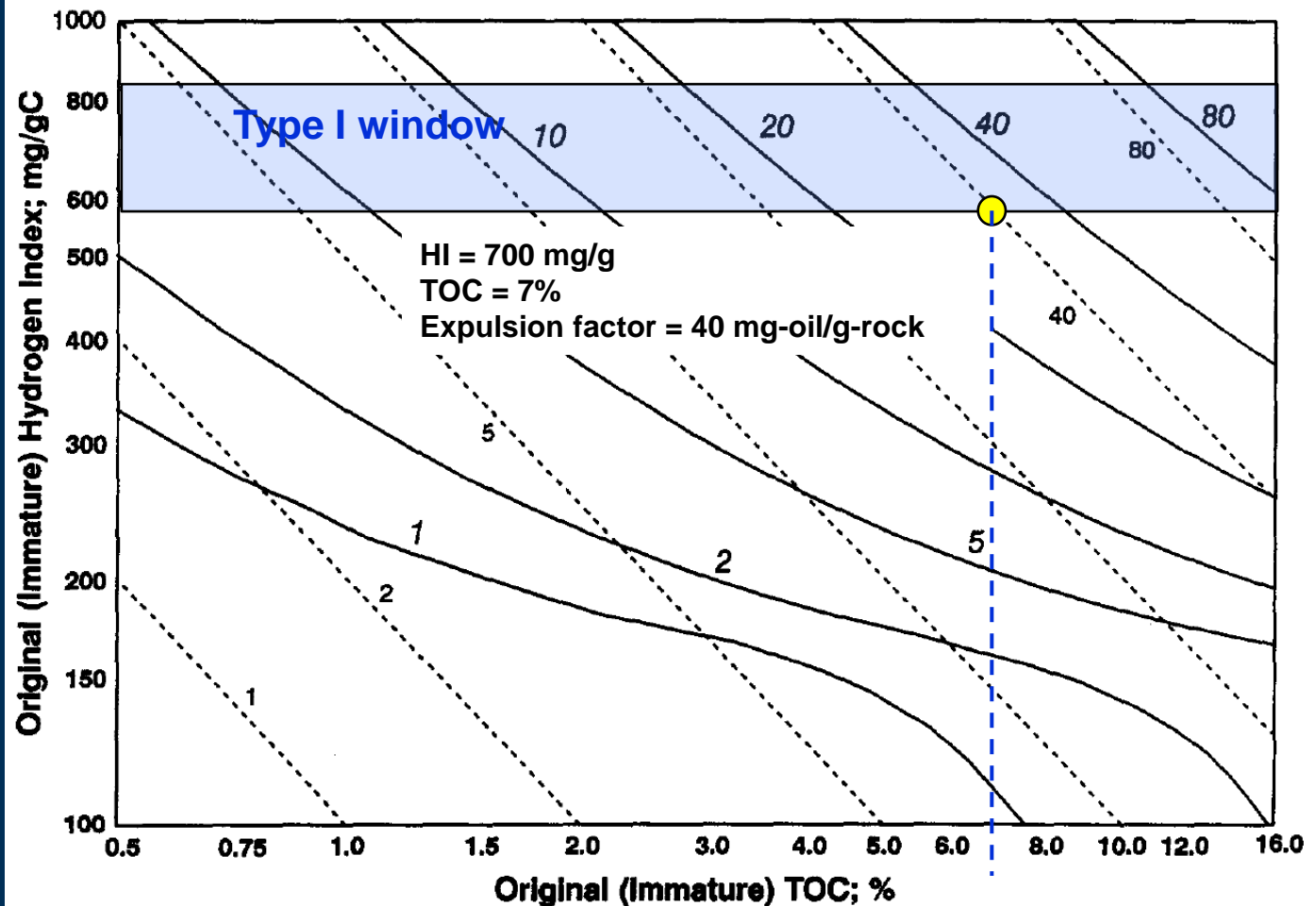Expulsion factor = 40 mg-oil/g-rock

Fig. 7. Calculated amounts (contours) of expelled oil (mg/g-rock), at moderately high maturity (transformation ratio = 0.95) vs TOC and HI (—). An absorptive retention of 10 g/100 mg-OM and a critical saturation of zero was used for these calculations. Contours of total Rock-Eval potential, S2, are also shown (– – –).

Org. Geochem. Vol. 19, Nos 1–3, pp. 77–87, 1992

(%, percentage; FA, Fischer assay; HI, hydrogen index; mg/g, milligrams per gram; TOC, total organic carbon)
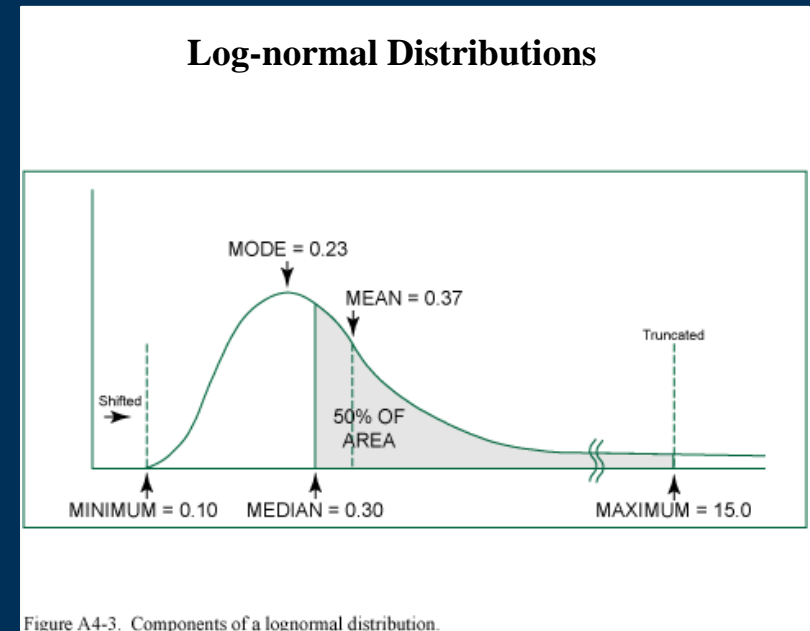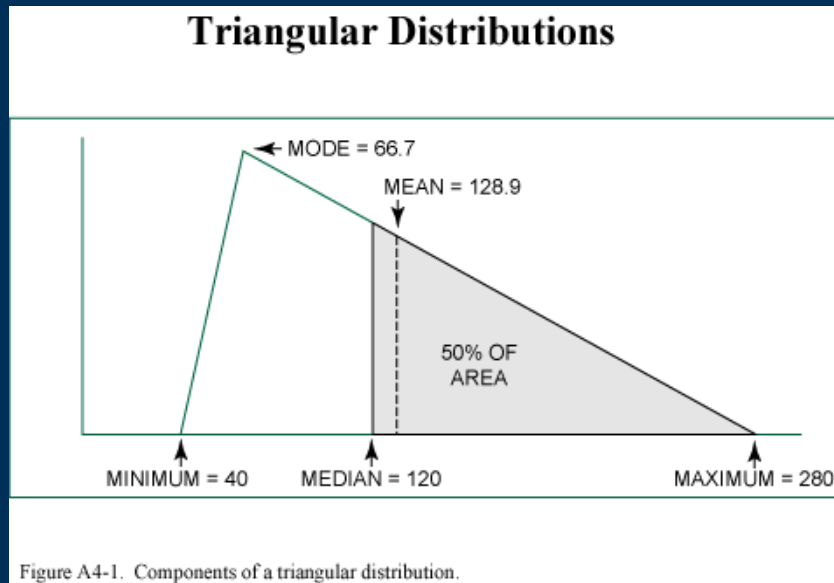
Parameter distributions

Triangular distributions

- Zone areas (900–2,000 mi^2)
- Transformation ratios (0.001–0.12)
- Rock densities (2.4–2.6 g/cm^3)
- Oil densities (0.88–0.92 g/cm^3)

Log-normal distributions

- Zone thicknesses (55 to >1,000 ft)
- Expulsion factors (5 – 50 mg-oil/g-rock)

Triangular Distributions

MODE = 66.7
MEAN = 128.9
50% OF AREA
MINIMUM = 40   MEDIAN = 120   MAXIMUM = 280

Figure A4-1. Components of a triangular distribution.

Log-normal Distributions

MODE = 0.23
MEAN = 0.37
Truncated
Shifted
50% OF AREA
MINIMUM = 0.10   MEDIAN = 0.30   MAXIMUM = 15.0

Figure A4-3. Components of a lognormal distribution.

(%, percent; ft, foot; g/cm^3, grams per cubic centimeter; mg-oil/g-rock, milligrams oil per gram of rock, mi^2, square mile)

Calculations

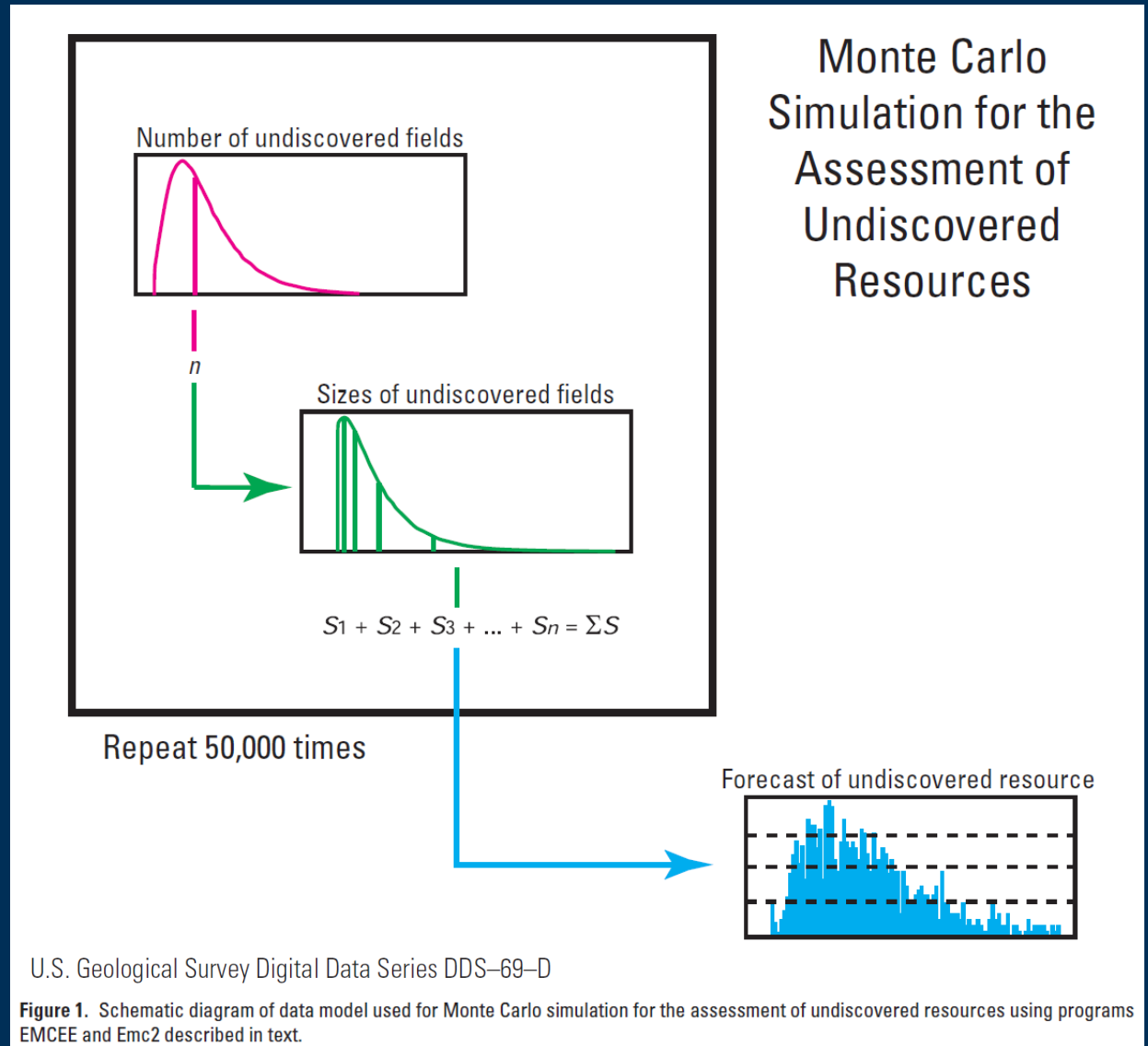Total estimates of generated and expelled oil were calculated using the expulsion factors and transformation ratios, converted to barrels per ton, and multiplied by an estimated total rock mass in each zone using an average rock density, the size of the depleted area for each zone (in square miles), and the thickness (in feet) of each oil shale zone to generate final estimates of the total expelled oil in barrels.

Calculations

We employed Monte Carlo simulations, similar to those used in U.S. Geological Survey oil and gas assessments, to estimate ranges of possible generated petroleum for each interval in the depleted area in the Uinta Basin.

Area × thickness × rock density × expulsion factor × transformation ratio ÷ oil density… conversion factors = barrels of oil

Monte Carlo Simulation for the Assessment of Undiscovered Resources

Number of undiscovered fields

n

Sizes of undiscovered fields

$S_1 + S_2 + S_3 + ... + S_n = \Sigma S$

Repeat 50,000 times

Forecast of undiscovered resource

U.S. Geological Survey Digital Data Series DDS–69–D

Figure 1. Schematic diagram of data model used for Monte Carlo simulation for the assessment of undiscovered resources using programs EMCEE and Emc2 described in text.

Results

- The total mean estimated expelled oil from the oil shale zones considered in this analysis was **29.2 billion barrels (bbl)** (range 14.8 to 45.8 billion bbls) or approximately (~) 6% of the depleted petroleum-generating potential of 509 billion bbls and 3% of the estimated 1,057 billion bbls of original oil shale resource in-place in the depleted area.

- The mean is around 30% larger than what is known to be present in the Green River-sourced **tar sands (~12 billion bbls; Schamel, 2013)** and **gilsonite deposits (~10 billion bbls; Cashion, 1967)** of the Uinta Basin today. Our inference is that most of the missing petroleum has escaped to the surface or was eroded away along with overlying rock.

Closing comments

- Recently acquired programmed pyrolysis data on cuttings from the deep part of the western Uinta Basin depocenter show reduced hydrogen indices and higher production index values relative to immature Green River oil shales, further indicating petroleum generation has occurred.

- The reason for the large discrepancy between estimates of depleted petroleum-generating potential and expelled oil are currently not well understood.

Closing comments

- It is possible that the organic richness in the western depocenter is not well represented by the Fischer assay oil yields from cores near the depleted-area boundary.

- The western depocenter may have had lower organic richness due to:
  - Greater dilution from detrital inputs,
  - Lower productivity of organic matter sources, and
  - Poor preservation conditions.

≋ USGS