Nahcolite and Halite Deposition through Time During the Saline Mineral Phase of Eocene Lake Uinta, Piceance Basin, Western Colorado

By Ronald C. Johnson and Michael E. Brownfield

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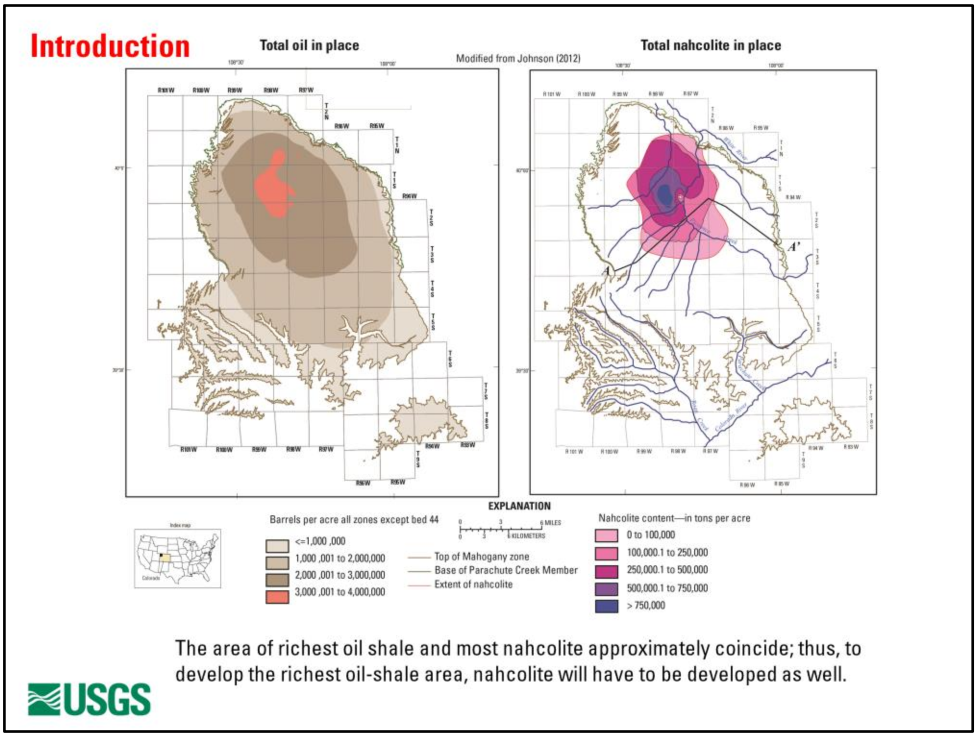
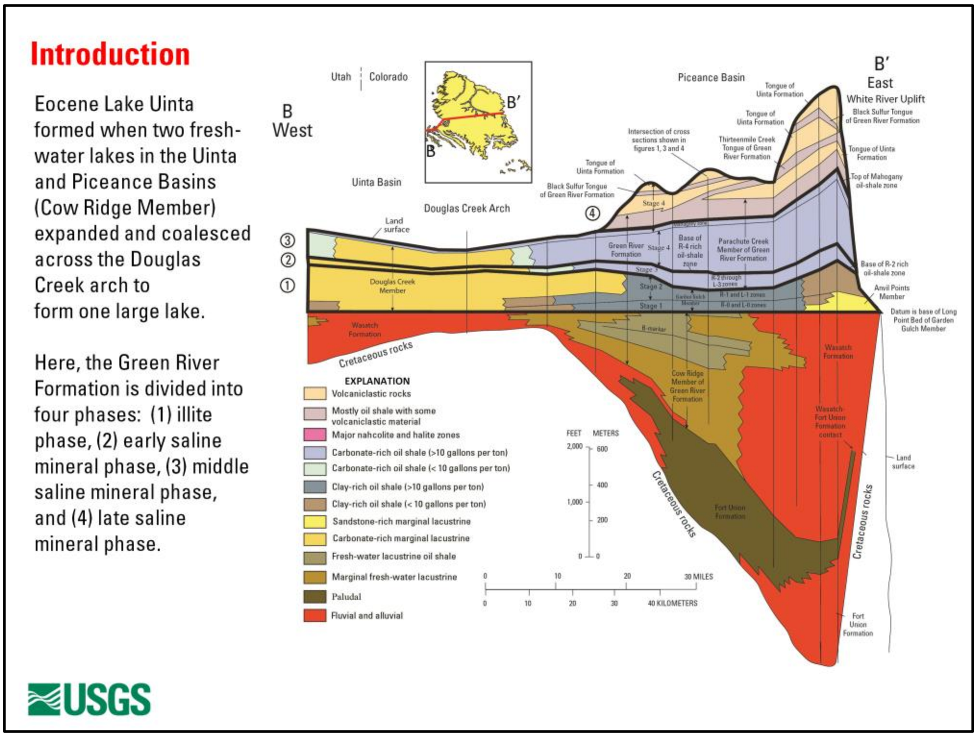


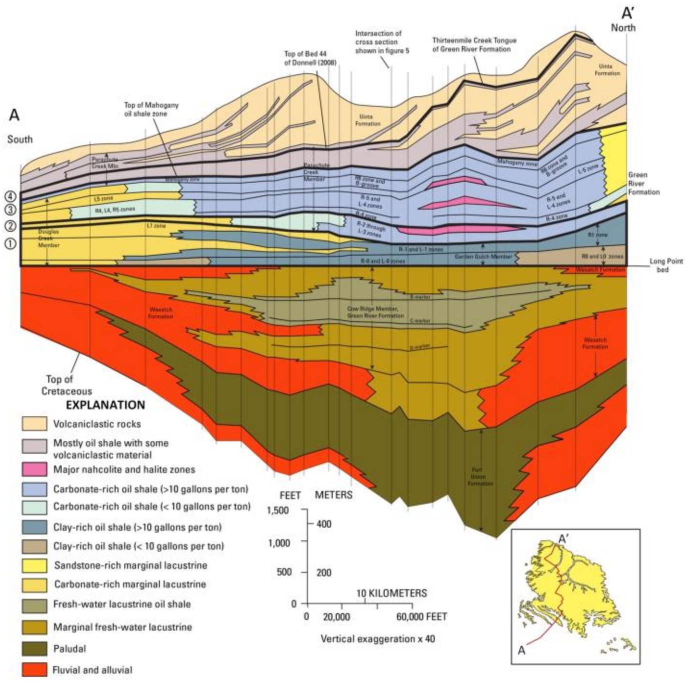
The isopach map on the left shows a total-in-place oil shale in all seventeen oil shale zones. The isopach map on the right shows the total amount of nahcolite in place in the eight oil shale zones that contain nahcolite. The richest oil-shale area in the basin and the area with the most nahcolite approximately coincide. Thus, in order to exploit the richest oil-shale area, nahcolite must also be produced.



Lake Uinta formed when two smaller fresh-water lakes, one in the Piceance Basin and one in the Uinta Basin to the west, expanded during the Long Point transgression (represented by the Long Point Bed) and coalesced to form a single large lake. Salinity in Lake Uinta progressively increased, first killing off the fresh-water mollusks that were ubiquitous during the earlier fresh-water phase and ultimately resulting in the deposition of dolomite-rich oil shale, nahcolite, and halite (Johnson, 1985). An illitic phase of Lake Uinta (labeled with a 1) preceded the carbonate and saline-mineral phase. Marginal infilling during the illitic phase produced broad marginal shelves surrounding a deeper central lake area where a saline brine layer in Lake Uinta later accumulated. The symbol > means greater than, and the symbol < means less than.

Introduction

The infilling of the Piceance Basin part of Lake Uinta by volcaniclastic rocks from the north is visible in this south to north cross section.



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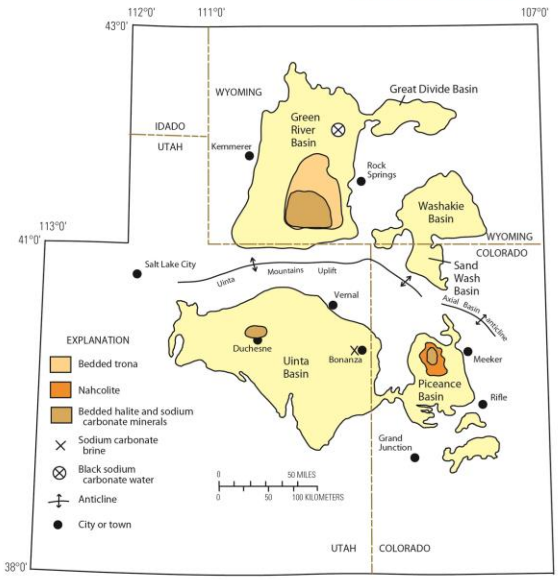
The symbol > means greater than, and the symbol < means less than.

Introduction



The Piceance Basin of northwest Colorado contains the world's second largest deposit of sodium carbonate in the form of Nahcolite ($NaHCO_3$) in the Parachute Creek Member of the Green River Formation.

The world's largest deposit of sodium carbonate is located in the Green River Basin of southwestern Wyoming in the form of trona ($Na_3(CO_3)(HCO_3){\bullet}2H_2O$) in the Wilkins Peak Member of the Green River Formation.

The Uinta Basin contains at least one minor deposit of bedded sodium carbonate minerals in the Green River Formation near the town of Duchesne, Utah.

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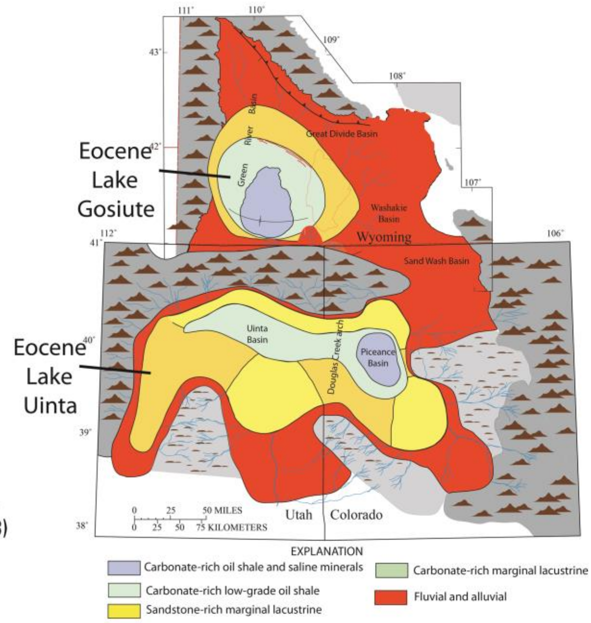
Sodium carbonate minerals in Colorado, Utah, and Wyoming. Modified after Dyni (1996)

Introduction

About two thirds of the nahcolite in the Piceance Basin is in rocks from the fourth stage of Lake Uinta, and most of the trona in the Green River Basin is in rocks from the middle part of the Wilkins Peak Member.



Lake Uinta during the Fourth Stage of Johnson (1985) (Uinta and Piceance Basins) and Lake Gosiute During Middle Part of the Wilkins Peak of Roehler (1993) (Green River Basin).

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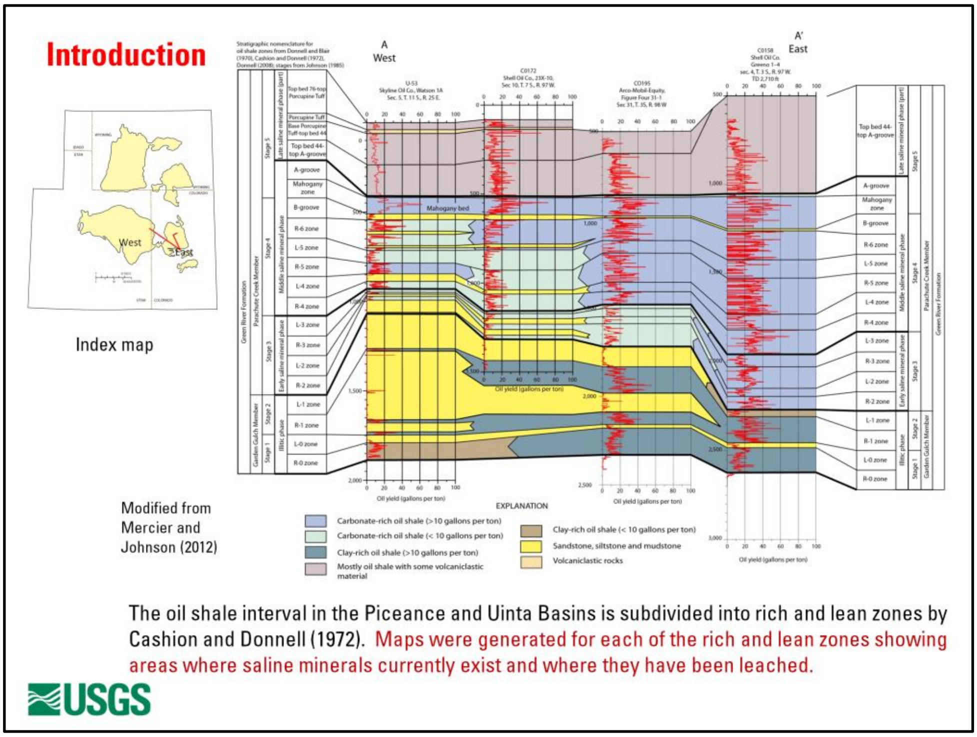

The symbol > means greater than, and the symbol < means less than.

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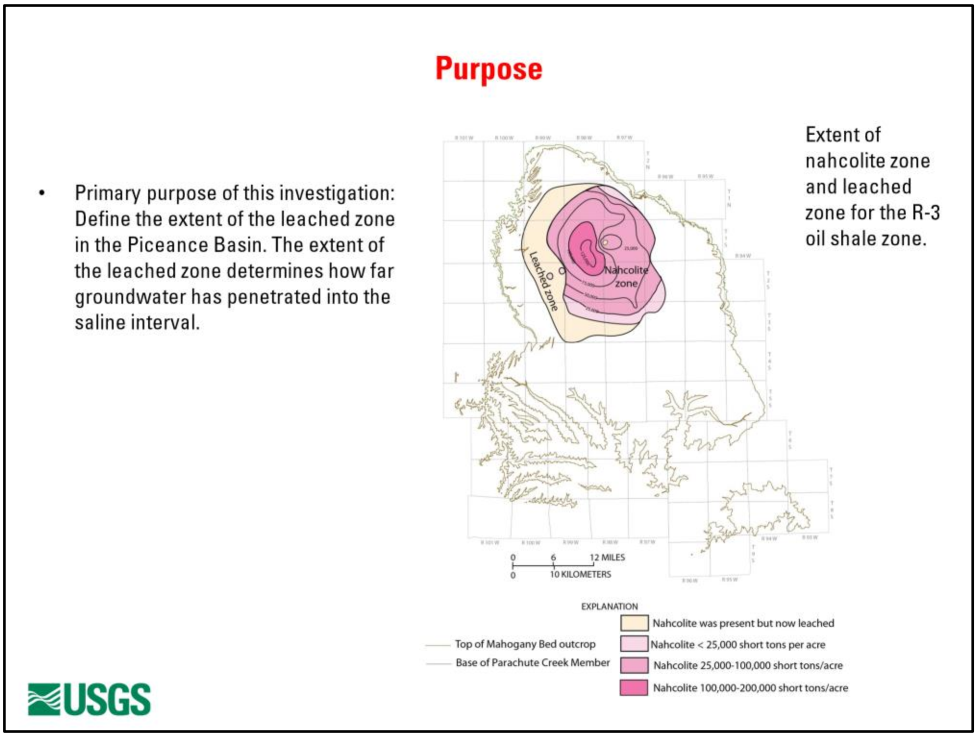
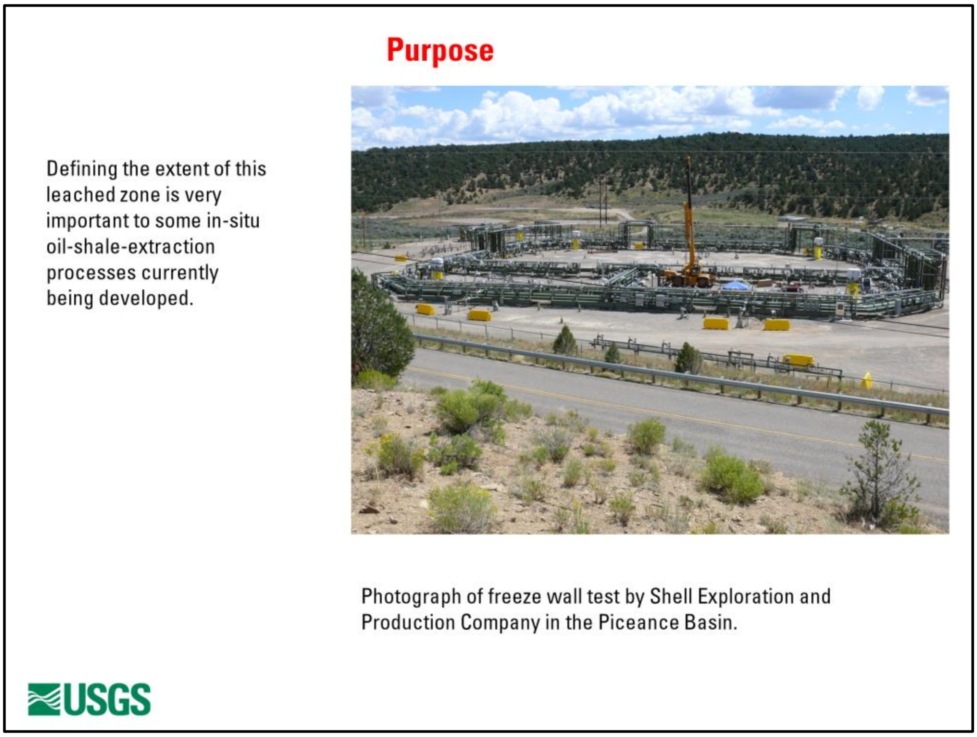
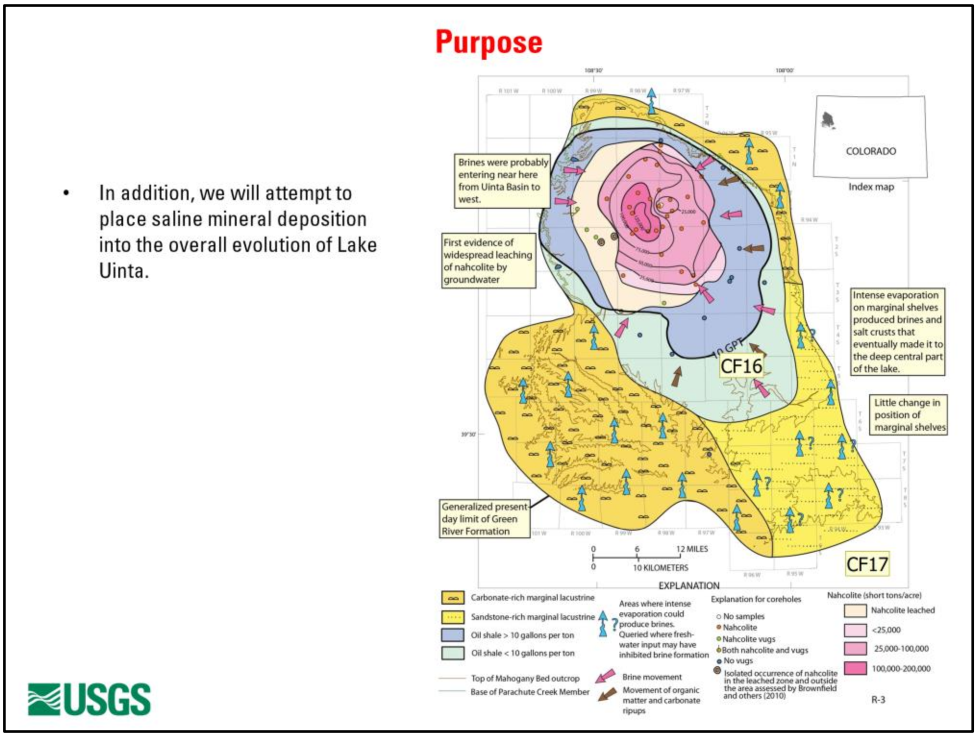


This map illustrates the present-day extent of nahcolite and the area where nahcolite was once present but has been leached. The symbol > means greater than, and the symbol < means less than.



Photograph of Shell’s freeze wall test, Piceance Basin.



On this map, we've put the present-day extent and former extent of nahcolite and halite (leached zone) into a geologic context by adding two marginal lacustrine facies, sandstone rich and carbonate rich, and different colors for average oil shale grades greater or less than 10 gallons per ton (GPT). The symbol > means greater than, and the symbol < means less than.

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Methodology

This study relied on existing core descriptions and x-ray analysis to study both the present-day extent and former extent of nahcolite and halite in the Piceance Basin.

Page from U.S. Bureau of Mines description of Colorado Corehole No. 1 in sec. 13, T. 1 N., R. 98 W.

C34

LITHOLOGIC DESCRIPTION OF SAMPLES SUBMITTED FOR ASSAY[1/]

Core samples of the Green River Formation from Bureau of Mines-Atomic Energy Commission Colorado Corehole No. 1 drilled in 1965 and 1966 in NW1/4NE1/4SE1/4 (2331 ft N of S line and 1284 ft W of E line), sec 13, T 1 N, R 98 W, Rio Blanco County, Colorado.

Surface elevation: 6003 feet
Described section: 770.0-3133.2 feet
Mahogany marker (?): 1070.6 feet

From	To	Description
770.0	771.8	Marlstone and some oil shale: buff to some medium brownish gray (10YR 8/2-7/2, some 6/2-5/2 lower part). Very faint distorted bedding to distinct streaks and stringers. Irregular to some fairly regular thick parting; slightly irregular fracture. Sample of buff marlstone from 770.1 feet: X-ray - calcite, quartz, dolomite; some feldspar, analcite, illite.
771.8	773.1	Oil shale: medium brownish gray to buff (10YR 5/2-7/2, rare 8/2 & 4/2). Fairly distinct slightly distorted to smooth streaks, bands, and laminae. Irregular thick parting; irregular fracture. A resinous black fossil leaf (?) on parting surface at 772.8 feet.
773.1	773.8	Oil shale: medium to dark brownish gray and rare tan to buff (10YR 4/2-3/2, some 5/2, rare 6/3-8/2). Faint to rare distinct smooth laminae and streaked bedding; rare fine to small loop structures. Rare high angle natural fractures with very fine calcite crusts. Very rare very fine pyritic streaks. Sample of medium to dark brownish gray oil shale from 773.6 feet: X-ray - dolomite, quartz, calcite, analcite; some feldspar, illite.
773.8	777.3	Oil shale: medium and rare dark brownish gray to buff (10YR 4/2-8/2, rare 3/2 upper part). Distinct to some faint, smooth to slightly distorted streaks and laminae. Slightly irregular thick to medium parting; irregular to slightly conchoidal fracture. Some small irregular folds at 775.5-775.7 feet. Rare fine gray pyritic streaks in lower part.
777.3	778.3	Oil shale: medium brownish gray to buff (10YR & 2.5Y 5/2-8/2, rare 4/2). Distinct slightly distorted streaks, stringers, and rare bands. Slightly irregular to irregular, thick to medium parting; irregular to slightly conchoidal fracture. Very rare very fine gray pyritic streaks.

1/ By L. G. Trudell

Illustration No. SBR-4052P (Sheet 1 of 212)

Laramie Petroleum Research Center, Laramie, Wyoming April 6, 1967

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Methodology

Source of core descriptions and x-ray analysis

- U.S. Geological Survey
- The former U.S. Bureau of Mines
- Private oil shale research company donations: oil shale boom in the early 1980s

Core descriptions are currently being scanned. X-ray analyses are being compiled. Both will be made available in digital archives as soon as possible.

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Methodology

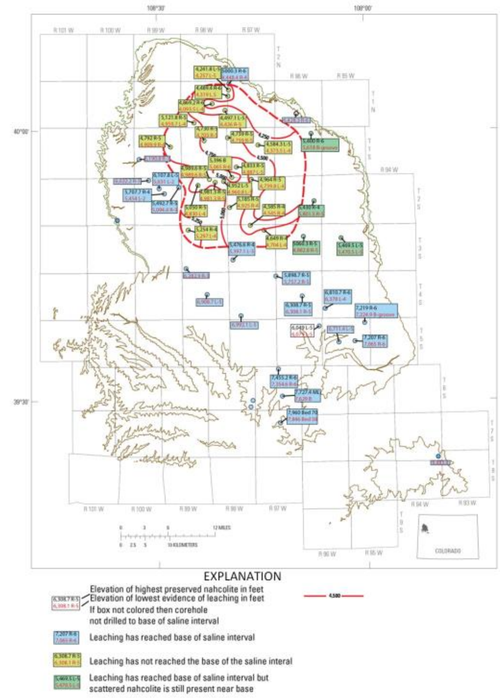
Other information collected includes:

(1) Elevation of highest preserved nahcolite and elevation of lowest evidence of leaching. This defines the transition zone where nahcolite is only partially leached.

(2) Core holes where leaching has not reached base of saline interval (green).

(3) Core holes where leaching has reached the base of the saline zone (blue).

(4) Core holes where leaching has reached the base of saline interval, but scattered nahcolite is still present near the base of saline zone (blue-green).



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Nahcolite

Nahcolite occurs as disseminated crystals and aggregates, and as beds commonly associated with halite.

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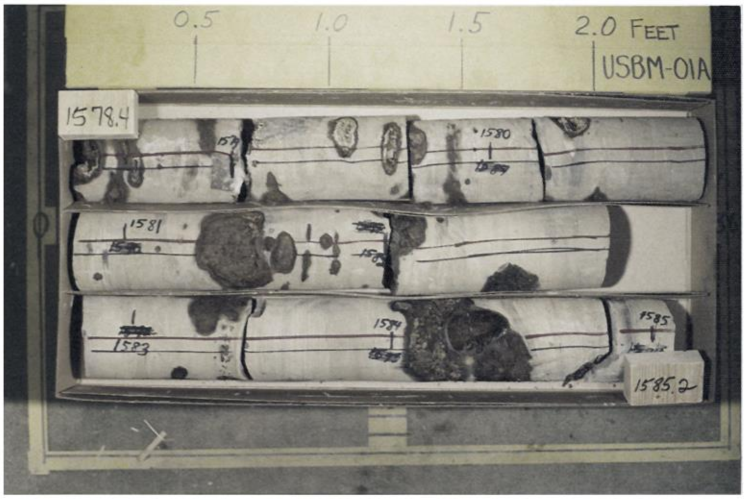
Nahcolite



Drill core containing white, coarse crystals of nahcolite; small nodules of nahcolite; and dark brown nahcolite aggregates of bladed crystals in oil shale. Some nahcolite aggregates are rimmed with pyrite. Recovered core from the U.S. Bureau of Mines 01A (C0334) bore hole (1,578.4 feet (ft) to 1,585.2 ft, R-5 oil shale zone). Core is located in the USGS Core Research Center, Lakewood, Colorado (from Brownfield and others, 2010).

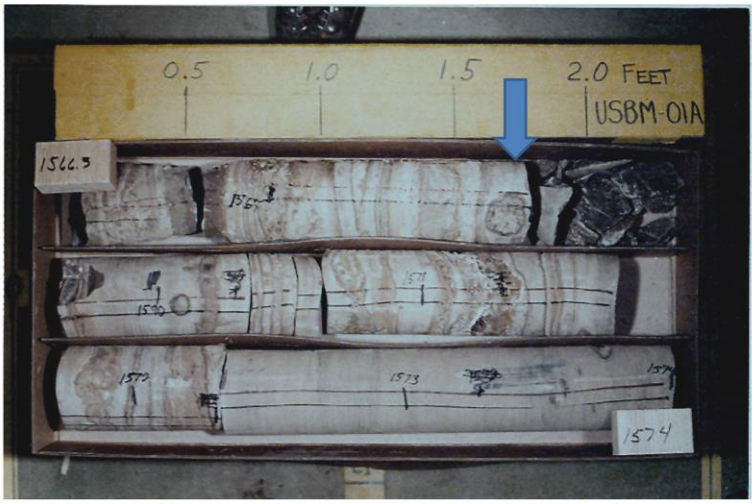
USGS

Nahcolite

Nahcolite aggregates in the R-5 oil shale zone, Superior quarry near the mouth of Piceance Creek (from Brownfield and others, 2010).

USGS

Nahcolite



This photograph shows a drill core containing alternating beds of light brown nahcolite and gray oil shale. White crystalline aggregate of nahcolite (arrow) is located in the right part of the upper piece of core. Recovered core from the U.S. Bureau of Mines 01A (C0334) borehole (1,566.5 ft to 1,574 ft, R-5 oil shale zone). Core is located in the U.S. Geological Survey Core Library, Lakewood, Colorado (from Brownfield and others, 2010).

USGS

Nahcolite

Drill core containing alternating beds of deeply dissolved halite and brown resistant wafer-like nahcolite. Recovered core from the U.S. Bureau of Mines 01A (C0334) borehole (1,712 ft to 1,719.4 ft, R-5 oil shale zone) (from Brownfield and others, 2010).

USGS

Photo shows a core containing thick nahcolite and halite beds that are present in the saline depocenter in the Piceance Basin. Maximum thickness of a single nahcolite and halite bed is more than 60 ft.

Nahcolite

Drill core containing collapsed breccia and brown nahcolite in the R-6 oil shale zone U.S Bureau of Mines 01A (C0334) borehole (1,219.6 to 1,226.5 ft,R-6 oil shale zone) Sec. 29, T. 1 S., R. 97 W.

USGS

Collapse breccias are produced when groundwater leaches out thick nahcolite and halite beds. These collapse breccias have very high porosities and permeabilities.

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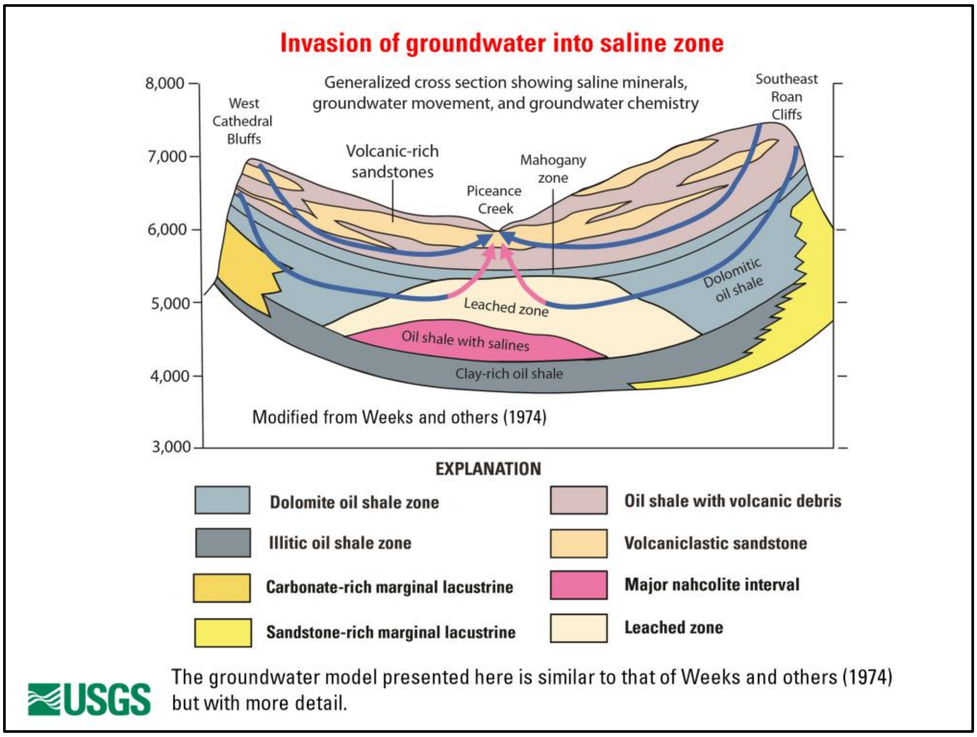
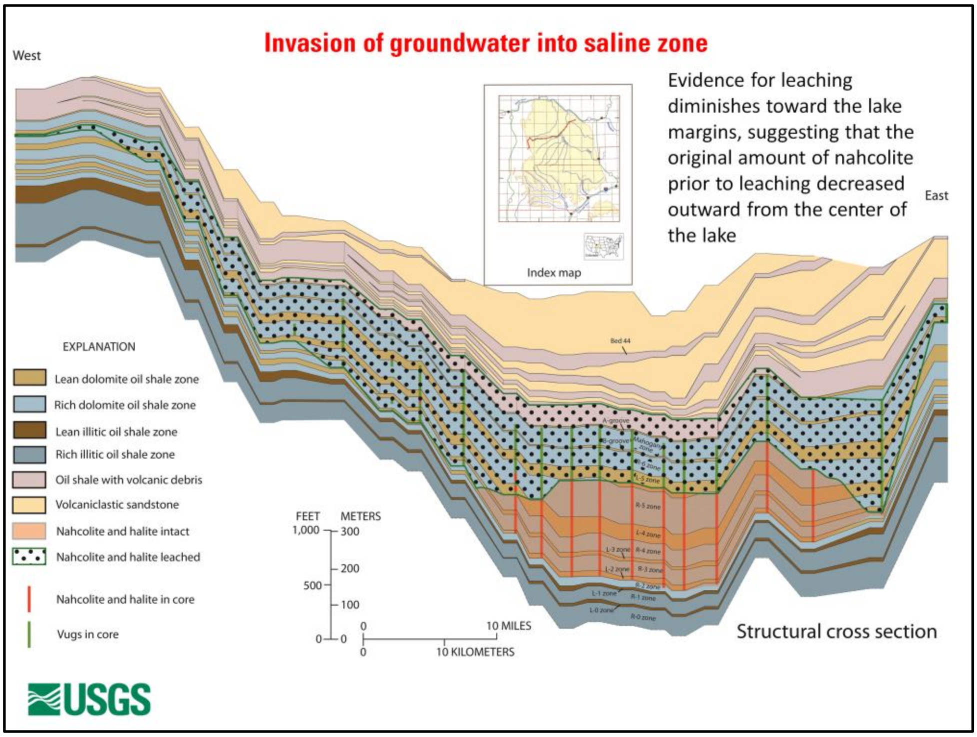
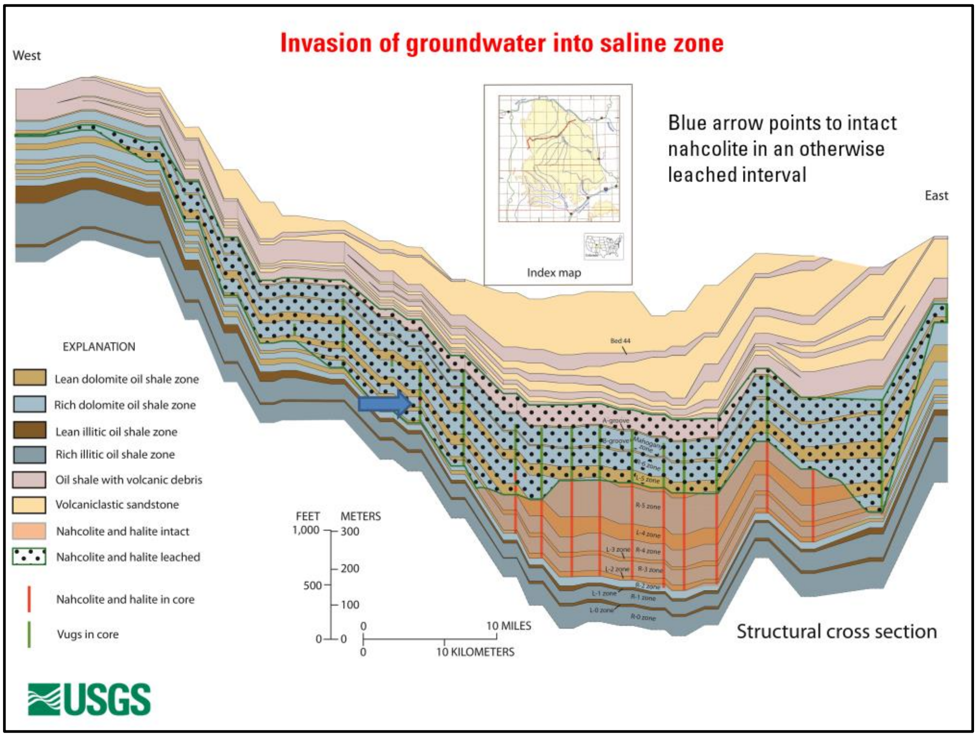
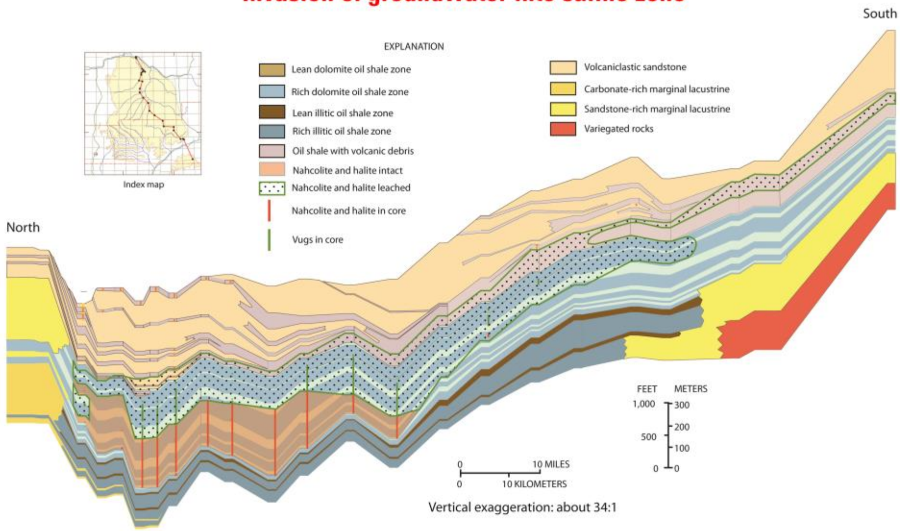

Invasion of groundwater into saline zone
Generalized cross section showing saline minerals, groundwater movement, and groundwater chemistry
8,000
7,000
6,000
5,000
4,000
3,000
West Cathedral Bluffs
Southeast Roan Cliffs
Volcanic-rich sandstones
Mahogany zone
Piceance Creek
Dolomitic oil shale
Leached zone
Oil shale with salines
Clay-rich oil shale
Modified from Weeks and others (1974)
EXPLANATION
Dolomite oil shale zone
Illitic oil shale zone
Carbonate-rich marginal lacustrine
Sandstone-rich marginal lacustrine
Oil shale with volcanic debris
Volcaniclastic sandstone
Major nahcolite interval
Leached zone
USGS
The groundwater model presented here is similar to that of Weeks and others (1974) but with more detail.



East-west structural cross section showing variations in elevation of the rich and lean oil shale zones in the Piceance Basin. Structural cross sections such as this are more useful to visualize groundwater movement than stratigraphic cross sections where the datum is a stratigraphic horizon.

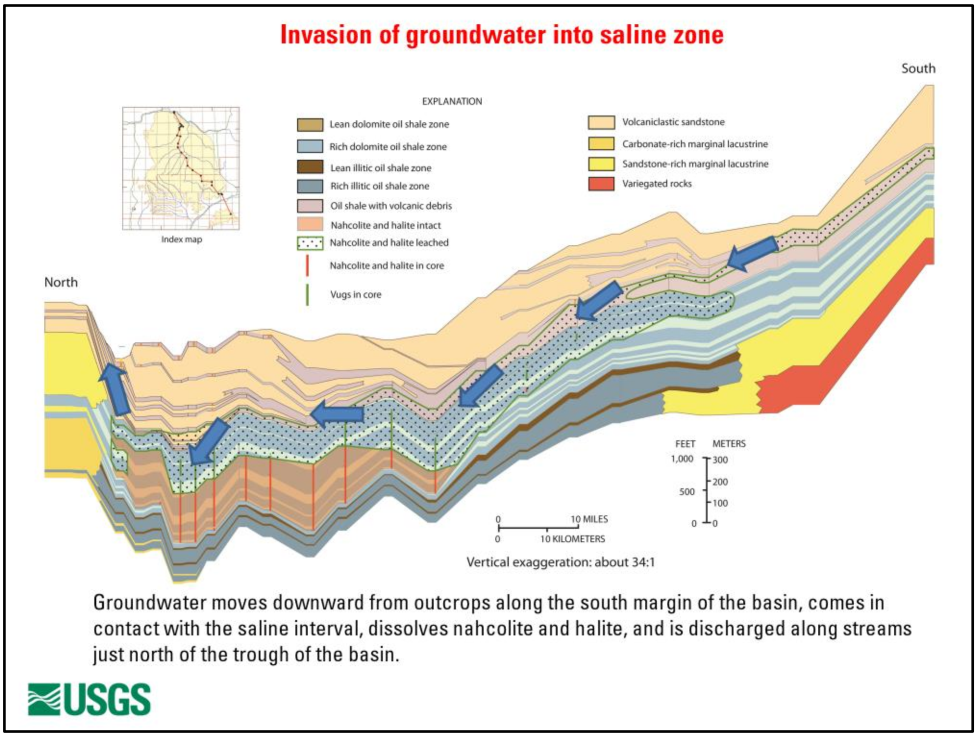

Invasion of groundwater into saline zone
West
East
Blue arrow points to intact nahcolite in an otherwise leached interval
Index map
EXPLANATION
Lean dolomite oil shale zone
Rich dolomite oil shale zone
Lean illitic oil shale zone
Rich illitic oil shale zone
Oil shale with volcanic debris
Volcaniclastic sandstone
Nahcolite and halite intact
Nahcolite and halite leached
Nahcolite and halite in core
Vugs in core
FEET
METERS
1,000
300
200
500
100
0
0
0
10 MILES
0
10 KILOMETERS
Structural cross section
USGS

Invasion of groundwater into saline zone

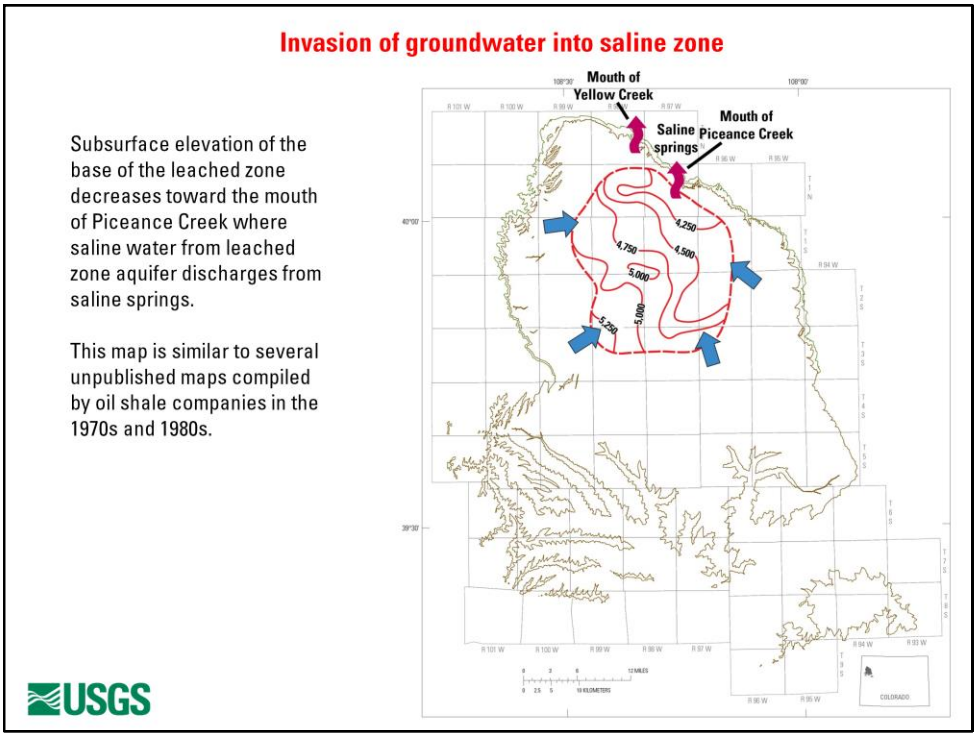


North-south cross section through the Piceance Basin. Again, note that the evidence for leaching generally decreases away from the central part of the saline depocenter.

USGS



The blue arrows represent groundwater moving from elevated recharge areas around the basin margin downward through the central part of the basin, leaching nahcolite and halite, and exiting the basin though saline springs where strata are upturned in the northern part of the basin.



The blue arrows represent groundwater penetrating the saline interval from elevated recharge areas at the basin margins. Groundwater encounters the saline interval and leaches some of the nahcolite and halite. Ultimately, the saline groundwater exits the basin through saline springs near the mouth of Piceance Creek.

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Results

A separate map was produced for each oil-shale zone showing where saline minerals are preserved and where they have been leached.

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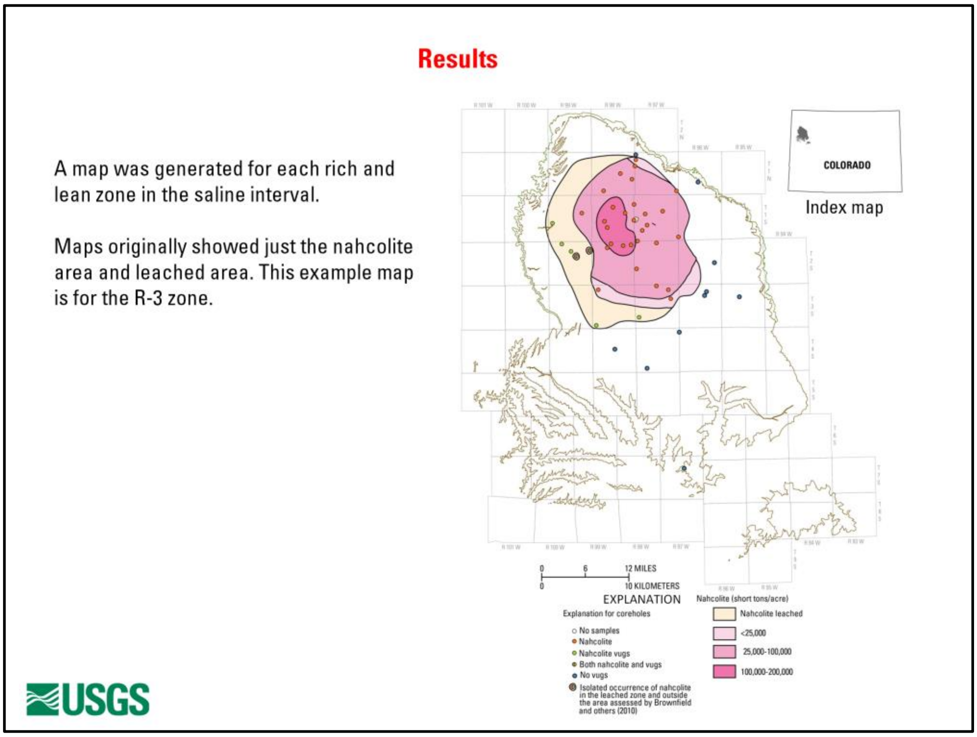
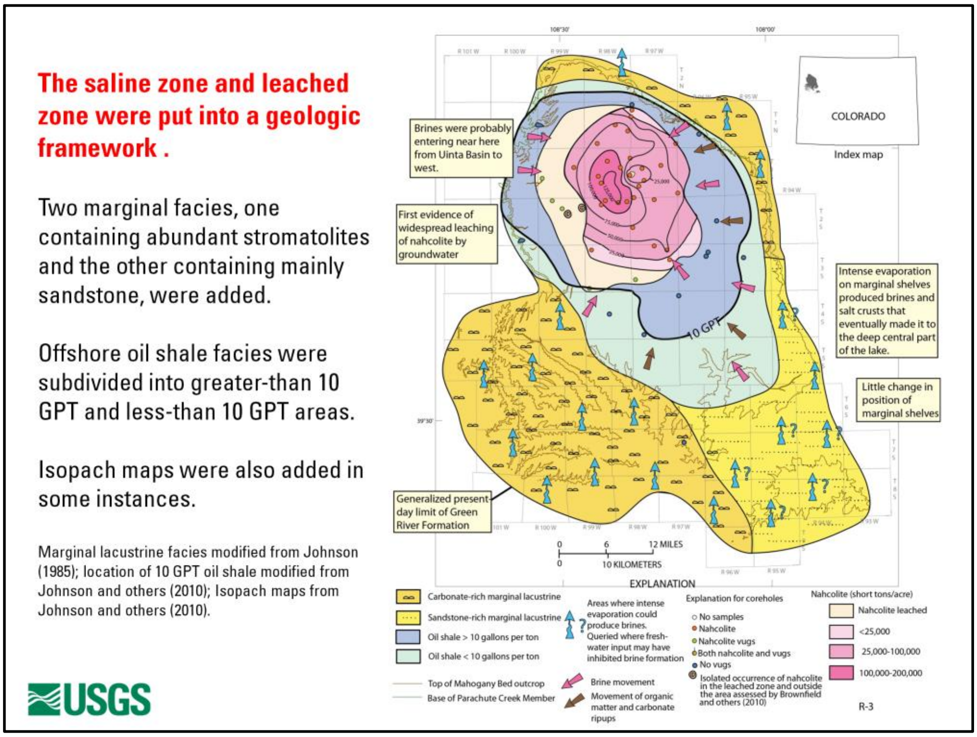
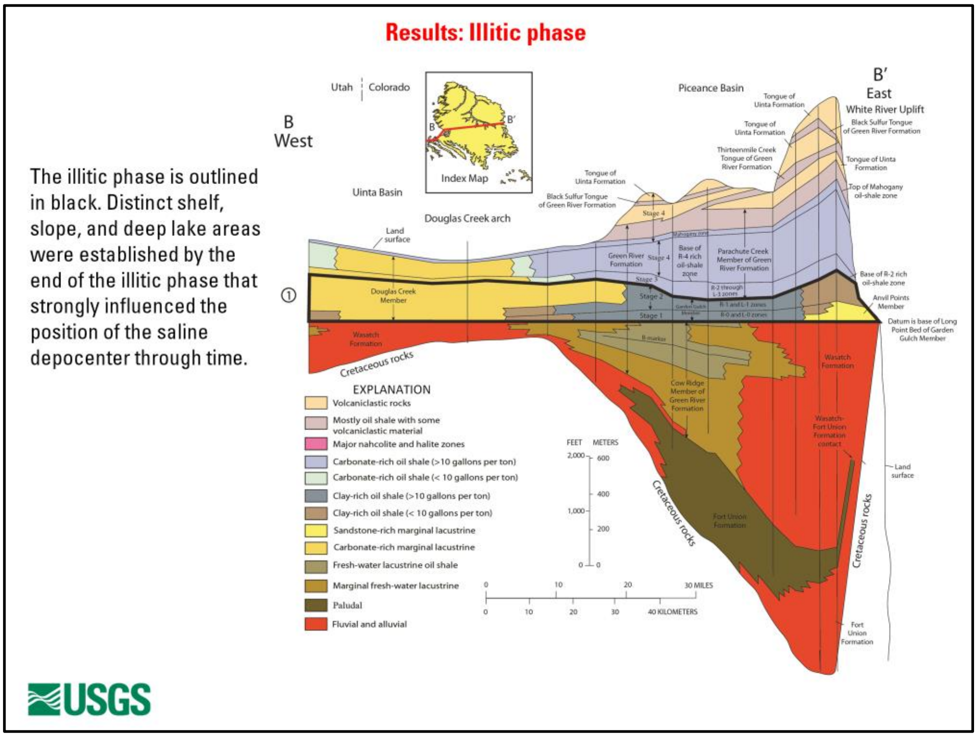


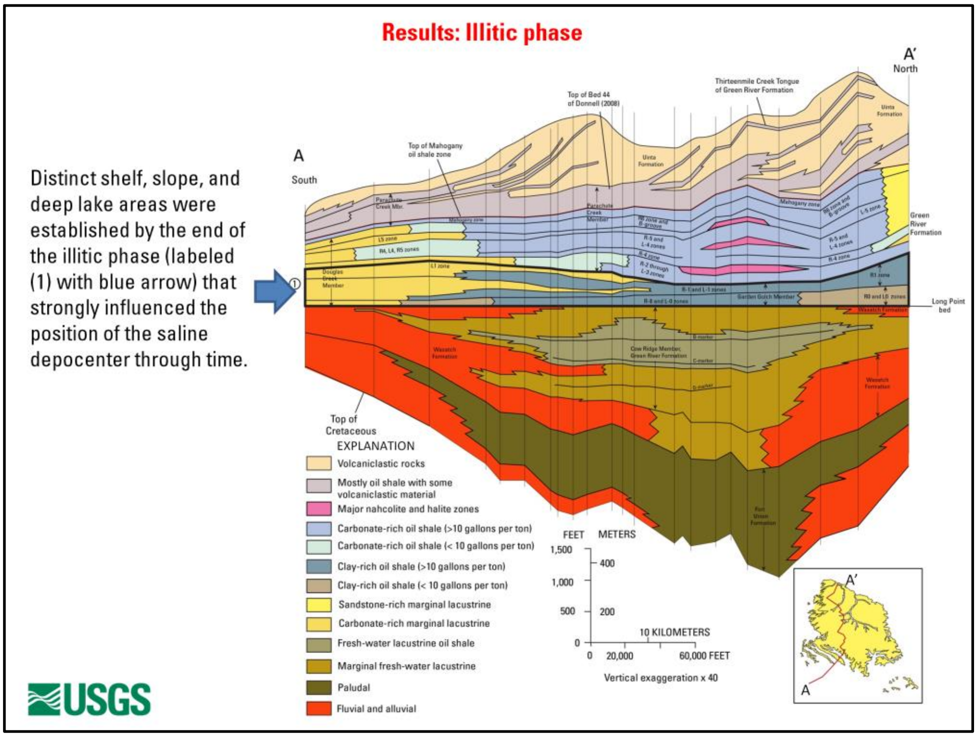
All of the control points used in this study are included in this map.



The extent of the present-day nahcolite and the leached zone where nahcolite was once present are placed into a geologic context by adding two marginal lacustrine facies and areas showing where the oil shale grade is greater or less than 10 GPT. The symbol > means greater than, and the symbol < means less than.



Note the thickening of the illitic phase of Lake Uinta toward the marginal shelves. At the end of the illitic phase, marginal shelves surrounded a deeper central lake area. The symbol > means greater than, and the symbol < means less than.



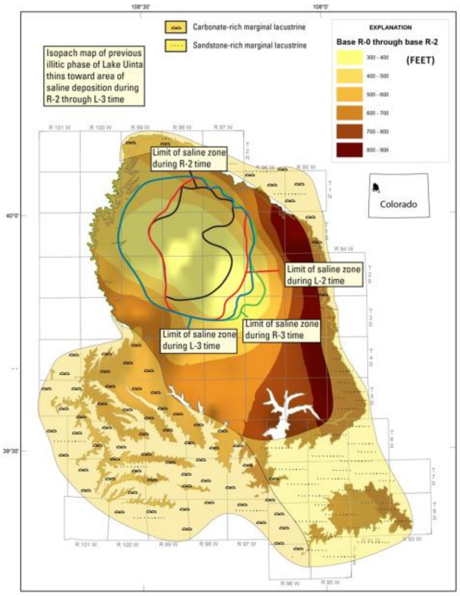
Note the thickening of the illitic phase of Lake Uinta toward the marginal shelves. At the end of the illitic phase, marginal shelves surrounded a deeper central lake area. The symbol > means greater than, and the symbol < means less than.

Results: Illitic phase

An isopach map of the illitic phase (R-0 through L-1 zones) shows thickening toward the margins of the basin where lake-margin shelves developed. Shallow-water carbonate-rich and sandstone-rich environments occupied these shelves.

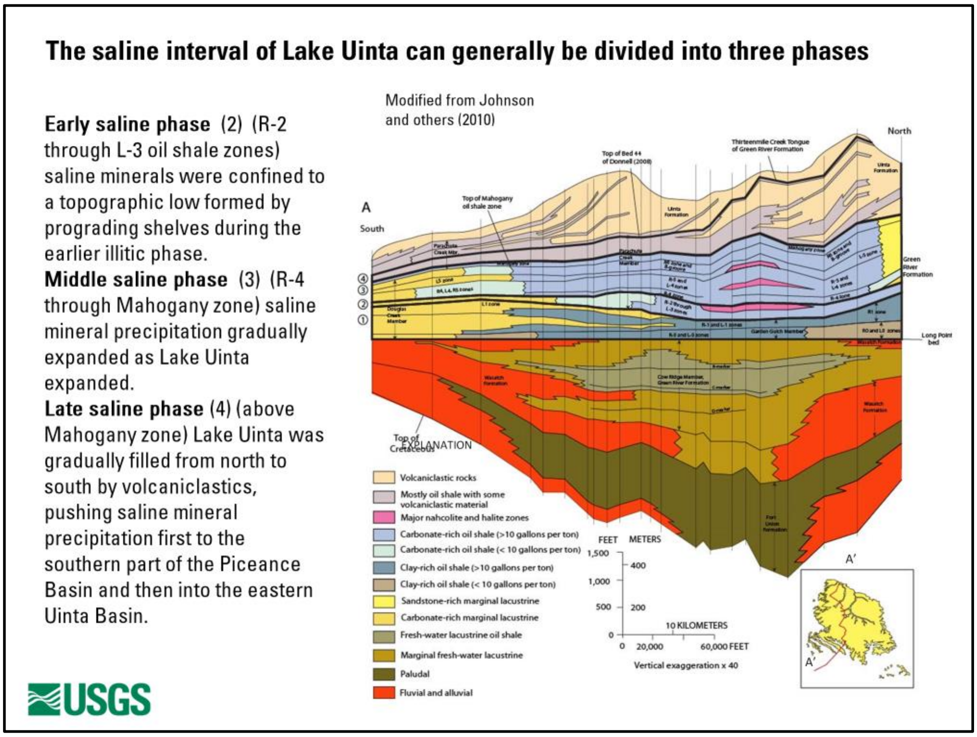
The isopach map suggests a slope between the shelf edge and central deep lake area of about 0.4-0.9 degrees.

In addition, Lake Uinta may have inherited some topography from the previous fresh-water phase (not discussed here).



USGS

This isopach map of the illitic phase of Lake Uinta thins toward the central part of Lake Uinta.



The symbol > means greater than, and the symbol < means less than.

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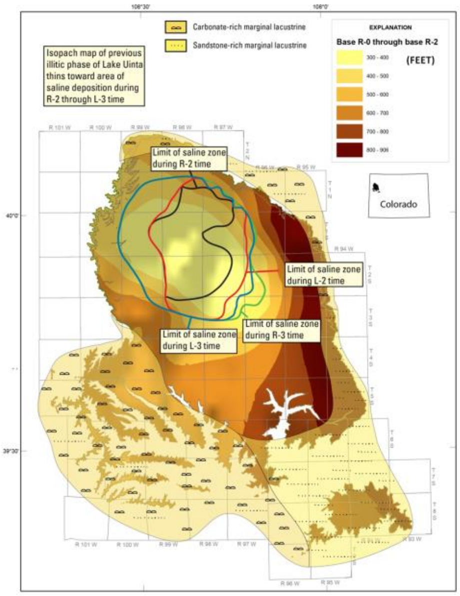
Results: Early saline mineral phase

Outlines of saline zones during the early saline mineral phase correspond closely to the topographic low formed by marginal shelf progradation during the previous illitic oil shale phase.



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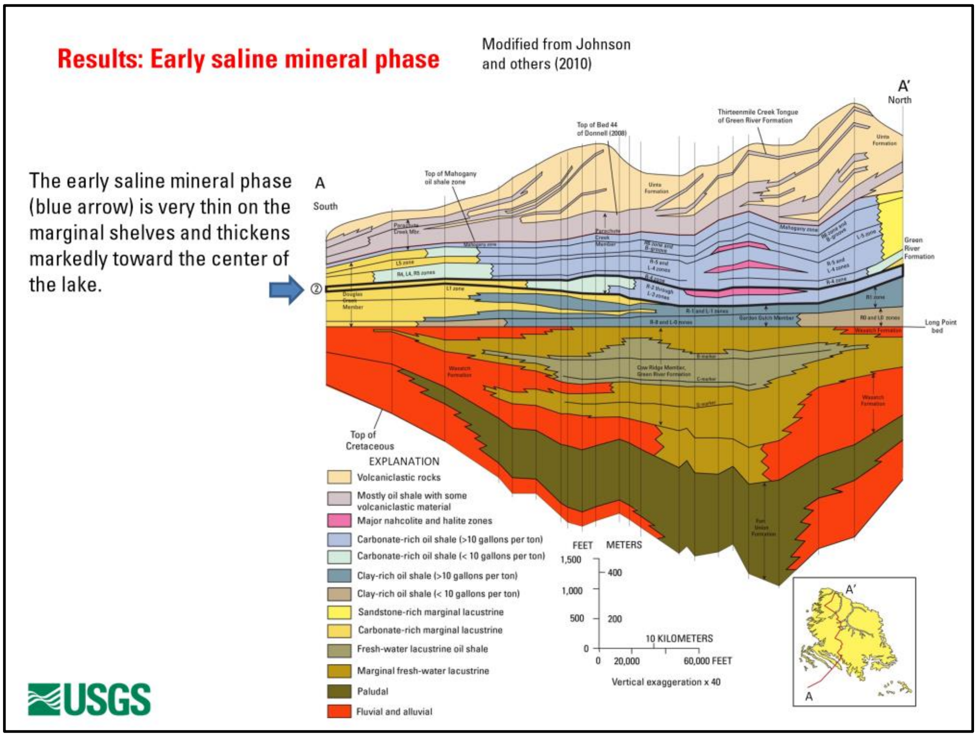
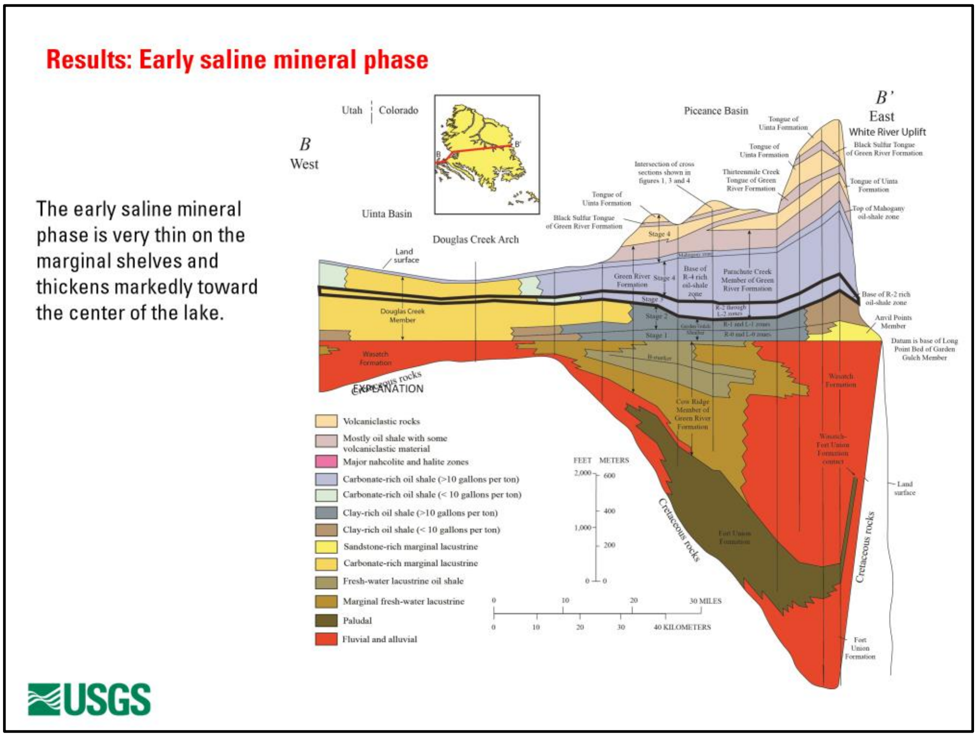
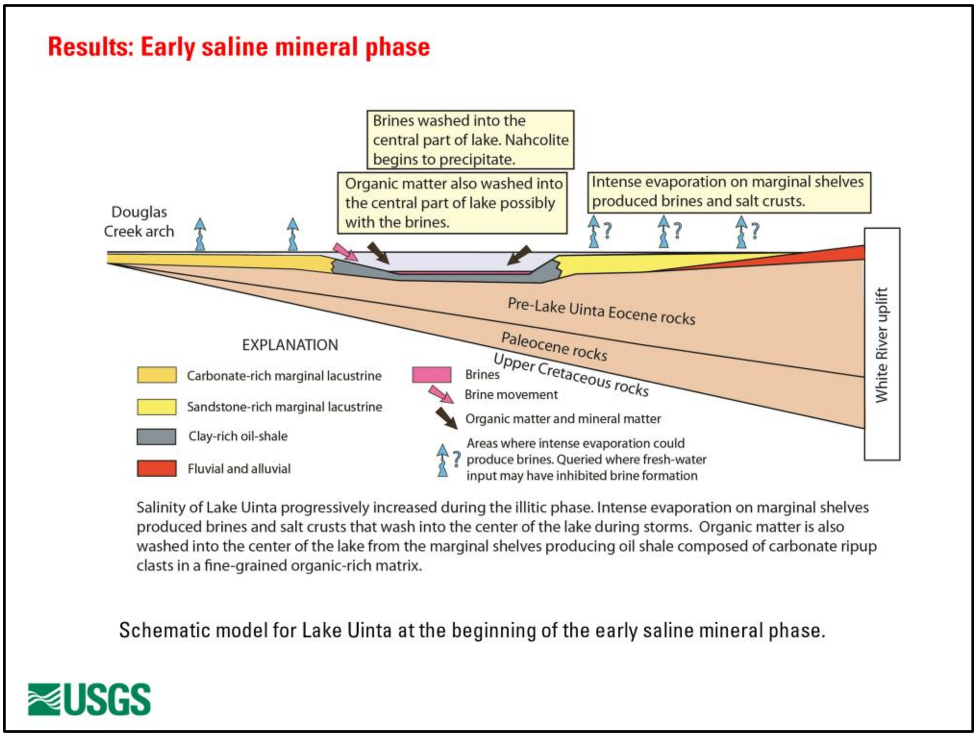


In contrast to the earlier illitic phase that thins toward the central part of Lake Uinta, the early saline phase thins toward the lake margins. The symbol > means greater than, and the symbol < means less than.

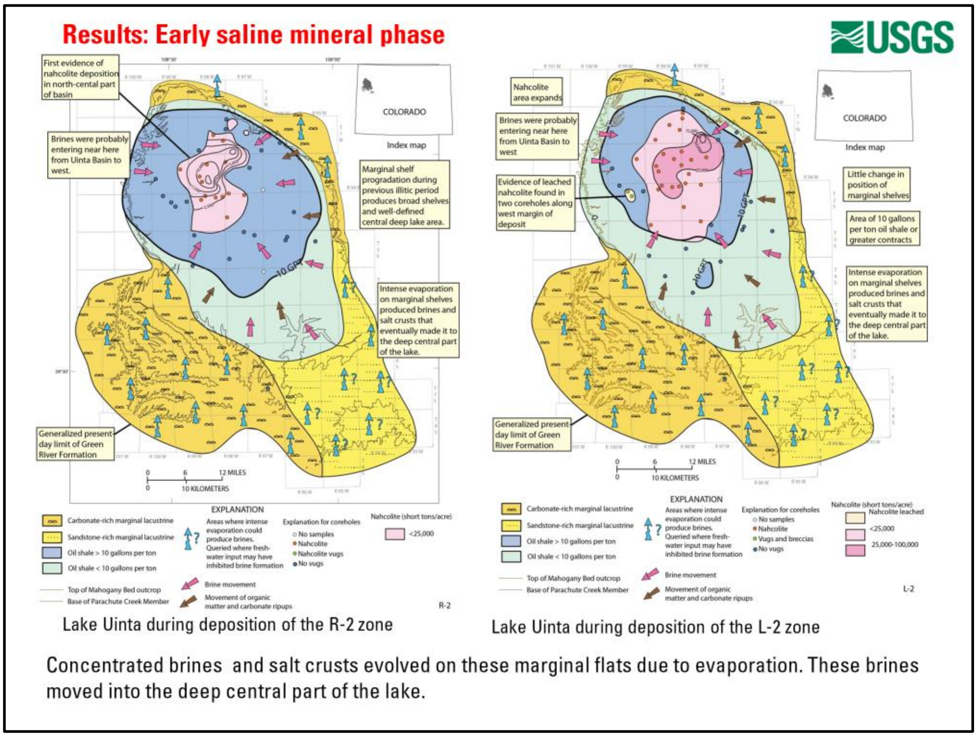


The symbol > means greater than, and the symbol < means less than.

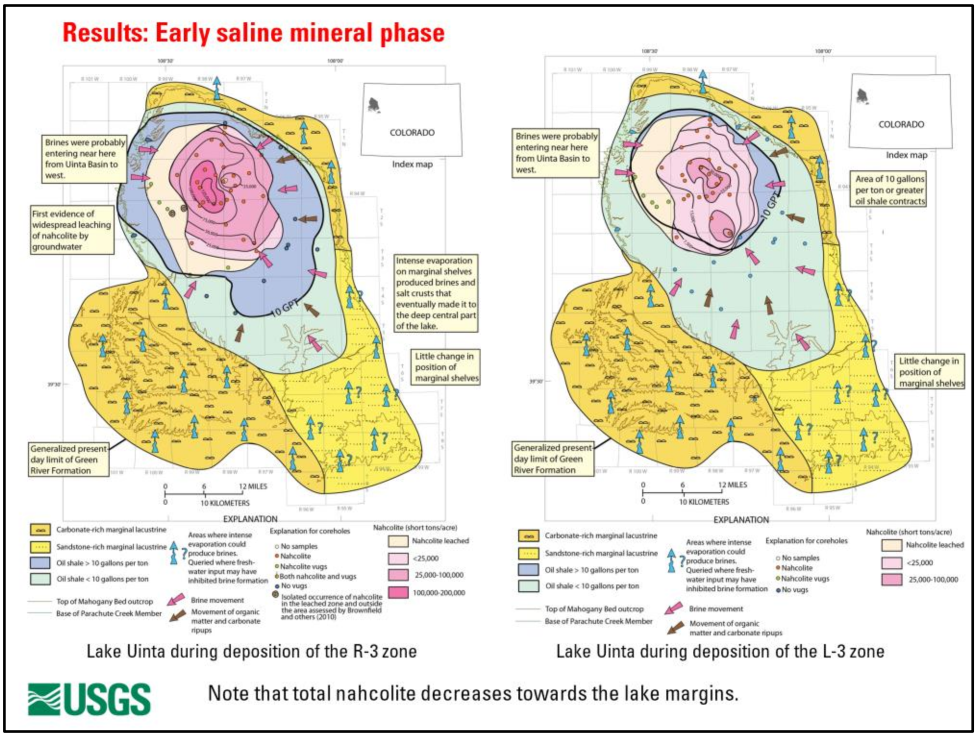


This schematic model attempts to place the development of Lake Uinta into the overall Lower Tertiary subsidence history of the Piceance Basin. It extends from west to east from the Douglas Creek arch on the west, across the central part of the Piceance Basin, to the White River uplift on the east. It shows that, prior to the development of Lake Uinta, the arch could be thought of as a hinge-line with subsidence rates increasing eastward from the crest of the arch toward the White River uplift.

The model depicts the beginning of the early saline phase and shows the marginal shelves that developed during the earlier illitic phase of Lake Uinta. It is proposed here that highly saline brines and salt crusts formed due to intense evaporation on these broad, shallow shelves, and that these brines and salt crusts were washed into the central deep part of Lake Uinta during storm events (pink arrows) forming a deep highly saline brine layer in the lake.



Zones R-2 and L-2 of the early saline mineral phase. Marginal shelves in some places were more than 25 miles wide during this phase. Highly saline brines and salt crusts evolved due to intense evaporation on these shelves and were washed into the central deep part of Lake Uinta during storm events (pink arrows) forming a deep highly saline brine layer in the lake. Note that the 10 GPT and greater area contracts during deposition of L-2 zone. The symbol > means greater than, and the symbol < means less than.



The symbol > means greater than, and the symbol < means less than.

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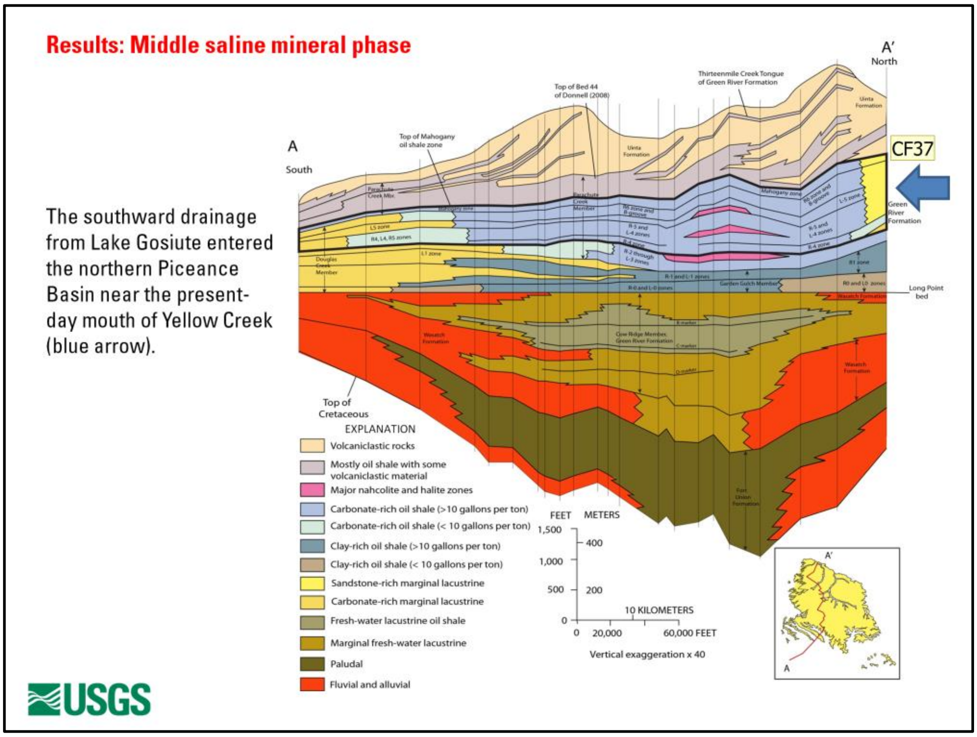
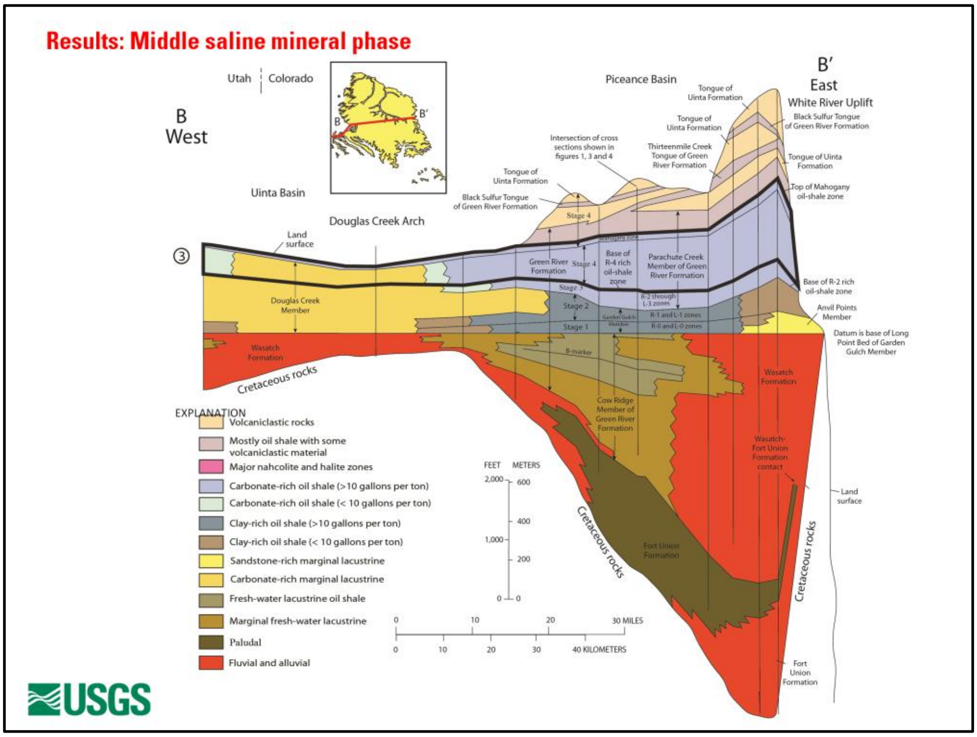
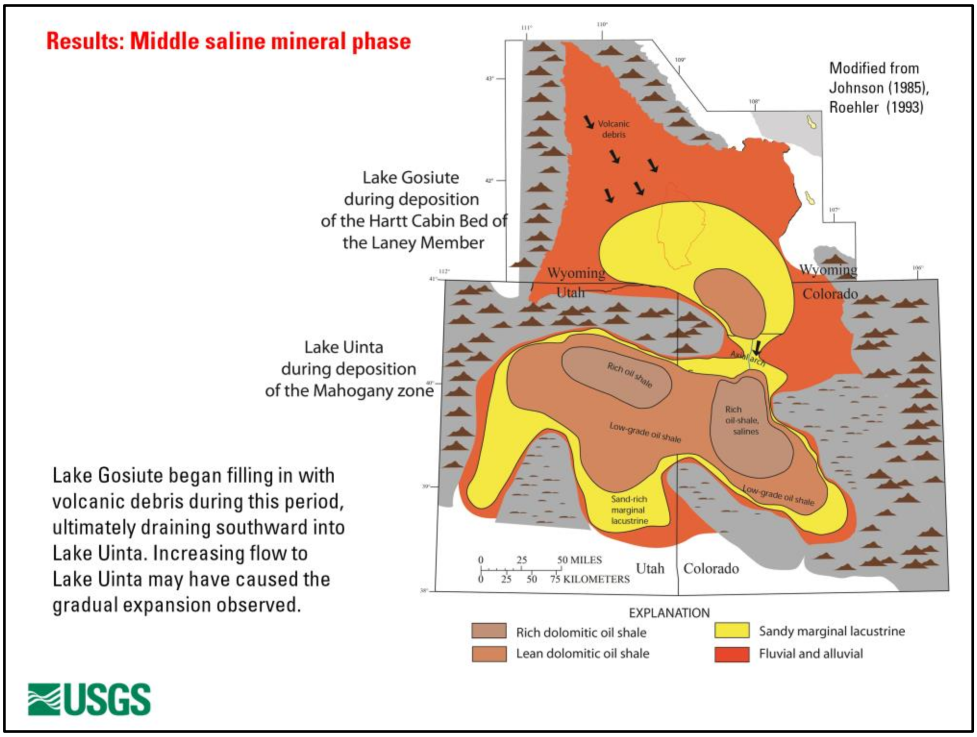


The middle saline mineral phase is outlined in black and labeled with a 3. This phase extends from the base of the R-4 oil shale zone to the top of the Mahogany zone. It thickens toward the central part of Lake Uinta due to oil shale and saline mineral deposition. Topographic relief may have diminished compared to the previous phase.

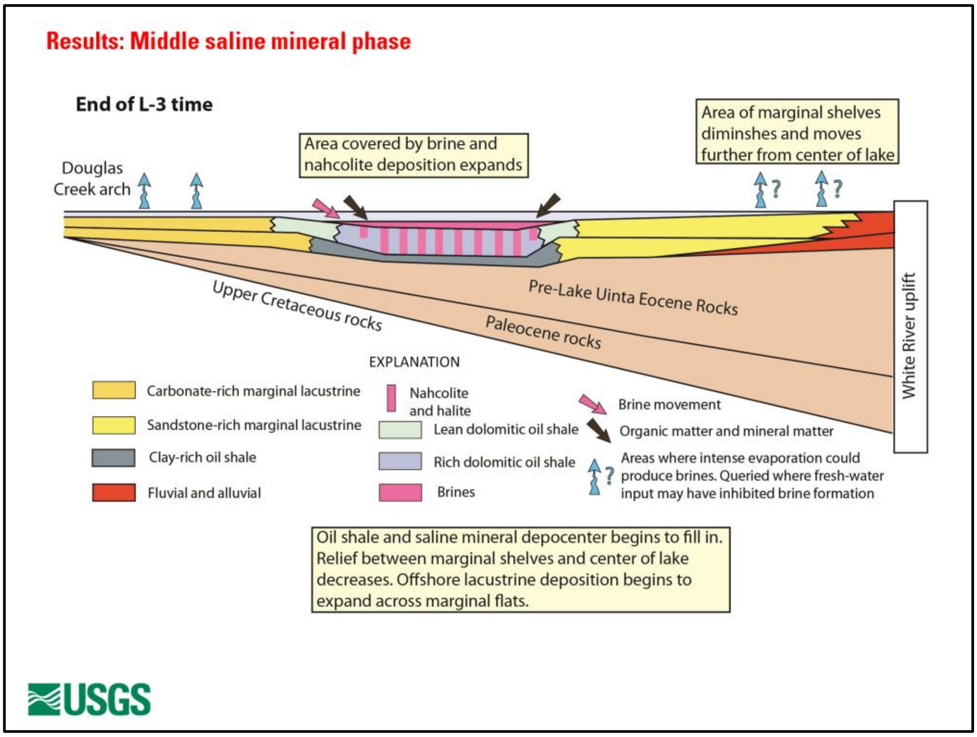
Oil-shale deposition progressively encroached on the outer parts of the marginal shelves. By the end of the middle saline mineral phase, rich oil shale deposition was occurring over the full extent of the marginal shelves, or at least over that part which is still preserved. Relatively recent erosion around the margins of the Piceance Basin has removed the marginal lacustrine facies that must have existed during Mahogany time. The expansion of Lake Uinta during this phase was probably due in part to inflow from Lake Gosiute to the north. The sandy marginal lacustrine area at the north end of the cross section (blue arrow) is probably where this inflow occurred. The symbol > means greater than, and the symbol < means less than.



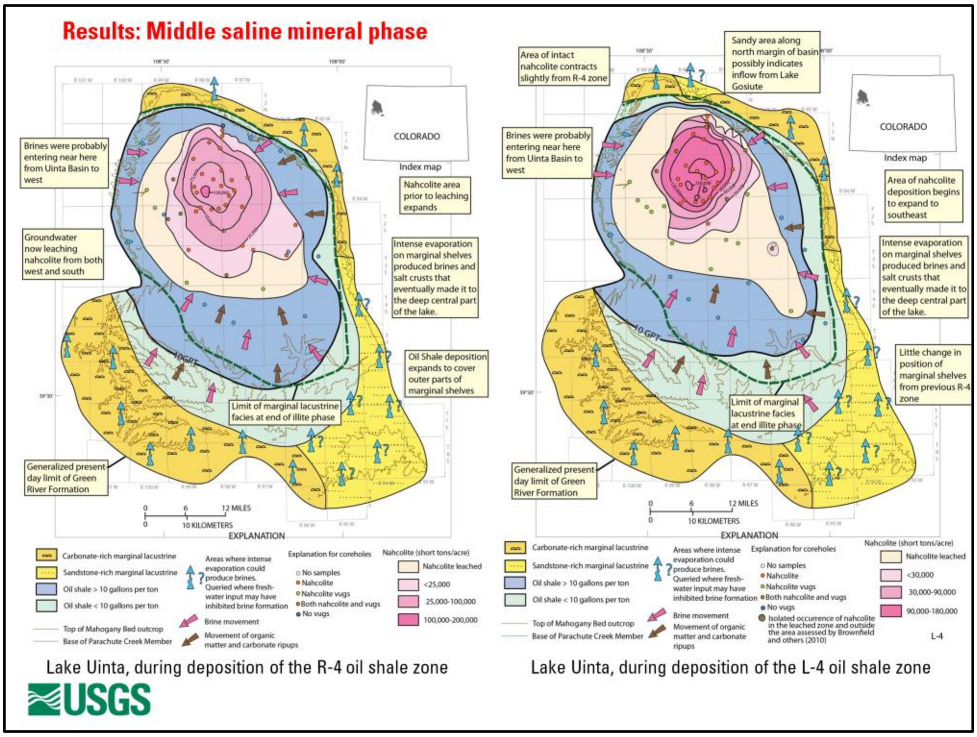
The middle saline mineral phase is outlined in black in this west-east cross section that extends from the easternmost part of the Uinta Basin, eastward across the Douglas Creek arch to the east margin of the Piceance Basin. Again, note the thickening of this interval toward the center of the lake and the gradual expansion of rich oil shale deposition across the marginal shelves. The symbol > means greater than, and the symbol < means less than.



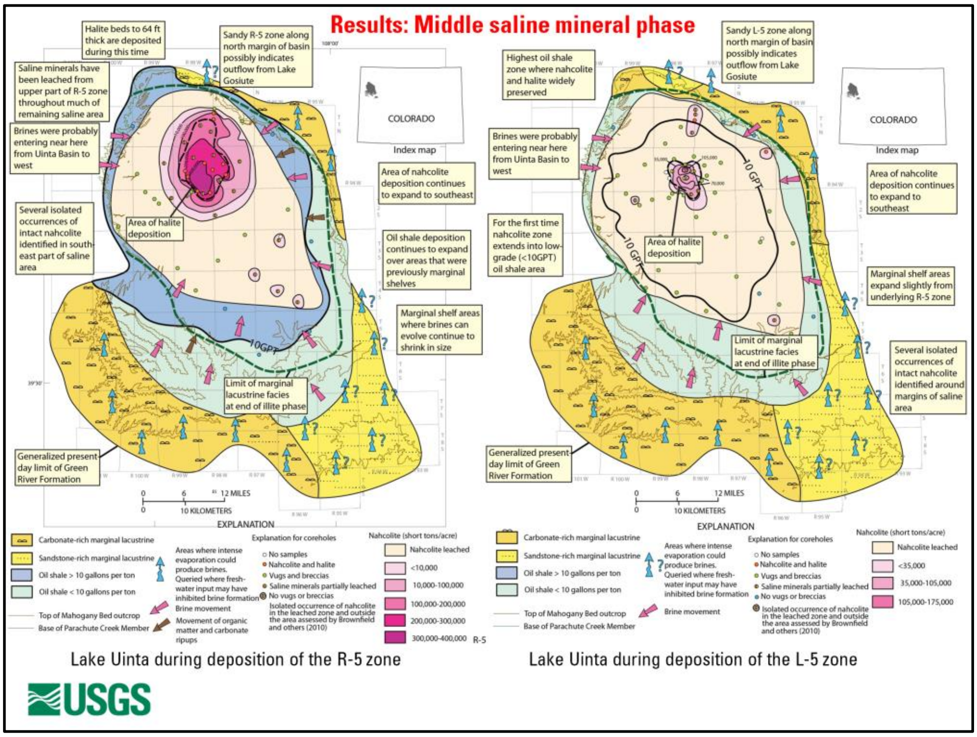
Lake Gosiute to the north was gradually filled by volcanic sediment from the north during the middle saline mineral phase of Lake Uinta, progressively pushing Lake Gosiute southward and ultimately causing it to flow into Lake Uinta. This increased water supply may have caused Lake Uinta to gradually expand.



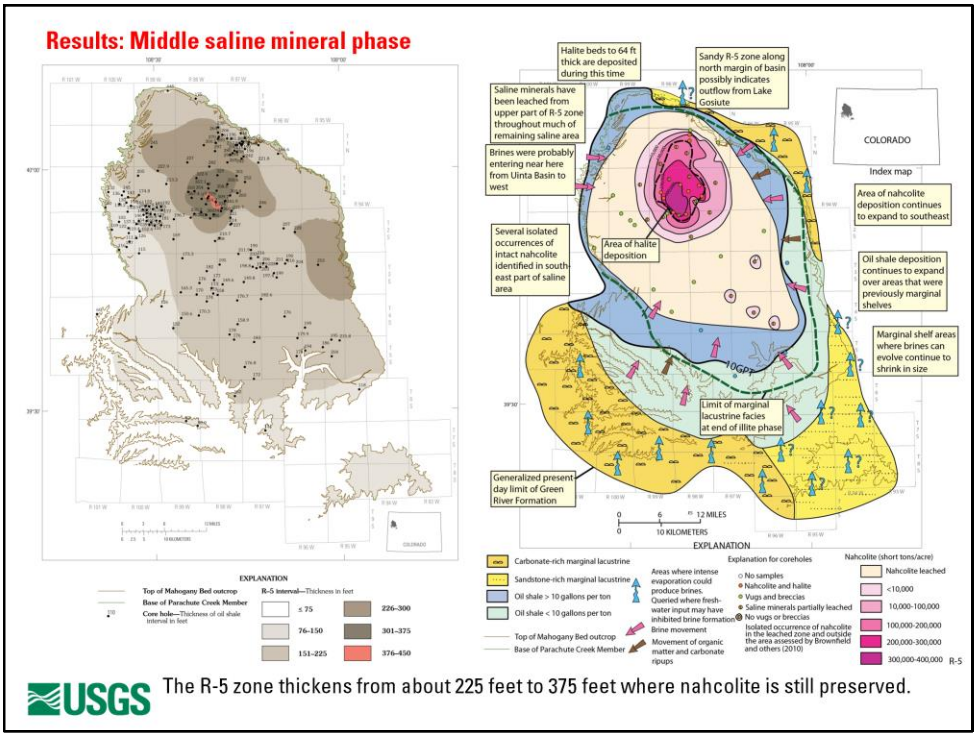
Sediment deposited during the early saline mineral phase and early part of the middle saline mineral phase have been added to the schematic presented earlier. The central part of Lake Uinta was gradually filled with oil shale and saline minerals during the early and middle saline mineral phases, and the relief between the shelves and deep lake area was probably diminishing. Deeper water conditions began to expand across the outer parts of the marginal shelves during the middle saline mineral phase. Although brines were still probably evolving on the marginal shelves of the Piceance Basin, the progressive drowning of the shelves by relatively deep-water conditions may have limited the volume of brines produced. Broad marginal shelves still existed in the Uinta Basin part of the Lake Uinta, and brines may still have been evolving there.



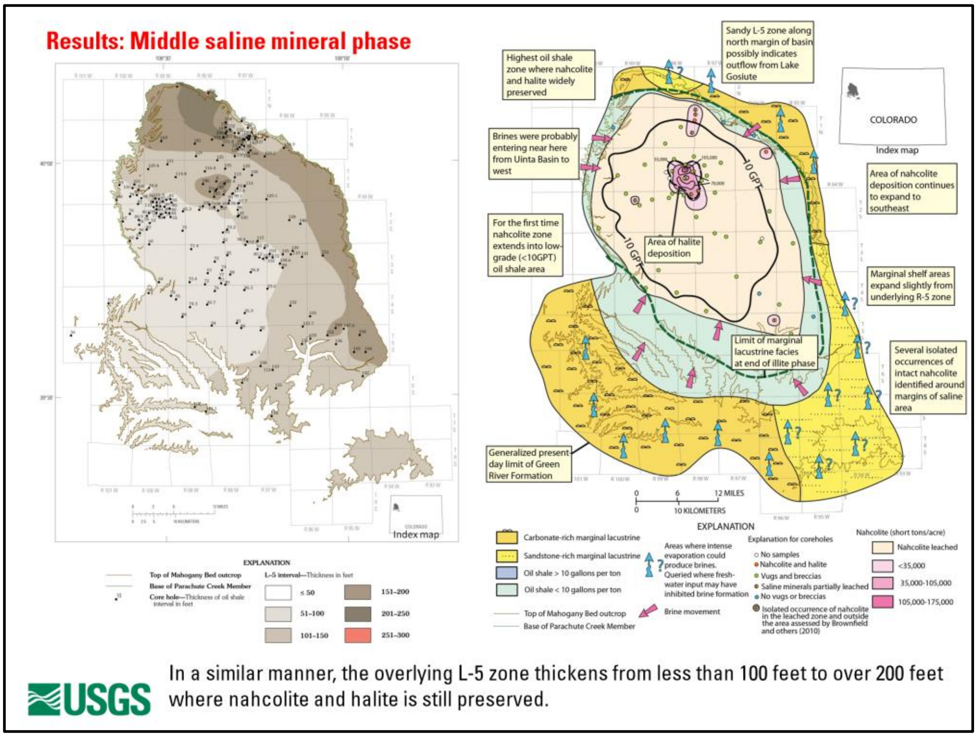
Progressive drowning of the outer parts of the marginal shelves occurred during deposition of the R-4 and L-4 oil shale zones (shelf edge at end of early saline phase shown as green dashed line). The original extent of nahcolite deposition, as defined by the leached zone, continued to expand, while the present-day extent of nahcolite progressively contracts. Note also the sandy marginal lacustrine deposit that appears along the north margin of the Piceance Basin during deposition of the L-4 where inflow from Lake Gosiute from the north was hypothesized to have occurred. This is the oldest possible evidence of inflow from Lake Gosiute. The symbol > means greater than, and the symbol < means less than.



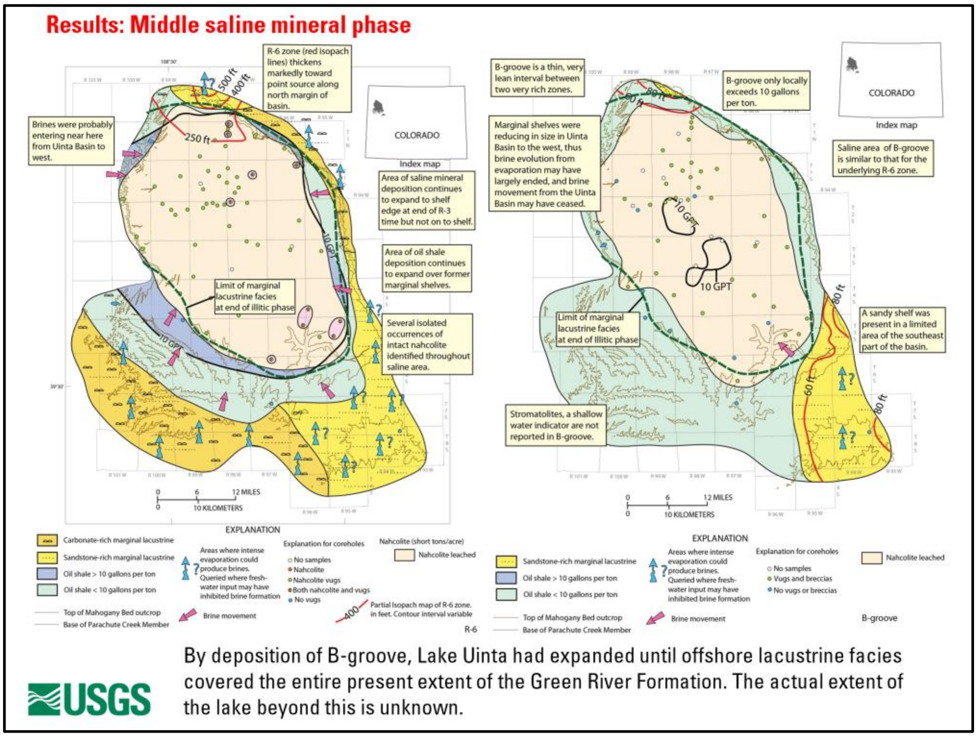
Bedded halite (black dashed line) occurs for the first time in the R-5 zone. The original extent of nahcolite and halite deposition continues to expand, while the present-day extent of these two saline minerals markedly contracts due to later groundwater invasion. Note several isolated occurrences of nahcolite preserved in the otherwise leached areas. Note again the sandy marginal lacustrine facies along the north margin of the basin where flow from Lake Gosiute to the north is hypothesized to have occurred. The symbol > means greater than, and the symbol < means less than.



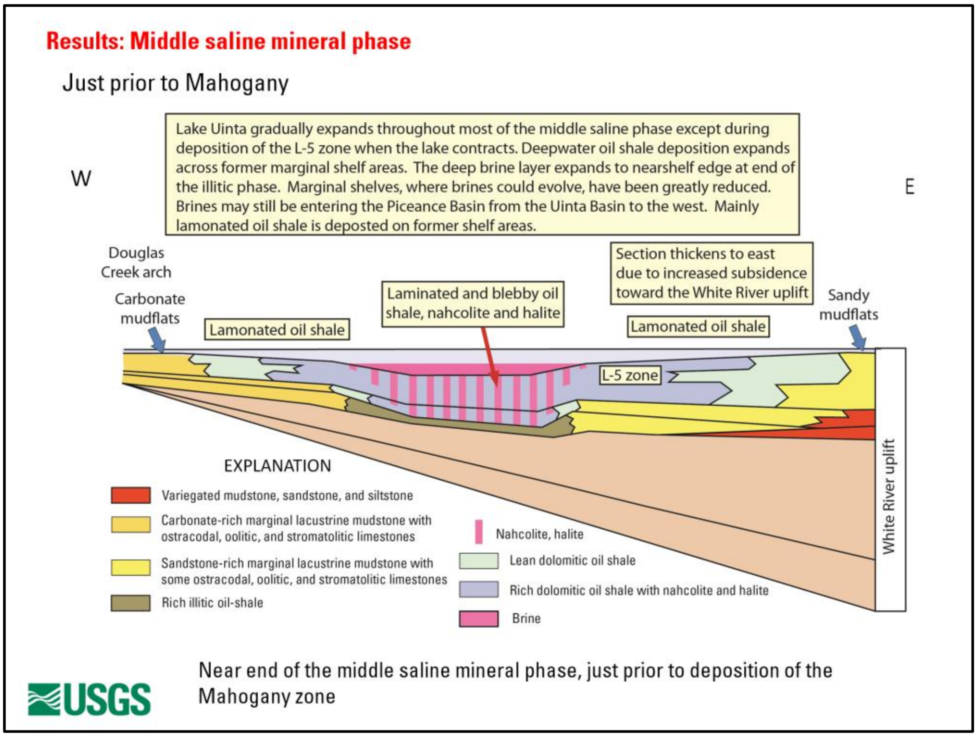
Leaching of nahcolite and halite beds that were 60 feet or thicker caused collapse and marked thinning of the R-5 interval from 375 feet to 225 feet. The symbol > means greater than, and the symbol < means less than.



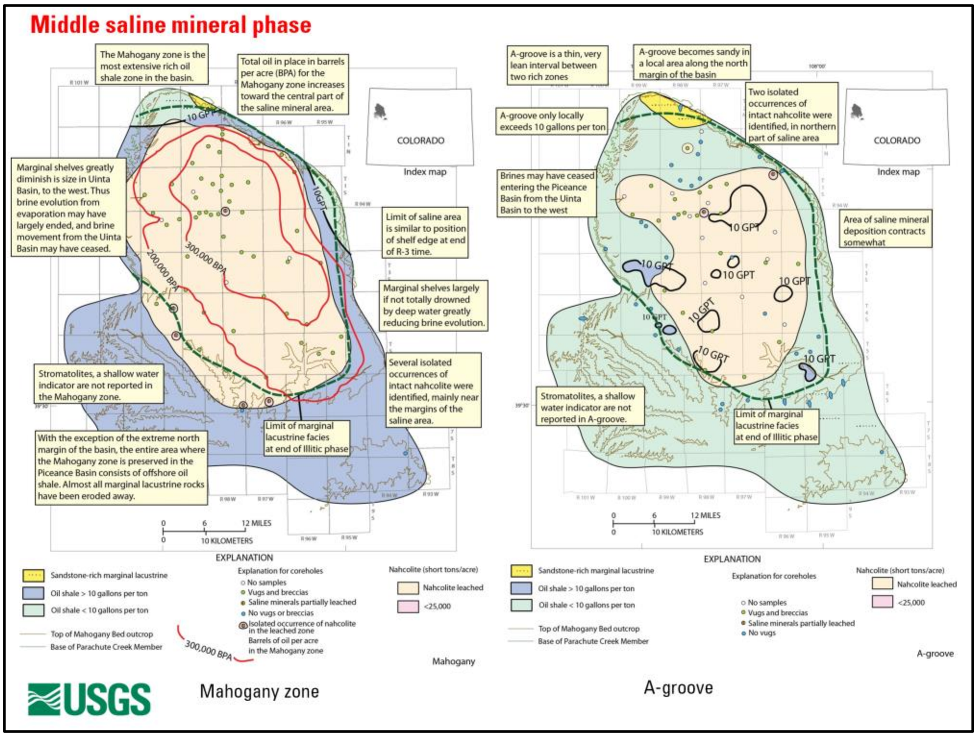
Collapsing extended into the L-5 zone which thins from over 200 ft to less than 100 ft where nahcolite and halite have been leached out. The symbol > means greater than, and the symbol < means less than.



With the exception of a few isolated occurrences, all nahcolite and halite have been leached out of the R-6 zone. The original extent of nahcolite and halite deposition in the R-6 zone and overlying B-groove, as defined by the leached zone, extended to near the position of the shelf break at the end of the early saline mineral phase (dashed green line), suggesting that there was still a topographic break at this position that confined the deep saline brine layer. Some isopach contours from the isopach maps of the R-6 zone and B-groove are included where these two zones thicken markedly. B-groove is a thin lean interval that varies from about 10-30 ft thick throughout most of the basin. Note, however, that it thickens to more than 80 ft along the north margin of the basin where inflow from Lake Gosiute was ongoing and to more than 80 ft in the southeast corner of the basin where another major drainage entered Lake Uinta. Note also the lack of evidence of shallow water deposition in most marginal areas in the B-groove interval. The symbol > means greater than, and the symbol < means less than.



West-east schematic cross section of Lake Uinta late in the middle saline mineral phase, just prior to deposition of the Mahogany zone. The deep central part of the lake has been largely filled by oil shale and saline minerals, but some topographic remnants of the earlier shelf break were probably present as the deep saline brines seem to have been constrained by that break. Deepwater rich oil shale deposition occurred over almost the entire preserved area of the former marginal shelves. Recent extensive erosion around the margins of the Piceance Basin has removed almost all evidence of marginal lacustrine deposition, and thus, only the offshore facies from this period can be studied.



The original extent of saline deposition during Mahogany time extended to near the shelf break at the end of the illitic phase (green dashed line). Offshore oil shale deposition extended to the present-day limits of the Green River Formation in the Piceance Basin; thus, the marginal lacustrine facies from this period cannot be studied. A slight decrease in the original extent of saline mineral deposition occurred during deposition of A-groove, another thin organically lean interval similar to B-groove. As with B-groove, note the general lack of marginal lacustrine facies.

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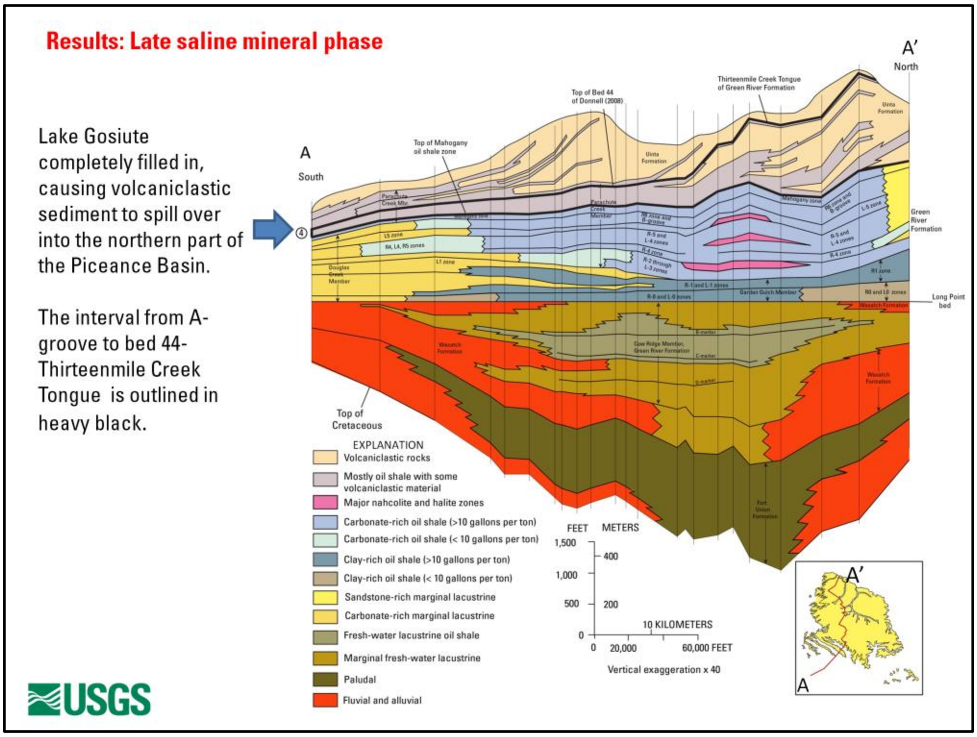
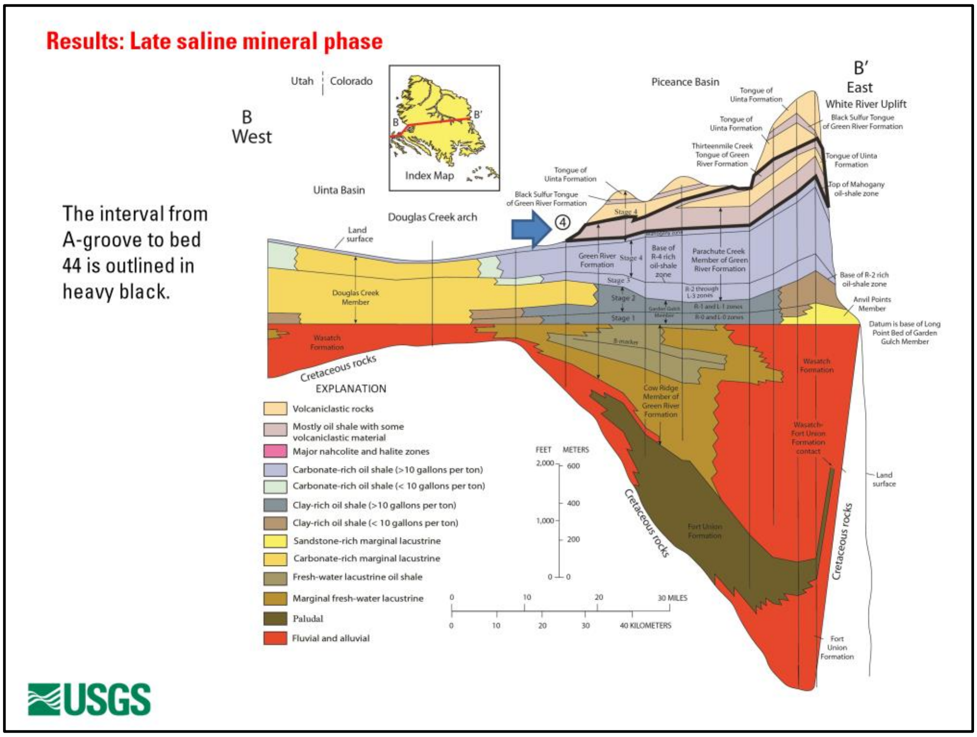
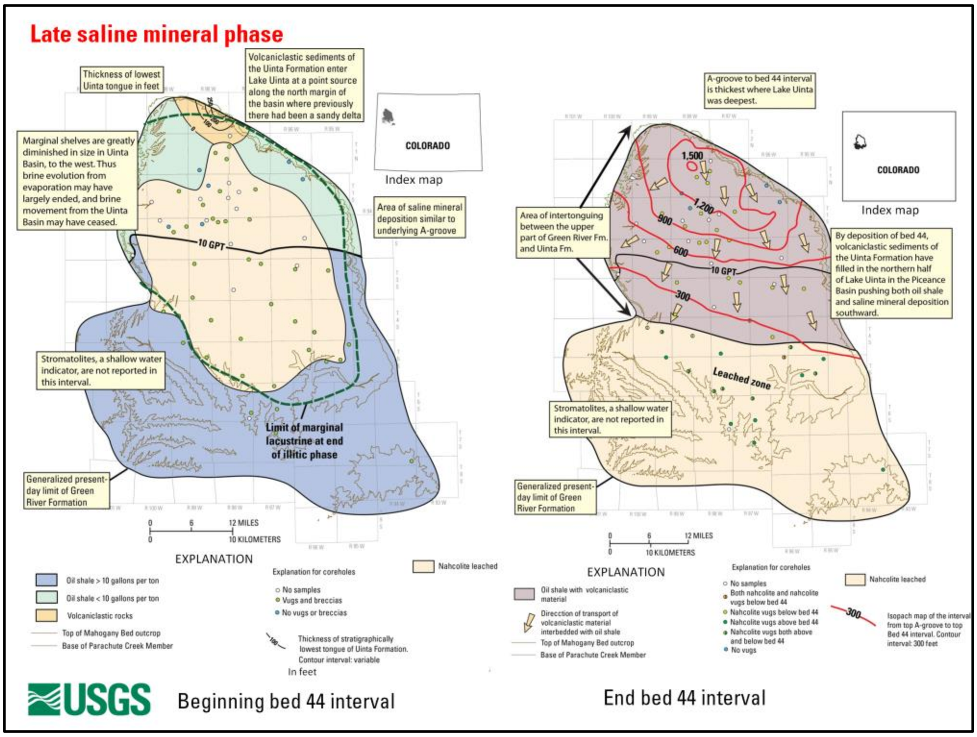


Once Lake Gosiute to the north was completely filled, it no longer acted as a sediment sink, and volcaniclastic debris entered the Piceance Basin. This resulted in a progressive north-to-south infilling of the Piceance Basin part of Lake Uinta. This prograding deltaic complex is as much as 1,500 ft thick, leading to the conclusion that the central part of Lake Uinta may have been as much as 1,000 ft deep at this time (Johnson, 1981). Only that part of the late saline mineral phase extending from the top of A-groove to the top of bed 44 of Donnell (outlined in heavy black) was studied in detail here. The symbol > means greater than, and the symbol < means less than.

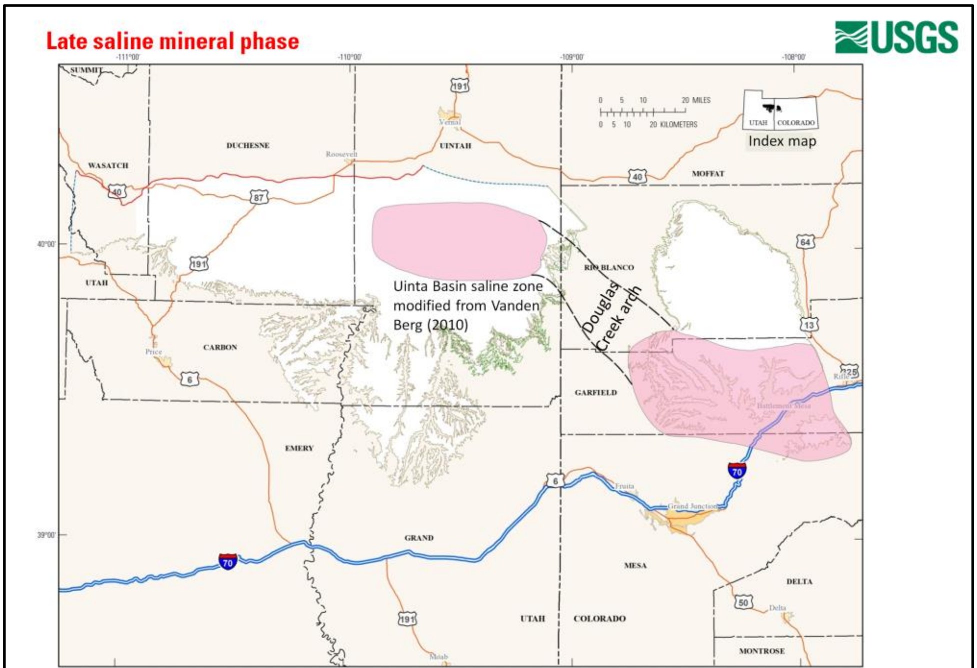


The late saline mineral phase is outlined on this east-west cross section. Note that some of the volcaniclastic tongues of the Uinta Formation are lenticular in an east-west direction. The symbol > means greater than, and the symbol < means less than.



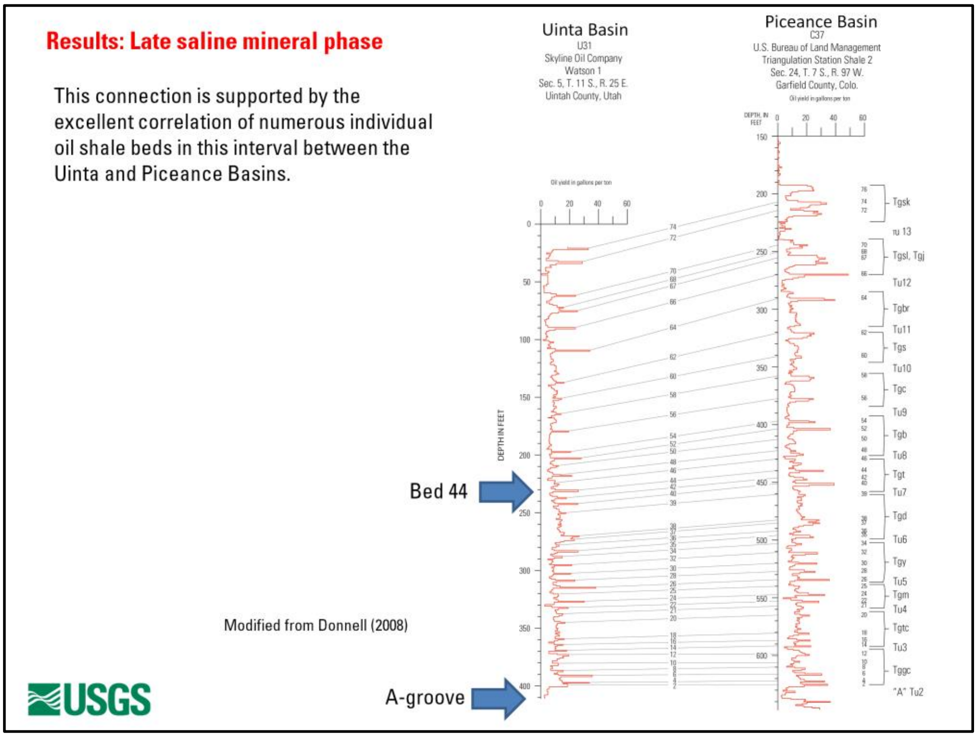
Lake Uinta in the Piceance Basin was actively being filled in during both late saline phase intervals represented by these maps. The isopach map shown at the north margin of the basin in the map on the left is the thickness of the stratigraphically lowest tongue of the volcaniclastic Uinta Formation, which probably occurs just above the top of the A-groove. Note that it is thickest where outflow from Lake Gosiute was indicated on earlier maps. Infilling is pushing rich oil shale deposition (greater than 10 gallons per ton) to the southern part of the basin. Saline mineral deposition, as defined by the extent of the leached zone, is still largely basinward of the shelf-slope break at the end of the early saline mineral phase.

On the map on the right, the isopached interval is from the top of A-groove to the top of bed 44 interval. This isopach map thickens markedly to the north from less than 300 ft to over 1,500 ft due to volcaniclastic wedges of the Uinta Formation. It appears that by the beginning of the bed 44 to top of Green River Formation interval, the deep oil shale and saline depocenter in the north-central part of the basin had been largely filled. This pushed the saline brines, as defined by the leached zone, into the southern part of the basin. The symbol > means greater than, and the symbol < means less than.



During this period, the saline depocenter was shifting from the Piceance Basin into the Uinta Basin to the west. The two depocenters were probably connected for a time across the Douglas Creek arch (dashed).

For the first time, evidence of nahcolite deposition in the form of leached nahcolite vugs is found in the eastern part of the Uinta Basin, indicating that the deep saline brine layer was shifting to the eastern Uinta Basin as the Piceance saline depocenter was filled in.



Numerous individual oil shale beds in this interval can be easily correlated between the eastern part of the Uinta Basin and the southern part of the Piceance Basin, suggesting that the deep brine pools in both basins were connected. The area where these two brine pools would have connected, however, has been eroded. This cross section correlates individual oil shale beds (numbered 2-76) in the upper part of the Eocene Green River Formation between the eastern Uinta Basin and southern part of the Piceance Basin. Groups of beds form named tongues (indicated by stratigraphic unit symbols) in the Piceance Basin. These tongues have not been identified in the Uinta Basin. Modified from Donnell (2008). Abbreviations used: MB, Mahogany bed; A, base of A-groove; Tggc, Marlstone at Greasewood Creek; Tgtc, Marlstone at Trail Canyon; Tgm, Marsltone at Mare Canyon; Tgy, Yellow Creek Tongue; Tgd, Dry Fork Tongue; Tgt, Thirteenmile Creek Tongue; Tgb, Black Sulfur Tongue; Tgc, Cough's Creek Tongue; Tgs, Stewart Gulch Tongue; Tgsl, Tgi, Marlstone at Barnes Ridge and Marder bed at Bull Fork; Tgsk, Marlstone at Skinner Ridge.

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Conclusions

- Distinct shelf, slope, and deep lake areas of Lake Uinta were well defined by the end of the illitic phase.
- Brines and salt crusts probably evolved on the broad marginal shelf areas and were later washed into the central part of the lake forming a deep saline brine layer.
- The deep saline brine layer was confined by these shelves until late in the history of the lake when the saline mineral depocenter was filled by prograding volcaniclastic sediment from the north.

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Conclusions (cont.)

- Oil shale and saline mineral deposition gradually filled the deep central part of the lake during the early and middle saline periods, diminishing the relief between the shelves and the deep central lake area.
- Deep-water oil-shale deposition gradually expanded over the shelves, culminating in Mahogany time, when rich oil shale was deposited over all the marginal areas of the basin.
- This expansion was in part caused by inflow from Lake Gosiute to the north.
- The deep brine layer expanded ultimately to the shelf edges but not onto the shelves, suggesting that the brines were still confined by a topographic barrier.

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Conclusions (cont.)

- Only late in the history of Lake Uinta, after the deep central part of the lake was filled by volcaniclastic sediments, did the saline mineral depocenter shift to the southern part of the basin.
- For a time, saline mineral depocenters were maintained in both the Uinta and the Piceance Basins.

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Conclusions (cont.)

- Leaching of saline minerals by groundwater began sometime after the end of lacustrine deposition and is still going on today.
- The base of the leached zone slopes toward the discharge area to the north.
- The base of the leached zone is not always a sharp surface as there are isolated pockets of nahcolite preserved in otherwise leached intervals due most likely to a lack of fractures to allow ground water to invade.

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References

- Brownfield, M.E., Mercier, T.J., Johnson, R.C., and Self, J.G., 2010, Nahcolite resources in the Green River Formation, Piceance Basin, Colorado — Oil shale and nahcolite resources of the Piceance Basin, Colorado: U.S. Geological Survey Digital Data Series DDS-69-Y, chap. 2, 51 p.
- Cashion, W.B., and Donnell, J.R., 1972, Chart showing correlation of selected key units in the organic-rich sequence of the Green River Formation, Piceance Basin, Colorado, and Uinta Basin, Utah: U.S. Geological Survey Oil and Gas Investigations Chart OC–65.
- Donnell, J.R., 2008, Intertonguing of the lower part of the Uinta Formation with the upper part of the Green River Formation in the Piceance Creek Basin during the late stages of Lake Uinta: U.S. Geological Survey Scientific Investigation Report SIR 2008-5237, 25 p.
- Donnell, J.R., and Blair, R.W., 1970, Resource appraisal of three rich oil-shale zones in the Green River Formation, Piceance Creek basin, Colorado: Colorado School of Mines Quarterly, v. 65, p. 73–87.
- Dyni, J.R., 1996, Sodium carbonate resources of the Green River Formation: U.S. Geological Open-File Report 96–729, 39 p.
- Johnson, R.C., 1981, Stratigraphic evidence for a deep Eocene Lake Uinta, Piceance Creek Basin, Colorado: Geology, v. 9, p. 55-62.
- Johnson, R.C., 1985, Early Cenozoic history of the Uinta and Piceance Creek basins, Utah and Colorado, with special reference to the development of Eocene Lake Uinta, *in* Flores, R.M., and Kaplan, S.S., eds; Cenozoic paleogeography of the west-central United States, Rocky Mountain Paleography Symposium 3: Denver, Colo., The Rocky Mountain Section, Society of Economic Paleontologists and Mineralogists, p. 247-276.

USGS

References Cited (cont.)

- Johnson, R.C., Mercier, T.J., Brownfield, M.E., Pantea, M.P., and Self, J.G., 2010, An assessment of in-place oil shale resources of the Green River Formation, Piceance Basin, Colorado: Oil Shale and Nahcolite Resources of the Piceance Basin, Colorado, U.S. Geological Survey Digital Data Series DDS-69-Y, Chapter 1, 187 p.
- Johnson, R.C., 2012, The systematic geologic mapping program and a quadrangle–by–quadrangle analysis of the time-stratigraphic relations within the oil shale-bearing rocks of the Piceance Basin, western Colorado: U.S. Geological Survey Scientific Investigations Report SIR 2012-5041. (Also available at http://pubs.usgs.gov/sir/2012/5041/.)
- Johnson, R.C., Mercier, T.J., Brownfield, M.E., Pantea, M.P., and Self, J.G., 2010, An assessment of in-place oil shale resources in the Green River Formation, Piceance Basin, Colorado, *in* U.S. Geological Survey Oil Shale Assessment Team, Oil Shale and Nahcolite Resources of the Piceance Basin, Colorado: U.S. Geological Survey Digital Data Series DDS–69–y, chap. 1, 187 p.
- Mercier, T.J., and Johnson, R.C., 2012, Isopach and isoresource maps for oil shale deposits in the Eocene Green River Formation for the combined Uinta and Piceance Basins, Utah and Colorado: U.S. Geological Survey Scientific Investigations Report 2012–5076, 85 p., 1 pl. (Also available at http://pubs.usgs.gov/sir/2012/5076/.)
- Roehler, H.W., 1993, Eocene climates, depositional environments, and geography, Greater Green River Basin, Wyoming, Utah, and Colorado: U.S. Geological Survey Professional Paper 1506–F, 74 p.
- Vanden Berg, M.D., 2010, Saline water disposal into the birds nest aquifer in the Uinta Basin: updated research on the implications for oil shale development, *in* Oil Shale Symposium 30th, Golden, Colo., Colorado School of Mines, Oct. 18-22, 2010, Power Point Presentation, CD-ROM: Golden, Colo., Colorado School of Mines Center for Oil Shale Technology and Research.
- Weeks, J.B., Leavesley, G.H., Welder, F.A., and Saulnier, G.J., Jr., 1974, Simulated effects of oil-shale development on the hydrology of Piceance Basin, Colorado: U.S. Geological Survey Professional Paper 908, 84 p.

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