TASK 2: GEOLOGIC EXAMINATION OF THE BIRDS NEST AQUIFER

Problem

Origin of the Birds Nest aquifer name, mud swallow nests in nahcolite cavities.

The Birds Nest aquifer is poorly understood and needs further study to determine potential impacts of saline water disposal.

- What is its areal and stratigraphic extent?
- How is it related to Utah's oil shale deposits?
- What causes the differing zones of dissolution and salinity?

Eastern Uinta Basin natural gas producers have identified the Birds Nest aquifer, located in the Parachute Creek Member of the Green River Formation, as the most promising reservoir suitable for large-volume saline water disposal. This aquifer, ranging in thickness from less than 100 feet on the basin margins to greater than 300 feet in the basin's depocenter, formed from the dissolution of saline minerals which left behind large open cavities and fractured rock. Understanding the aquifer's areal extent, thickness, water chemistry, and zones of differential dissolution will help determine possible saline water disposal volumes and safe disposal practices, both of which could directly impact the success of increased hydrocarbon production in the region.

The Birds Nest aquifer is typically several hundred feet above the richest oil shale interval called the Mahogany zone. A significant concern is that saline water disposal into the Birds Nest by conventional gas producers could hinder oil shale development by creating unforeseen water disposal problems.

Research/Deliverables

- Conduct comprehensive literature review and historic data collection.
- Evaluate the Birds Nest aquifer in core:
  - 22 wells have been identified as having all or part of the Birds Nest captured in core. To date, 21 cores have been examined.
- Evaluate the Birds Nest aquifer on outcrop:
  - Good outcrop exposures can be found on the southeastern side of the basin.
- Evaluate the Birds Nest aquifer on geophysical logs.
- Determine how disposal into the Birds Nest aquifer could affect future oil shale development.
- Determine how gilsonite veins might influence water flow and saline mineral dissolution (see panel 3).
- Create a GIS database and maps showing:
  - Outcrop,
  - Thickness,
  - Lateral extent,
  - Water quality (see panel 3), and
  - Interburden between Birds Nest and "economic" oil shale zones.

Preliminary Conclusions and Suggestions

- The included maps of the Birds Nest aquifer should be used as a guide showing where saline water disposal might be possible. Additional drilling should be performed to confirm the presence of a suitable disposal zone (e.g., it is currently unclear where large zones of no saline mineral dissolution exist).
- Wells for saline water disposal into the Birds Nest aquifer should be accompanied by downdip water monitoring wells in aquifers both above and below the disposal unit.
- Flow tests should be conducted in wells near gilsonite veins to test for linear movement of water.
- Tracer tests should be conducted to determine the destination of the water in the Birds Nest aquifer.

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Spatial extent and thickness:

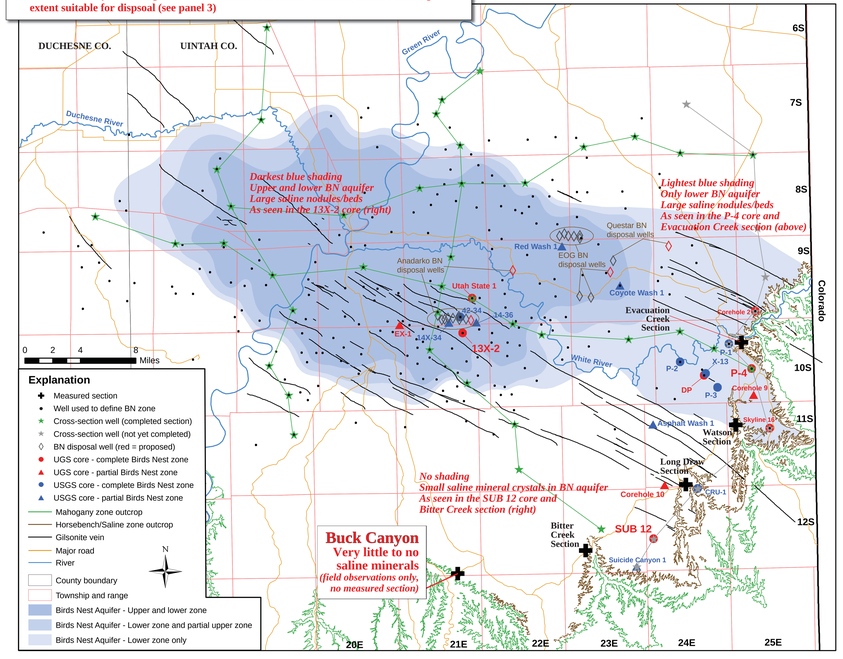
Research methods: Core, outcrop, and geophysical log examinations

The Saline Zone is nearly 400 feet thick in the basin's paleo-depocenter. Within the Saline Zone, the Birds Nest aquifer is separated into an upper (~40 feet thick) and a lower (~100 feet thick) zone where dissolution of the saline minerals has created significant porosity and permeability for the transmission of water (see 13X-2 core log). The large saline mineral nodules and beds in the paleo-depocenter are recorded as spikes to low density on geophysical logs. To the east, the upper zone disappears and only the lower zone exists (as seen in the P-4 core). Farther from the depocenter, the Saline Zone thins to ~130 feet and contains much smaller saline mineral crystals (<1 inch) as compared to the large (up to 1 foot) nodules found near the basin's center, and the bulk density signature is lost (there is still a zone of dissolution in the lower portion of the Saline Zone which could transport water and is roughly equivalent to the lower Birds Nest zone found in the basin's center). This transition is only confirmed to the south where cores and outcrop exposures are present (see SUB 12 core log and Bitter Creek section). It is presumed that the same transition to small saline crystals exists to the north and west, but no cores exist to confirm this suspicion.

• **Highlight:** Using geophysical logs, UGS has mapped the spatial extent and thickness of the Birds Nest aquifer where large nodules exist in both an upper and/or lower zone. This area could be the location suitable for saline water disposal, but only where water currently within the zone is greater than 10,000 mg/L TDS (see panel 3).

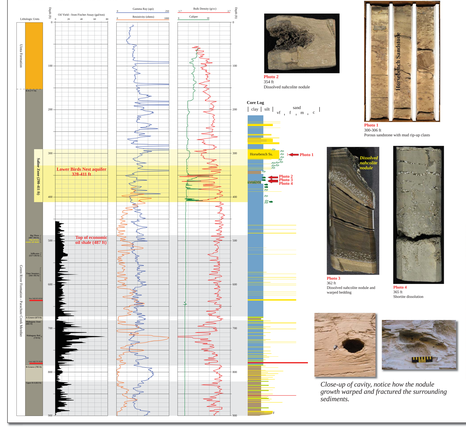
Maximum areal extent for possible saline water disposal into the Bird Nest aquifer

- **Areal extent of large saline nodules/beds - in one or two zones**
- **Chemistry of water currently in aquifer will be a limiting factor (see panel 3)**
- **Some areas may be lacking suffient dissolution of the saline minerals, further limiting extent suitable for disposal (see panel 3)**



P-4 - Lower Birds Nest aquifer only

Operator: White River Shale Project
Location: T10S, R25E, Sec. 19, UTM E 659426, UTM N 4421812
Cored interval: 214 - 1173 ft, 3.5 inch diameter
Core location: Utah Core Research Center



The Birds Nest aquifer thins to 83 feet on the eastern side of the basin as shown by core from the P-4 well (this zone seems to correlate to the lower aquifer seen in the center of the basin). The aquifer is defined by very large nahcolite nodules (up to 1-foot in diameter, seen better in outcrop near the well) and almost total saline mineral dissolution. Significant, porous sand beds (Horsebench) overlay the Saline zone and could be part of the aquifer system. The sand deposition might represent fresh water entering the lake which changed the local water chemistry, stopping the saline mineral deposition.

Photo 1
164 ft
Dissolved nahcolite nodule

Photo 2
390-398 ft
Porous sandstone with mud rip-up clasts

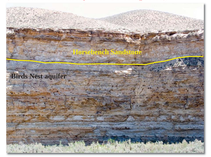
Photo 3
362 ft
Dissolved nahcolite nodule and warped bedding

Photo 4
384 ft
Shoulder dissolution

Close-up of cavity, notice how the nodule growth warped and fractured the surrounding sediments.

Evacuation Creek Section

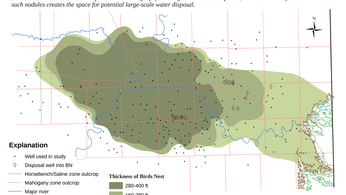
~60 ft of abundant large saline mineral nodules representing the lower Birds Nest aquifer
(measured section yet-to-be completed)



Birds Nest aquifer in outcrop along Evacuation Creek, eastern Uinta Basin. The large cavities resulted from the dissolution of nahcolite nodules, creating the aquifer's porosity and permeability.

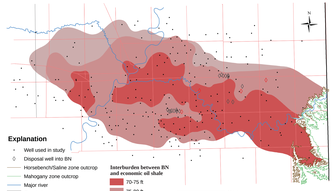
Birds Nest Aquifer Isopach

The Birds Nest aquifer isopach is measured from the base of the lower zone to the top of the upper zone (if present). Where both zones exist, the thickness ranges up to 400 feet; however, where only the lower zone is present (mainly to the east), the thickness drops to between 40 and 100 ft. This map only records where large saline mineral nodules/beds are present based on geophysical logs and core descriptions, the dissolution of such nodules creates the space for potential large-scale water disposal.



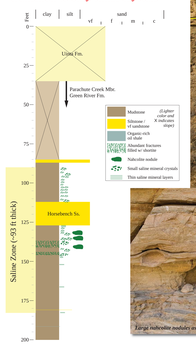
Interburden Between Birds Nest and Economic Oil Shale

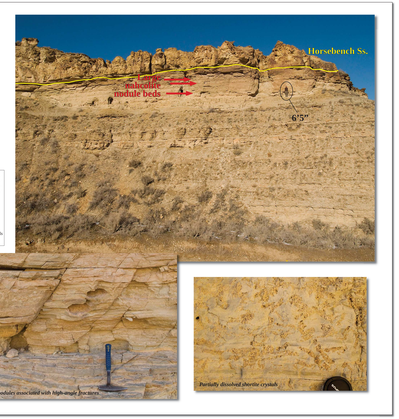
The base of the Birds Nest aquifer is between 70 and 90 ft above the top of economic oil shale, picked at the top of the Big 3 oil shale beds. Saline water disposal could impact development of the underlying oil shale if vertical migration of water occurs via fractures or joints.



Watson Section

Three isolated beds of large saline mineral nodules, near southern transition to only small crystals





13X-2 - Upper and lower Birds Nest aquifer

Utah State 13X-2 exhibits extensive saline mineral dissolution (see dissolution log) in two distinct zones, the upper aquifer is 47 feet thick (1525-1572 ft) and the lower aquifer is 107 feet thick (the lower zone could be separated into two zones, 1690-1732 ft and 1758-1797 ft). This well is very near Anadarko's saline water disposal wells.

Operator: Tosco Corp.
Location: T10S, R21E, Sec. 2, UTM E 625912, UTM N 4425960
Cored interval: 120 - 2191 ft, 3.5 inch diameter (only examined 1289-1818 ft)
Core location: UGS and USGS Core Research Center

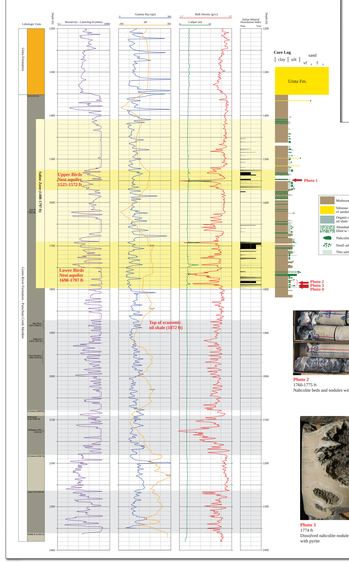


Photo 1
1532 ft
Shortite dissolution

Photo 2
1760-1775 ft
Nahcolite beds and nodules with dissolution

Photo 3
1774 ft
Dissolved nahcolite nodule lined with pyrite

Photo 4
1793 ft
Dissolved nahcolite

South Uinta Basin 12

Operator: U.S. ERDA-LERC
Location: T12S, R24E, Sec. 19, UTM E 648046, UTM N 4402078
Cored interval: 91 - 621 ft, 1.8 inch diameter
Core location: Utah Core Research Center

The South Uinta Basin 12 (SUB 12) core, as well as nearby outcrop sections (Long Draw and Bitter Creek), display how the saline mineral crystals within the Birds Nest aquifer get much smaller to the south, closer to the basin margin; no large saline nodules are present. The SUB 12 core displays a 38-foot zone (206.2-240.6 ft) where the <1-inch nahcolite crystals show significant dissolution indicating that water passes through this section despite the small crystal size. However, only where the large nodules exist farther to the north, is there the possibilities of large volume saline water disposal. The smaller saline mineral crystals are not recognized by geophysical log measurements, making core and outcrop the only way to characterize the Birds Nest zone in this area.

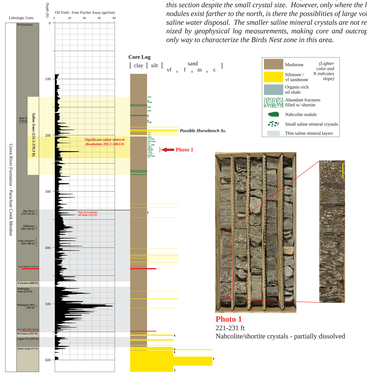


Photo 1
221-231 ft
Nahcolite/shortite crystals - partially dissolved

Bitter Creek Section

No large saline nodules, only small crystals