[PS]Hydrostratigraphic Controls from Uranium Mineralization - Example: The Nebraska Panhandle*

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Abstract

The Nebraska Panhandle is arguably one of the most overlooked uranium provinces in the US. Since 1991, the Crow Butte mine in Northwest Nebraska has produced a little over 13 million pounds of U_3O_8 utilizing ISR technology. Demand and price increases indicate the possibility for additional exploration, exploration that may be enhanced by an improved understanding of the hydrostratigraphic controls on the uranium deposits. Uranium at the Crow Butte deposit occurs in the basal sandstone of the Chamberlain Pass Formation (CPF). New stratigraphic models can be used to reconstruct the paleohydrogeology of the White River Group (WRG) and provide direction for exploration.

The CPF consists of a basal white to greenish white sandstone composed of coarse grains of quartz, quartzite and chert. Extensive chemical weathering including the removal of iron and kaolinization give the sandstone a “bleached” appearance. The sandstone thickness varies from 0 to 350 feet and unconformably overlies the Cretaceous Pierre Shale or the Yellow Mounds Paleosol. The uppermost part of the CPF is the bright red Interior Paleosol Series and the laterally equivalent light green Weta Paleosol Series. The Chadron Formation unconformably overlies these paleosols and consists of bluish green mudstones; thin, interbedded, lacustrine limestone beds and localized channel sandstone deposits. The Chadron Formation sandstones are arkosic and contain more weatherable minerals than the CPF. Differentiation of the two sandstones is likely a critical factor in exploring for uranium.

The tuffaceous WRG rocks have long been considered the source of uranium in the Tertiary basins of Wyoming. Although the overlaying Chadron Formation bentonitic mudstones might be considered a source of uranium, evidence from paleohydrogeology [tufas, lacustrine limestone, reducing paleosols] suggests that groundwater table was high and groundwater discharge was largely local. In contrast, groundwater during the development of the Interior-Weta Paleosol Series was largely oxidizing and groundwater flow was downward into the underlying aquifers [CPF and older units]. Thus the initial uranium mineralization at Crow Butte probably occurred during the development of the Interior-Weta Paleosol Series at the CPF-Chadron Formation unconformity. Exploration efforts in Nebraska should consider these hydrostratigraphic relationships and be directed to permeable formations underlying the Interior-Weta Paleosol Series.

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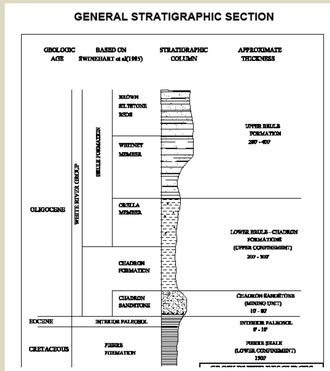
HISTORY AND PRODUCTION

Photo courtesy of Cameco Corp.

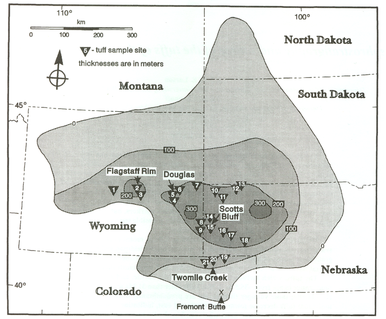
Crow Butte Uranium Deposit was discovered in 1981 with production beginning in 1991.

- Reserves ≥ 25 Million lbs U_3O_8 Grade ≥ 0.25%.
- Produces ≈ 800,000 lbs/ year using In Situ Recovery [ISR].
- Total production to date – 13 million lbs.

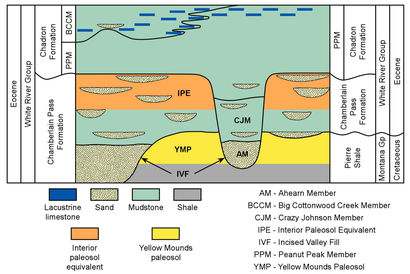


Older stratigraphic interpretation of White River Group with one basal sand at the base of the Chadron Formation, thickness = feet [courtesy of Cameco Corp.]

WHITE RIVER GROUP DISTRIBUTION AND STRATIGRAPHY

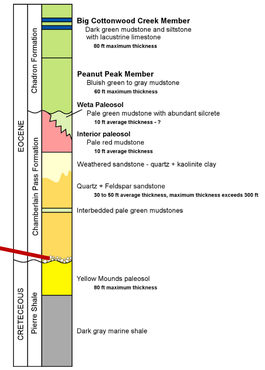


Distribution and thickness of White River Group . Larson & Evanoff (1998)



New interpretation of White River Group stratigraphy with two different basal sands separated by the Interior Paleosol and an unconformity. The older basal sand is part of the Chamberlain Pass Formation while the younger basal sand is the Ahearn member of the Chadron Formation [modified from Terry, 1998]

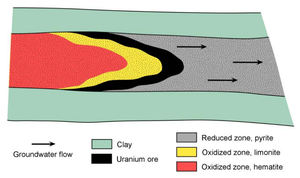
Pebble conglomerate of the Chamberlain Pass Formation near Whitehead Creek, Nebraska. Clasts consist of quartz, chert, and quartzite. The Chamberlain Pass Formation was deposited prior to the exposure of the Precambrian core of the Black Hills Uplift [Evans, 1996]. Uranium mineralization at Crow Butte is found in the Chamberlain Pass Formation.



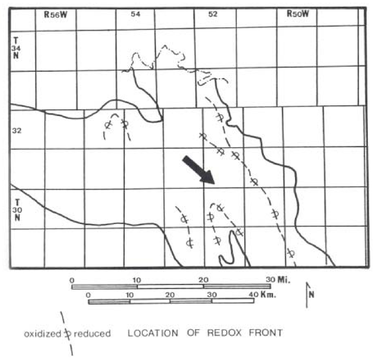
Composite stratigraphic column for the Chamberlain Pass Formation. Not all units are present in any one outcrop. The Weta Paleosol is the lateral equivalent of the Interior Paleosol.

Chamberlain Pass Formation [CPF] type section, near Kadoka South Dakota. Geologist is standing on Yellow Mounds Paleosol. Resistant ledges are silcrete. Overlying the CPF is the Peanut Peak Member of the Chadron Formation which shows typical haystack weathering.

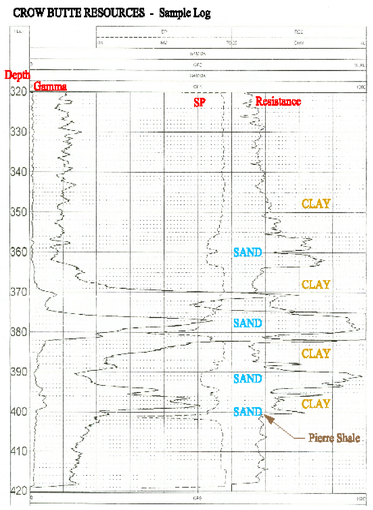
MINERALIZATION



Uranium mineralization occurs in a typical roll front deposit. Uranium precipitates [coffinite] at the interface between oxygen rich groundwater and oxygen poor groundwater. This interface is also known as a "Redox Front" Iron minerals change from hematite to pyrite at the "Redox Front". The change in iron mineralization is often used as an exploration tool.

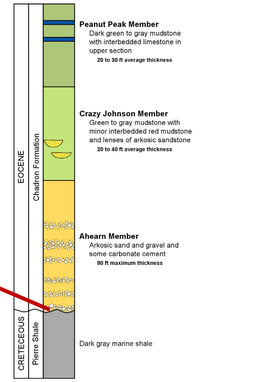


Roll front mineralization trends NW-SE. The groundwater flow direction during mineralization is shown by the arrow Gjelsteen and Collings. 1988 The area of well field development is east of the arrow and is 6 miles long and ¼ mile wide.



Mineralization occurs in the basal sands of the White River Group. Electric log courtesy of Cameco Corp.

Arkosic gravels of the Ahearn member of the Chadron Formation near Red Shirt, South Dakota. Clasts include granite and metamorphic rocks from the exposed Precambrian core of the Black Hills uplift. No significant uranium mineralization has been found to date in the Chadron Formation.

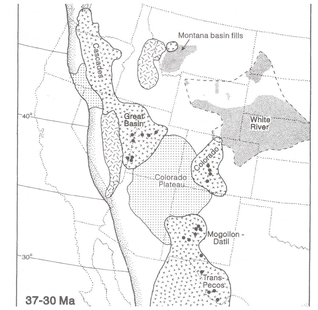


Stratigraphic column for the Chadron Formation in the Red River Paleovalley in South Dakota. [modified from Clark et al, 1967]

SOURCE OF URANIUM

Volcanic Glass + H_2O = Clay [montmorillonite] + SiO_2 + U^{+6} (in solution)

Tuffaceous sediments of the White River Group are likely the source of the uranium in the Gas-Hills, Crooks Gap, Shirley Basin, and Powder River Basins deposits of Wyoming. Zielinski (1983)



The Source of the White River Group tuffs has been shown to be from the calderas of the Great Basin in what is now eastern Nevada and western Utah. Larson & Evanoff (1998)

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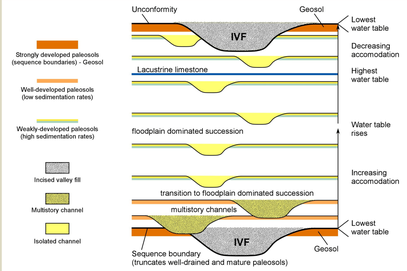
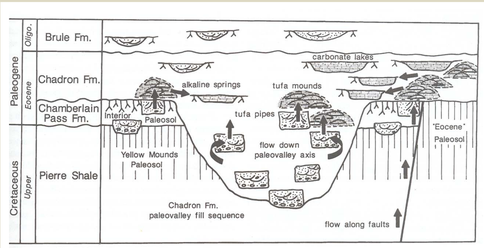
HYDROSTRATIGRAPHY AND MINERALIZATION



Paleosol development in different stages of fluvial accommodation. Sequence bounding paleosols [geosols] developed over a significant period of time and are associated with significant drops in the water table. The Interior Paleosol is a widespread sequence bounding paleosol or geosol while the paleosols of the Chadron Formation are less well developed. [modified from Catuneanu, 2006]



Paleogroundwater deposits [mostly carbonates] indicate that groundwater flow direction was predominantly upward during Chadron Formation deposition [from Evans and Welzenbach 1998] Leaching of uranium while groundwater was flowing upward may result in the weak uranium mineralizationin the calcareous mudstones noted by Dickinson 1990.

Photo courtesy of J.E.Evans

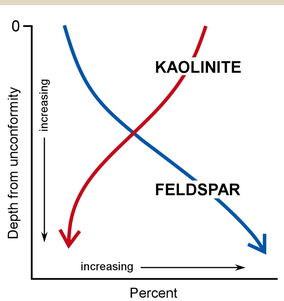
Tufa [nonpedogenic calcrete pinnacle] demonstrates groundwater flow was upward during carbonate deposition.

Interior Paleosol or Chadron Paleosol Series –

Which is the Source of Uranium?

The Interior Paleosol developed over a significant period of time and is associated with a significant drop in the water table which would expose previously deposited tuffaceous sediments to leaching in the vadose zone. In contrast, the Chadron Formation paleosols are less well developed and there was a higher water table. Th/U ratios might be useful in determining which paleosols are depleted in uranium with respect to thorium. However, this might not tell us the fate of the uranium leached. Reconstructing the paleohydrogeology should be one of the criteria used when evaluating potential sources for uranium. If there is a high water table, any uranium leached may end up discharged into a stream or lake. In a low water table situation, any uranium leached is much more likely to end up in the underlying aquifer. It is for these reasons that the authors prefer the Interior Paleosol as a source for the uranium.

Chamberlain Pass Formation sand overlain by Peanut Peak Member of the Chadron Formation. Sand has been extensively weathered, feldspars have been altered to kaolinite and iron has been "bleached" or reduced prior to Chadron Formation deposition. Removal of iron oxides or reprecipitation of pyrite by reduction reactions can obscure the original oxidation event that formed the uranium roll front and make exploration difficult. The paleosols developed within the upper part of the Chamberlain Pass Formation show both oxidizing and reducing conditions (Terry and Evans, 1994). Methane, which is present locally, can also react and reduce iron oxides.



An inverse relationship between feldspar and kaolinite is seen in this type of weathering profile. "Bleaching" was caused by low pH and low pe water.

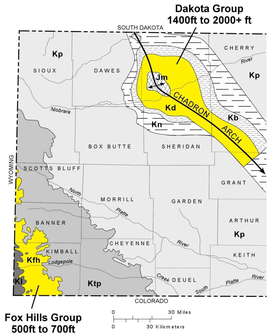
Sequence of Deposition and Mineralization and Implications for Exploration

1) Deposition of Chamberlain Pass Formation in local incised valleys.
2) Valleys fill and deposition becomes lower energy but widespread.
3) Local pyrite formation where carbonaceous material present – incised valley margins.
4) Tectonic uplift – shift from deposition to erosion and paleosol formation.
5) Development of Interior Paleosol and leaching of uranium, formation of roll front deposits.
6) Acidic and reducing weathering of Chamberlain Pass causes "bleaching".
7) Deposition of Chadron Formation, uranium is deposited in weakly mineralized evaporitic lacustrine mudstones due to a high water table.

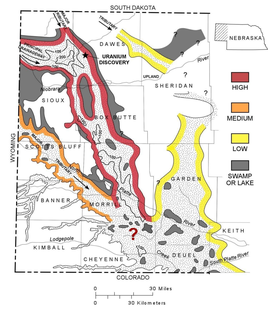
The implications for explorations are as follows:

1) Permeable formations underlying the Interior Paleosol are possible exploration targets.
2) Iron minerals may not always be an effective exploration tool.
3) The Chamberlain Pass Formation is much more likely to host roll front deposits than the Chadron Formation.
4) Differentiation of the two sands is a critical factor in exploration.

POTENTIAL URANIUM EXPLORATION TARGETS

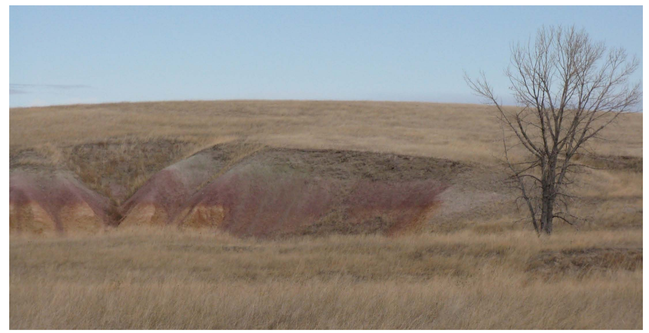


Subcrop map of the geology underlying the White River Group in the Nebraska Panhandle. Permeable units are colored yellow. During the 1970's, Ferret Exploration found mineralization in the Fox Hills in Kimball Co. Union Carbide found mineralization in the Dakota Group on the Chadron Arch in Sheridan Co. Both units are dominantly marine sandstones and permeability could limit the feasibility of ISR mining. Map from Swinehart et al. 1985

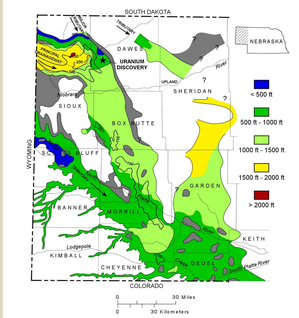


Distribution of sands in the Chamberlain Pass Formation. Permeability of the Chamberlain sands and gravels are high and are very amenable to ISR mining. Highest potential for uranium roll front deposits is along the margins of the main valley entering Nebraska from Wyoming in northern Sioux Co. The major tributary entering Nebraska from Wyoming in southern Sioux Co. also has potential. The tributaries entering Nebraska from South Dakota are less attractive due to lack of mineralization seen in outcrop [see next photo]. Map from Swinehart et al. 1985

Carbonaceous material and Mn oxides at base of the Chamberlain Pass Formation. No uranium mineralization is present. This channel tributary is located near Whitehead Creek, Nebraska and flow direction is from north to south from South Dakota.



Outcrop of Interior Paleosol [red] developed directly on top of Yellow Mounds Paleosol [yellow] west of Whitehead Creek, Nebraska. The previously weathered Cretaceous shale would not make a good source rock for uranium. This is typical of the relationship between the two paleosols seen in the northern Panhandle of Nebraska and South Dakota. In contrast, the red Interior Paleosol overlies the green mudstones of the Chamberlain Pass Formation in the subsurface in Nebraska.



Depth to the base of the Chamberlain Pass Formation. Most of the areas with the potential for uranium mineralization are at relatively shallow depths.

SUMMARY

- Considering paleohydrogeology is an important step in evaluating uranium sources.
- The Interior Paleosol is the most likely source of uranium at Crow Butte.
- The best potential for uranium deposits is in the Chamberlain Pass Formation.
- The margins of the incised valleys entering from Wyoming have the best potential.
- Iron minerals may not always be an effective exploration tool due to "bleaching".
- High permeability of the Chamberlain Pass sands are ideal for ISR.

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