

UPDATED EXPERT OPINION ON THE ENVIRONMENTAL SAFETY OF IN-SITU LEACH MINING OF URANIUM NEAR MARSLAND, NEBRASKA (15 February 2018)

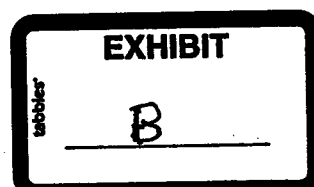
Hannan E. LaGarry, Ph.D.
55 Whispering Pines
Chadron NE 69337
hlagarry@olc.edu

INTRODUCTION

I am offering this expert opinion regarding Crow Butte Resources' proposed in-situ leach (ISL) uranium mining near Marsland, Nebraska because I am concerned that this mining will lead directly to the transmission of lixiviant and spilled waste water into the High Plains Aquifer, the Niobrara River, and the White River. I am not against uranium mining in fact or principle. My concerns stem from the fact that northwestern Nebraska and the entire northern Plains region is currently experiencing what may be an extended period of drought and water shortages. These water shortages increase the agricultural and municipal demands for water extracted from wells in the High Plains Aquifer which will likely be contaminated by the proposed mining operations. This issue isn't about the uranium, it is about protecting the region's water supply and the future inhabitability and agricultural viability of northwestern Nebraska. In this document, I will briefly explain the basis for my concerns. In a previous expert opinion I proposed a series of studies that could clarify whether or not Crow Butte Resources is contaminating the region's water, and if so, how much. However, because ISL mining near Marsland will require drilling much deeper to reach uranium-bearing rocks, such studies are not feasible in this situation. Therefore, I have no choice but to oppose the proposed activity.

PROFESSIONAL BACKGROUND

I have 25 years of experience studying the rocks and fossils of northwestern Nebraska. From 1988-1991 I collected fossils from northern Sioux County for my dissertation work. From 1991-1996 I led field parties from the University of Nebraska State Museum while mapping the fossils and geology of the Oglala National Grassland in Sioux and Dawes Counties. From 1996-2006 I led a team of geologists from the Nebraska Geological Survey that mapped in detail the surficial geology of most of northwestern Nebraska (a total of 80 1:24,000 quadrangles). This mapping included the entire Pine Ridge area and the area between Crawford, Nebraska and Pine Ridge, South Dakota. These maps,



including digital versions (ArcInfo) and supporting field notes, are available from the University of Nebraska-Lincoln School of Natural Resources. As a direct consequence of this mapping, I have published peer-reviewed articles on the Chadron Formation (Terry & LaGarry 1998), the Brule Formation (LaGarry 1998), the mapping of surficial deposits (Wysocki & others 2000, 2005), and local faults (Fielding & others 2007). In future, we also intend to revise and reclassify the remaining rocks and surficial sediments of northwestern Nebraska and adjacent South Dakota.

In addition to my ongoing geological work in Nebraska, I have been working with students and faculty to study the geology, groundwater, surface water, and heavy metal contaminants of southwestern South Dakota and the Pine Ridge Reservation. For the past 6 years our research has been funded by the National Science Foundation's Tribal Colleges and Universities Program and Experimental Program for Stimulating Competitive Research, and the USDA National Institute for Food and Agriculture Tribal College Equity Program. We have formed and maintained partnerships with Chadron State College, the South Dakota Geological Survey, the South Dakota School of Mines and Technology, South Dakota State University, the University of Illinois Urbana-Champaign, the University of Illinois Center for Advanced Materials Purification of Water Systems, the Department of Health Physics at the University of Michigan School of Nuclear Engineering, the University of Washington Native American Research Center for Health, and the Technological University of Darmstadt, Germany. I have authored or coauthored reports detailing the preliminary results of studies describing toxic heavy metal contamination of drinking water (Salvatore & others 2010, Botzum & others 2011), characteristics of local aquifers (Gaddie & LaGarry 2010, LaGarry & others 2012), potential uranium contamination risk to communities on the Pine Ridge Reservation (LaGarry & Yellow Thunder 2012), and the transmission of uranium-contaminated water along regional faults (Bhattacharyya & others 2012), among others.

STRATIGRAPHY OF WATER-BEARING ROCKS IN NORTHWESTERN NEBRASKA

The rocks of northwestern Nebraska range from Cretaceous to Pleistocene in age (Figure 1), and consist entirely of sedimentary rocks. These rocks vary in thickness and geographic extent, and are described from oldest to youngest as follows (see LaGarry & LaGarry 1997, Terry 1998).

Pierre Shale – underlies all other units, generally 1000'-2000' thick. Contributes small amounts of sulfur and arsenic to overlying surface aquifers (e.g. modern White River alluvium) and water in streams and impoundments. Generally impermeable, except where fractured. Joints and faults within this unit contain minerals deposited by water movement in the geological past. In the Marsland area these rock are in subsurface only.

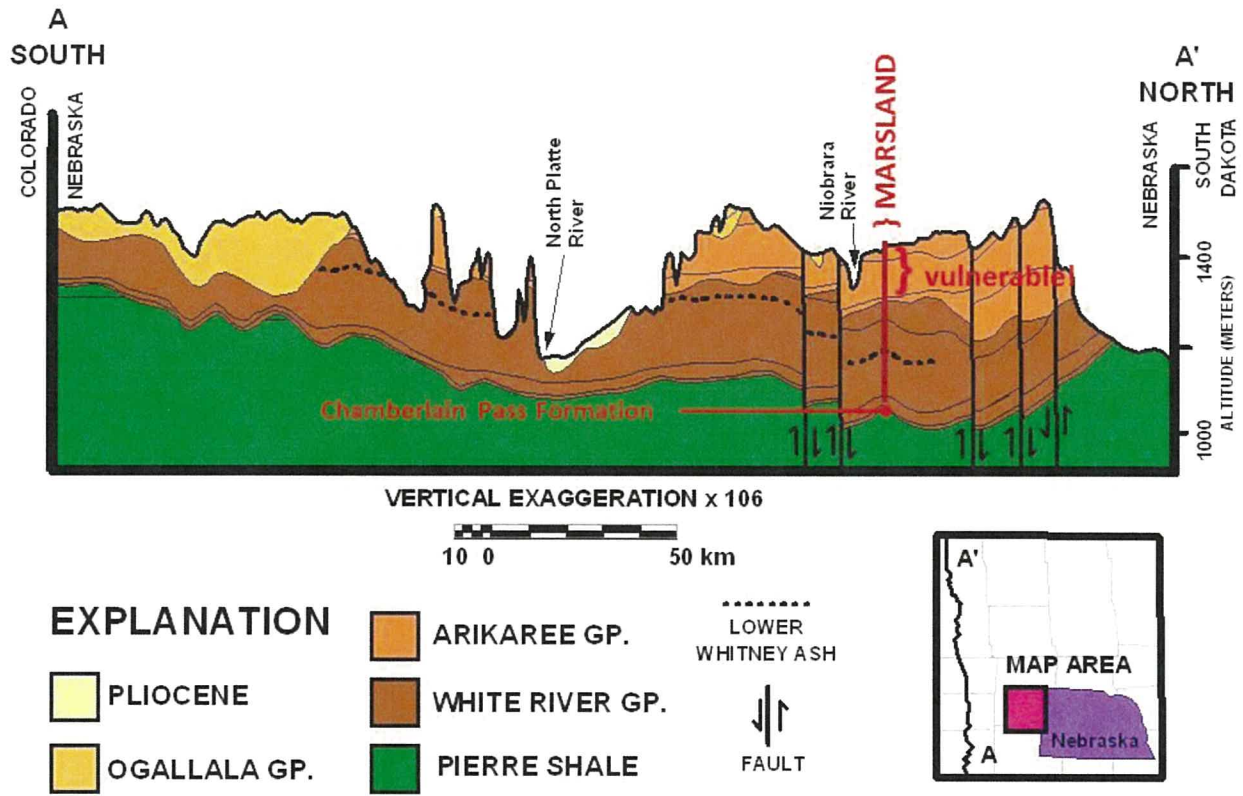


Figure 1. Geologic cross-section of far western Nebraska showing proposed drilling near Marsland, the stratigraphic position of the Chamberlain Pass Formation, the positions of known faults, and the vulnerable portion of the high Plains Aquifer. After Swinehart and others (1985).

Chamberlain Pass Formation – formerly ‘basal Chadron sandstone,’ base of White River Group, overlies Pierre Shale, underlies Chadron Formation. Channel sandstones within this unit are a local aquifer and are mined for uranium. Water from this unit is typically used for residential and livestock supplies. Unit was deposited in an ancient paleovalley oriented generally from Crawford in the N-NW and Bayard to the S-SE. Joints and faults within this unit contain minerals deposited by water movement in the geological past. In the Marsland area these rocks are subsurface only.

Chadron Formation – middle of White River Group, overlies Chamberlain Pass Formation, underlies Brule Formation and modern river alluvium. Generally impermeable, except where fractured. Many

faults and joints contain minerals deposited by water movement in the geologic past. In the Marsland area these rocks are subsurface only.

Brule Formation – top of White River Group, overlies Chadron Formation, underlies Arikaree and Ogallala groups (High Plains Aquifer) and modern river alluvium. Generally impermeable, except where fractured. Where fractured, has enough water to be included with overlying High Plains Aquifer. Used locally for residential and low-intensity agricultural supplies. Secondary porosity in Brule can transmit water up to 1500' day. Many faults and joints contain minerals deposited by water movement in the geologic past. In the Marsland area these rocks are in the subsurface only. However, they are exposed along the headwaters of the Niobrara River.

Arikaree Group – base of High Plains Aquifer, overlies Brule Formation of the White River Group, underlies Ogallala Group and modern river alluvium. Consists of moderately porous and permeable sandstones and silty sandstones. Coarser sandstone beds deposited along preexisting fault traces. Unit highly faulted and jointed along Pine Ridge Escarpment. Water supplies springs that feed local creeks, and is used for high-capacity irrigation wells. Water is used for high-capacity irrigation wells. In the Marsland are these rocks are exposed at the land surface and in the valleys of the White and Niobrara rivers. These rocks are a primary aquifer in northwestern Nebraska.

Ogallala Group – upper part of High Plains Aquifer, overlies Arikaree Group, underlies modern river alluvium and sand dunes. Consists of highly porous and permeable sandstones and conglomerates, Coarser sandstone beds deposited along preexisting fault traces. Unit highly faulted and jointed along Pine Ridge Escarpment. Water is used for high-capacity irrigation wells. In the Marsland are these rocks are exposed at the land surface and in the valleys of the White and Niobrara rivers. These rocks are a primary aquifer in northwestern Nebraska.

Pliocene, Pleistocene, and Holocene river alluvium – overlies all bedrock units at one place or another. Consists of layers of silt, sand, and coarse gravel. Unit also overlies major fault zones. Unit is used as aquifer, and supplies water to residences, livestock, and in the case of the White River, supplies water to the cities of Crawford, Nebraska and Pine Ridge, South Dakota, among

others. In the Marsland area these sediments are exposed at the land surface, are extremely porous and permeable, and include at least three terraces of the Niobrara River.

Recent mapping of the geology of northwestern Nebraska has shown that the simplified, “layer cake” concept applied by pre-1990’s workers is incorrect, and overestimates the thickness and areal extent of many units by 40-60%. Many units’ distributions are heavily influenced by the contours of the ancient landscapes onto which they were deposited. For example, when considered to be the ‘basal Chadron sandstone,’ the Chamberlain Pass Formation was assumed to have a distribution equal to that of the overlying Chadron Formation. However, the Chamberlain Pass Formation is 1-1.5 million years (Ma) older than the Chadron Formation, and has a distribution determined by the ancient topography weathered into the Pierre Shale prior to deposition of the Chamberlain Pass Formation. The Chadron Formation was then deposited later on a different landscape.

CONTAMINANT PATHWAYS

In-situ leach mining in the Marsland area would likely contribute toxic heavy metal contaminants, including but not limited to uranium, through three pathways: (a) surface leaks and spills, (b) underground leaks and spills (excursions), and (c) lack of containment. Once in the aquifer, contaminants would (d) migrate laterally through porous and permeable sandstones into the White and Niobrara rivers (Figure 1).

Surface leaks and spills. The soils in western Nebraska are thin, and directly overly permeable, porous bedrock. The rocks exposed at the surface near Marsland are either the Anderson Ranch Formation of the Arikaree Group or the Runningwater Formation of the Ogallala Group. Both are sandstone. Any leaks or spills onto the landscape would be transmitted directly into the High Plains Aquifer within a few years. There are no confining layers within this aquifer, and in some areas the water table is within 20 meters of the surface. Figure 1 shows the interval of the aquifer vulnerable to surface leaks and spills.

Underground leaks and spills (excursions). In order to reach the uranium in the Chamberlain Pass Formation, injection and extraction wells will need to be drilled through the Anderson Ranch, Harrison, Coffee Mill Butte, Monroe Creek, and Ash Creek formations of the Arikaree Group. All of these contain water, and an excursion into any of them would be catastrophic, with contaminants

quickly spreading throughout the entire section of the aquifer. Under these rocks are the less permeable siltstones of the Brule and Chadron formations, which may contain useable water if sufficiently fractured (otherwise not). Below these are the uranium bearing rocks of the Chamberlain Pass Formation. Figure 1 shows the interval of the aquifer vulnerable to underground excursions.

Lack of containment. Diffendal (1994) showed that there are several potential faults in the Marsland area, and Swinehart and others (1985) show known faults both north and south of Marsland. These faults may allow the transmission of mining fluids to travel upward into the aquifer and laterally into adjacent areas to the west and east. The faults shown in Figure 1 are those that were large enough to be discovered by Swinehart and others (1985) who compiled data from ~12,500 drilling records in western Nebraska and conducted new drilling at 5 mile intervals along the transect shown. My work over the past 25 years has shown that there are likely hundreds more that are too small to be shown on such a diagram.

Lateral migration. Water in underground aquifers does not stay in the same place. It moves around laterally following the contours of the ancient landscapes the aquifer sediments were deposited onto. This water is also draw to wells (such as center pivots and stock tanks), springs (such as those that spawn the White River), and groundwater-fed rivers (such as the close-by Niobrara River). If contaminants were to escape into the High Plains Aquifer, within a few hears it could be drawn out of the ground and sprayed onto crops by center pivots, or be drawn to the surface by stock tanks placed to water cattle and horses. It would likely migrate eastwards (down gradient) and contaminate the White River, which supplies the towns of Glenn, Crawford, Whitney, and Pine Ridge with water. It could quickly find its way into the Niobrara River, which is a National Scenic River used by thousands of people for recreation every year (Figure 1).

CONCLUDING REMARKS

Based on the arguments presented above, it is my expert opinion that ISL mining in the Marsland, Nebraska area should not be allowed. Of greatest concern is its proximity to the Niobrara River (a National Scenic River), which is used for recreation by thousands of people each year. Unfortunately, if the High Plains Aquifer were to become contaminated, the effects would be irreversible and catastrophic for the local agricultural economy. It would likely lead to the depopulation of the region.

REFERENCES

- Bhattacharyya, P., Converse, K., Ejniak, J. W., LaGarry, H. E., and A. L. Riesen. 2012. Studying uranium contamination levels in ground water from the Pine Ridge Reservation, South Dakota: A community-university partnership. *Geological Society of America Abstracts with Programs* 44 (6):77.
- Botzum, C. J., Ejniak, J. W., Converse, K., LaGarry, H. E., and P. Bhattacharyya. 2011. Uranium contamination in drinking water in Pine Ridge Reservation, southwestern South Dakota. *Geological Society of America Abstracts with Programs*, 43(5):125.
- Diffendal, R. F. 1994. Geomorphic and structural features of the Alliance 1 degree x 2 degree Quadrangle, western Nebraska, discernible from synthetic-aperture radar imagery and digital shaded-relief maps. *Rocky Mountain Geology*; October 1994, 30 (2):137- 147.
- Evans, J. E. & D. O. Terry, Jr. 1994. The significance of incision and fluvial sedimentation in the basal White River Group (Eocene-Oligocene), badlands of South Dakota, U. S. A. *Sedimentary Geology* 90:137-152.
- Fielding, C. R., H. E. LaGarry, L. A. LaGarry, B. E. Bailey, & J. B. Swinehart. 2007. Sedimentology of the Whiteclay gravel beds in northwestern Nebraska, USA: structurally controlled drainage promoted by early Miocene uplift of the Black Hills Dome. *Sedimentary Geology* 202:58-71.
- LaGarry, H. E. 1998. Lithostratigraphic revision and redescription of the Brule Formation (White River Group), northwestern Nebraska, pp. 63-92 in (D. O. Terry, Jr., H. E. LaGarry, & R. M. Hunt, Jr., eds.) *Depositional environments, lithostratigraphy, and biostratigraphy of the White River and Arikaree Groups (late Eocene to early Miocene, North America)*. Geological Society of America Special Paper 325, 216 p.
- LaGarry, H. E. & L. A. LaGarry. 1997. *Geology of the Montrose, Orella, Wolf Butte, Roundtop and Horn 7.5' USGS quadrangles, Sioux and Dawes counties, Nebraska*. University of Nebraska-Lincoln Conservation and Survey Division Open-file Report 48, 161 p.
- LaGarry, H. E. and E. Yellow Thunder. 2012. Surface and subsurface distributions of uranium-bearing strata in northwestern Nebraska and southwestern South Dakota. *Proceedings of the 122nd Annual Meeting of the Nebraska Academy of Sciences*, pp 91-92.
- LaGarry, H. E., Marcot, J. D., Fox, D. L., Belile, C., and H. Gaddie. 2012. Revised lithostratigraphic correlation of the Arikaree Group from northwestern Nebraska and southwestern South Dakota. *Proceedings of the 122nd Annual Meeting of the Nebraska*

Academy of Sciences, pp 92-93.

- Swinehart, J. B., V. L. Souders, H. M. DeGraw, & R. F. Diffendal Jr. 1985. Cenozoic paleogeography of western Nebraska, pp. 209– 229 in (R. M. Flores & S. S. Kaplan, eds.), *Cenozoic Paleogeography of West-Central United States. Proceedings of Rocky Mountain Paleogeography Symposium 3*, Society of Economic Paleontologists and Mineralogists. Denver, Colorado.
- Terry, D. O., Jr. & H. E. LaGarry. 1998. The Big Cottonwood Creek Member: a new member the Chadron Formation in northwestern Nebraska, pp. 117-142 in (D. O. Terry, Jr., H. E. LaGarry, & R. M. Hunt, Jr., eds.) *Depositional environments, lithostratigraphy, and biostratigraphy of the White River and Arikaree Groups (late Eocene to early Miocene, North America)*. Geological Society of America Special Paper 325, 216 p.
- Terry, D. O., Jr. 1998. Lithostratigraphic revision and correlation of the lower part of the White River Group: South Dakota to Nebraska, pp. 15-38 in (D. O. Terry, Jr., H. E. LaGarry, & R. M. Hunt, Jr., eds.) *Depositional environments, lithostratigraphy, and biostratigraphy of the White River and Arikaree Groups (late Eocene to early Miocene, North America)*. Geological Society of America Special Paper 325, 216 p.
- Wysocki, D. A., P. J. Schoeneberger, & H. E. LaGarry. 2005. Soil Surveys: a window to the subsurface. *Geoderma* 126:167-180.
- Wysocki, D. A., P. J. Schoeneberger, & H. E. LaGarry. 2000. Geomorphology of soil landscapes, pp. E5-E39 in (M. E. Sumner, editor-in-chief) *CRC Handbook of Soil Science*. Chemical Rubber Company Press.