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OCCURRENCES OF RADIOACTIVE ELEMENTS IN HOT SPRINGS COUNTY, WYOMING

by

Ray E. Harris, W. Dan Hausel, and Jonathan K. King

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The Geological Survey of Wyoming
Box 3008, University Station
Laramie, Wyoming 82071-3008
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Abstract

Although uranium has not been produced from Hot Springs County, several different types of occurrences have been reported. Most occurrences (greater than 50 parts per million uranium) in the county are in Tertiary age phosphatic rocks in the southeastern part of the county. Additional uranium occurrences are reported in titaniferous black sandstones of the Mesaverde Formation; in a carbonaceous shale of the Jurassic Morrison Formation; at depth in a petroliferous sandstone of the Triassic Chugwater Formation; and in Precambrian granite.

The reported occurrences in the county are all apparently low grade and lack adequate reserves for development. Although unconformity-related uranium occurrences have not been reported from Hot Springs County, two unconformities have the potential to host this type of occurrence. One unconformity is between the Cambrian Flathead Sandstone and underlying Precambrian rocks. The other unconformity is between Tertiary rocks and underlying Precambrian rocks. The greatest potential for future development of uranium in Hot Springs County is probably from yet undiscovered unconformity-related occurrences.

Introduction

This open file report is the third of a county-by-county series on uranium and other radioactive elements in Wyoming. The first two reports in this series were on Goshen and Lincoln Counties, respectively (Harris and King, 1993a; Harris and King, 1993b). Information for these reports (which are part of a regional study of all Wyoming uranium mines, radioactive elements, and radioactive mineral occurrences) was gathered and compiled over a period of 11 years from publications, mine permits, company data, and field investigations. William L. Chenoweth, Warren I. Finch, and J. David Love have been valuable sources of information throughout this project.

Uranium, thorium, potassium-40 (^{40}K), and their daughter products, such as radium, are the naturally-occurring radioactive elements. The first three elements and their isotopes commonly occur in nature. The element radium and its isotopes, however, are rare in nature. Isotopes are different species of the same chemical element that have different numbers of neutrons in the nucleus of their atoms, and therefore have different atomic masses.

Uranium is the most important radioactive element because of its ability to undergo fission, a spontaneous or induced process in which uranium atoms release large amounts of energy and subatomic particles, and form other atoms. The energy released can be used to produce steam for the generation of electricity.

Thorium is used in refractory materials and aerospace alloys. It also has limited use as a nuclear fuel. Radium, which is only found naturally in any abundance in uranium ores, is used mostly for medicinal purposes. Current demands for radium are met both by recycling and through production as a by-product of reactions in nuclear reactors. Potassium-40 on the other hand occurs in nearly every rock type but has no commercial use.

Background

Radioactive elements in Wyoming

The radioactive element uranium is one of the best known mineral products of Wyoming. Uranium exploration and production has had a colorful history in Wyoming that dates back to about 1918.

Because uranium has been reported in nearly every time-rock unit in the State, Wyoming is often considered a uranium metallogenic province (Stuckless, 1979; Houston, 1979). In the United States, Wyoming ranks first in economic (minable) reserves of uranium (Energy Information Administration, 1990) and ranks second to New Mexico in cumulative uranium production and estimated resources. Twenty-eight uranium minerals and 12 other minerals known to contain accessory uranium have been identified in Wyoming (**Table 1**).

In Wyoming, the largest and most important discovered uranium deposits occur as roll fronts in Paleocene and Eocene sedimentary rocks in Tertiary basins. Over 187 million pounds of uranium oxide concentrate have been produced from roll-front deposits (Chenoweth, 1991) in the Gas Hills, Shirley Basin, Crooks Gap, Southern Powder River Basin, Pumpkin Buttes, and other uranium districts (**Figure 1**).

Other types of uranium deposits in Wyoming have been mined to various extents. Large amounts of ore have been mined from tabular uranium and vanadium deposits in Lower Cretaceous rocks of the Black Hills. Ore has also been mined from Tertiary unconformity-related deposits in the Copper Mountain uranium district, and from paleokarst deposits in Mississippian limestones in the Little Mountain uranium district and in the Shirley Mountains (**Figure 1**).

Although thorium has never been produced in Wyoming or anywhere else in large amounts, the element is abundant at several locations in Wyoming. One of the largest identified thorium resources in the United States occurs in Tertiary peralkaline igneous rocks in the southern Bear Lodge Mountains of northeastern Wyoming (Staatz, 1983). A smaller resource occurs in Cambrian fluvial paleoplacers at Bald Mountain in north-central Wyoming (Borrowman and

Table 1. Uranium- and thorium-bearing minerals identified in Wyoming.

Mineral	Chemical formula	Common occurrence
URANIUM MINERALS		
Reduced forms (U^{4+})		
brannerite	$(U,Ca,Ce)(Ti,Fe)_2O_6$	placers, pegmatites
coffinite	$U(SiO4)(OH)_4$	widespread
uraninite-thorian uraninite	$(U,Th)O_2$	widespread
Oxidized forms (U^{6+})		
abernathyite	$K_2(UO_2)_2(AsO_4)_2 \cdot 8H_2O$	sedimentary redox
autunite	$Ca(UO_2)_2(PO_4)_2 \cdot 8\text{-}12H_2O$	igneous and metamorphic
bayleyite	$Mg_2(UO_2)(CO_3)_3 \cdot 18H_2O$	sedimentary redox
becquerelite	$CaU_6O_{19} \cdot 10H_2O$	sedimentary redox
carnotite	$K_2(UO_2)_2V_2O_8 \cdot 3H_2O$	sedimentary redox
liebigite	$Ca_2(UO_2)(CO_3)_3 \cdot 11H_2O$	widespread
meta-autunite	$Ca(UO_2)_2(PO_4)_2 \cdot 4\text{-}6H_2O$	igneous and metamorphic
meta-torbernite	$Cu(UO_2)_2(PO_4)_2 \cdot 8H_2O$	widespread
meta-tyuyamunite	$Ca(UO_2)_2V_2O_8 \cdot 3\text{-}5H_2O$	sedimentary redox
phosphuranylite	$(H_3O)_2Ca(UO_2)_3(PO_4)_2(OH)_4 \cdot 4H_2O$	widespread
rutherfordine	$(UO_2)(CO_3)$	various
sabugalite	$HAl(UO_2)_4(PO_4)_4 \cdot 16H_2O$	widespread
schoepite	$UO_3 \cdot 2H_2O$	sedimentary redox
schroeckingerite	$NaCa_3(UO_2)_2(CO_3)_3SO_4F \cdot 10H_2O$	widespread
sklodowskite	$(H_3O)_2\,Mg(UO_2)_2(SiO_4)_2 \cdot 4H_2O$	widespread
torbernite	$Cu(UO_2)_2(PO_4)_2 \cdot 8\text{-}12H_2O$	widespread
tyuyamunite	$Ca(UO_2)_2V_2O_8 \cdot 8H_2O$	sedimentary redox
umohoite	$(UO_2)(MoO_2)(OH)_4 \cdot 2H_2O$	sedimentary redox
uranocircite	$Ba(UO_2)_2(PO_4)_2 \cdot 12H_2O$	various
uranophane	$(H_3O)_2Ca(UO_2)_2(SiO_4)_2 \cdot 3H_2O$	widespread
uranopilite	$(UO_2)_6(SO_4)(OH)_{10} \cdot 12H_2O$	widespread
weeksite	$K_2(UO_2)_2Si_6O_{15} \cdot 4H_2O$	various
zellerite	$Ca(UO_2)(CO_3)_2 \cdot 5H_2O$	sedimentary redox
zeuherite	$Cu(UO_2)_2(PO_4)_2 \cdot 40H_2O$	various
zippeite	$K_4(UO_2)_2(SO_4)_3(OH)_{10} \cdot 16H_2O$	various
THORIUM MINERALS		
thorianite-uranoan thorianite	$(Th,U)O_2$	pegmatites, placers
thorite-uranothorite	$(Th,U)SiO_4$	igneous rocks
thorutite	$(Th,U,Ca)Ti_2O_6$	igneous rocks
MINERALS THAT OFTEN CONTAIN ACCESSORY URANIUM AND(OR) THORIUM[1]		
allanite	$(Ce,Ca,Y,U)_2(Al,Fe_2)_3(SiO_4)_3OH$	carbonatites, pegmatites
apatite	$Ca_5(PO_4)_3(F,OH,Cl)_3$	carbonatites, phosphorites
brockite	$(Ca,Th,Ce)PO_4 \cdot H_2O$	carbonatites
euxenite	$(Y,Ce,U,Th,Ca)(Nb,Ta,Ti)_2(O,OH)_6$	pegmatites, placers
fergusonite	$(Y,Er,Ce,Fe)(Nb,Ta,Ti)O_4$	pegmatites, placers
fluorite	CaF_2	carbonatites, veins
monazite	$(Ce,La,Th,U)PO_4$	placers, carbonatites, and veins
mckelveyite	$Na_2Ba_4(Y,Ca,Sr,U)_3(CO_3)_9 \cdot 5H_2O$	trona, phosphorite
rhabdophane	$(Ce,Y,La,Di)PO_4 \cdot H_2O$	sedimentary, siliceous

Table 1. *(continued)*

Mineral	Chemical formula	Common occurrence
samarskite	$(Y,Fe,Ca,U,Ce,Th)(Nb,Ta,Ti)_2(O,OH)_6$	pegmatites, placers
xenotime	YPO_4	placers, veins(?)
zircon	$ZrSiO_4$	placers

GENERAL OR NONSPECIFIC TERMS

pitchblende:	amorphous or cryptocrystalline variety of uraninite that can contain thorium.
gummite:	fine-grained, secondary, hydrous, sometimes amorphous, uranium minerals associated with uraninite.
thucolite:	uranium and thorium-bearing carbonaceous material.

Apatite, fergusonite, fluorite, rhabdophane, xenotime, and zircon may sometimes contain either uranium or thorium in the interstitial spaces. Because the uranium and thorium **are not** part of the crystal structure of these six minerals, the accessory uranium and thorium are not shown in the chemical formulas. For the other minerals listed, the accessory uranium and thorium **are** part of the crystal structure and the radioactive elements are shown in the chemical formulas.

Rosenbaum, 1962) (**Figure 1**). Thorium is also abundant in other Cambrian paleoplacers and in Cretaceous beach paleoplacer deposits (black sandstones) scattered about central and western Wyoming (Houston and Murphy, 1970). Three thorium minerals and 12 other minerals known to contain accessory thorium have been identified in Wyoming (**Table 1**).

Radium was produced from the Silver Cliff mine near Lusk, in Niobrara County, Wyoming, in the years just after World War I. Radium is a daughter product in the four decay series ^{238}U, ^{235}U, ^{234}U, and ^{232}Th. It is found in small amounts in all uranium and thorium deposits and occurrences. The only recorded radium production from Wyoming was from the Silver Cliff mine. Some of this radium production reportedly was shipped to the Curies in France for their experiments with radiation (Peck, 1969).

Although ^{40}K occurs in all rocks in the State, it has no commercial use. Because it is so abundant in granitic and arkosic rocks that are common in the State, a large portion of the natural gamma radiation in Wyoming is from the decay of ^{40}K.

Classification of deposits and occurrences

Deposits and occurrences of uranium and thorium are of many different types, based upon their method of formation. The classification scheme used in this report (**Table 2**) is modified from Mickle and Mathews (1978). In part, this classification is based on the type of host rock (sedimentary, igneous, or metamorphic) and the suspected origin. Because the characteristics

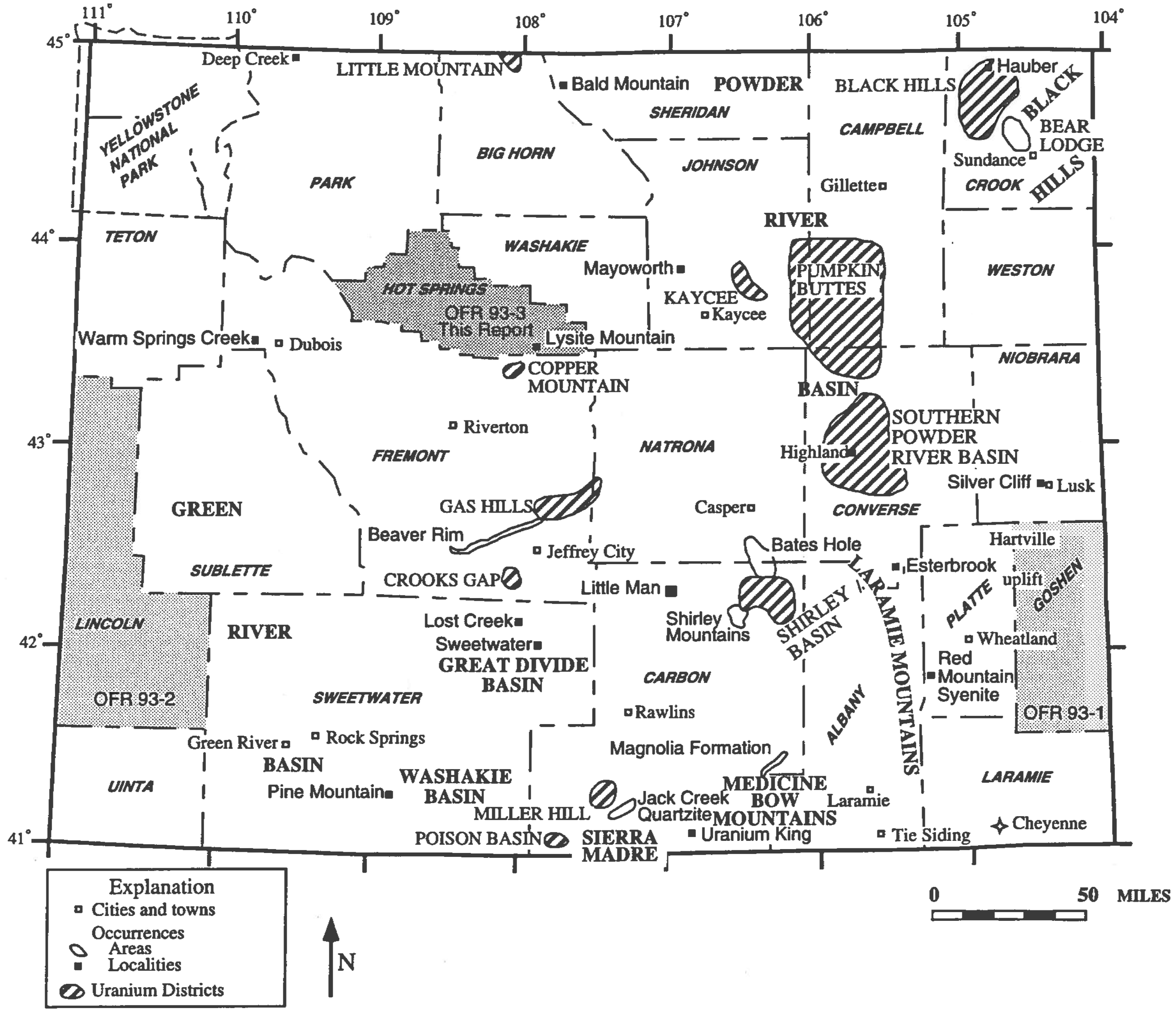

Figure 1. Index map of Wyoming showing major uranium districts and other occurrences of radioactive elements (both areas and localities); the location of other county reports on radioactive elements (light stipple); and the location of Hot Springs County, Wyoming (dark stipple). (OFR refers to a Geological Survey of Wyoming Open File Report number.)

of classes often overlap and the differences between classes are gradational, some occurrences are unclassified (and are placed in the unknown category). Unconformity-related occurrences are separated because they are found in Wyoming in all types of host rocks. Shear-zone-hosted, vein-hosted, fracture-filling, and replacement occurrences are not dependent on the type of host rock and are also classified separately. Still other occurrences are classified as unknown due to insufficient data.

For the purposes of these county reports, an occurrence of a radioactive element is defined as a concentration in which the amount of the element, as determined by either radiometric or

Table 2. Classification of uranium and thorium mineralization, with Wyoming examples (modified from Mickle and Mathews, 1978).

Symbol	Classification	Wyoming examples
	OCCURRENCES IN SEDIMENTARY ROCKS	
	Redox[1]	
RX	Roll front	Wasatch and Fort Union Formations (and equivalents); Statewide
RT	Tabular	Inyan Kara Group, northeastern Wyoming
	Mechanical accumulations	
BP	Beach placer	Mesaverde Formation, Statewide
FP	Fluvial placer	Flathead Formation, northwestern Wyoming
QC	Quartz-pebble conglomerate	Magnolia Formation, Medicine Bow Mountains (Albany and Carbon Counties)
	Chemical codeposition	
BS	Marine black shale	Minnelusa Formation, eastern Wyoming
MP	Marine phosphorite	Phosphoria Formation, western Wyoming
LP	Lacustrine phosphorite	Wilkins Peak Member, Green River Formation (Sweetwater County)
	Carbonate	
CP	Paleokarst	Madison Limestone, Little Mountain district (Bighorn County)
CS	Surficial coating	Browns Park Formation, Carbon County
CR	Reduction related	Sundance Formation, Mayoworth area (western Johnson County)
DE	Desert evaporite	surface deposits, Lost Creek area (northeastern Sweetwater County)
CL	Coal	Wasatch Formation, Great Divide Basin (eastern Sweetwater County)
	OCCURRENCES IN IGNEOUS ROCKS	
IM	Initial magmatic	Precambrian granites; Statewide
PG	Pegmatitic	Sherman Granite, Tie Siding area (southeastern Albany County)
MH	Magmatic hydrothermal	Eocene intrusives, Bear Lodge Mountains (Crook County)
AT	Autometasomatic	Eocene intrusives, Bear Lodge Mountains (Crook County)
PN	Pneumatolytic	Yellowstone National Park
SP	Postmagmatic silica-poor	uncertain
SR	Postmagmatic silica-rich	possibly Moonstone Formation, central Wyoming
	OCCURRENCES IN METAMORPHIC ROCKS	
CM	Contact metamorphic	uncertain
AN	Anatectic	Ralph Platt pegmatites, Saratoga Valley (southern Carbon County)
MR	Redox[1]	Little Man mine, Pedro Mountains (northern Carbon County)
MV	Vein	Esterbrook area (southern Converse County)
UC	UNCONFORMITY-RELATED	Silver Cliff mine (southern Niobrara County)
UN	UNKNOWN	numerous
	OTHER OCCURRENCES	
SZ	Shear-zone-hosted	Sierra Madre (southern Carbon County)
VN	Vein-hosted	Esterbrook area (southern Converse County)
FR	Fracture-filling	Michigan mine (Goshen County)
RP	Replacement	Bear Lodge Mountains (Crook County)

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[1] Formed at a geochemical interface between oxidizing and reducing environments where oxidation-reduction chemical reactions occur.

chemical analysis, is greater than 50 parts per million (0.005 percent). Equivalent uranium (eU), thorium (eTh), or other radioactive element concentration is determined by measuring the radioactivity of a sample. Chemical uranium (cU), thorium (cTh), or other radioactive element concentration is determined by quantitative chemical analysis. A concentration of radioactive elements greater than 50 parts per million (ppm), determined by **either** method, is sufficient to define an occurrence. Alternatively, an occurrence (or anomaly) is also defined as a locality with ten times or more radioactivity than the normal background radiation.

Because occurrences of radioactivity in sedimentary rocks have been intensively studied in Wyoming, the classification system for this category has more and better defined subdivisions. Redox occurrences are by far the most common class in Wyoming, and all of the large mines in the State produce or have produced uranium from deposits of this type.

By way of explanation, uranium is soluble in water as various complex ions under oxidizing conditions. Under reducing conditions uranium is not soluble. Redox occurrences are formed by precipitation at geochemical boundaries where the Eh (oxidation-reduction potential) changes from oxidizing to reducing. Most uranium production outside of the United States is from classes of deposits other than redox, particularly from unconformity-related deposits and deposits of Precambrian quartz-pebble conglomerates.

Uses of uranium and thorium

Uranium is primarily used as a fuel in nuclear-powered electrical generating plants. Yellowcake produced from Wyoming's uranium mills is purchased by electric utility companies. Yellowcake (uranium oxide concentrate) contains uranium oxide as ammonium diuranate, sodium diuranate, or uranium peroxide (List and Coleman, 1979). The utilities stockpile yellowcake and ship it to enrichment plants when fuel is needed for their power plants. Enrichment plants concentrate the fissionable uranium isotope ^{235}U from the less than 0.7 percent that is present in natural uranium and yellowcake to the 3 percent needed for nuclear power plants.

Minor amounts of uranium are also used in the manufacture of detonators for nuclear weapons. In the United States, uranium was used as the explosive in the first fission weapons. Nuclear weapons and detonators require concentrations of more than 90 percent ^{235}U (Beckmann, 1976).

The uranium remaining after the fissionable isotope has been removed is called depleted uranium metal. This uranium is used in armor-piercing projectiles, in counterweights (especially for elevators), in chemical catalysts, in reactor shielding (Kirk, 1980), and recently, in armor plating itself (Bob Peck, personal communication, 1988).

Most thorium is used in aerospace alloys. Other uses include refractory materials, the light-producing material in gas lantern mantles, electronic components, and in chemical catalysts. A few nuclear reactors in foreign countries use ^{232}Th as fuel. The last nuclear reactor in the United States to use thorium as a fuel was the Fort St. Vrain power plant in Colorado. The plant closed over a decade ago. Refractory materials containing thorium oxide (thoria) are used in molds and crucibles that are used for casting and making high temperature alloys. As an alloying material, thorium is primarily added to magnesium to give the magnesium higher strength and resistance to deformation at high temperatures. Thorium as thorium nitrate is used to improve tungsten welding rods and to facilitate welding of stainless steel and nickel alloys. New uses of thorium under development include breeder reactors which use thorium for fuel, and in fuel rods and core retention beds in conventional reactors in order to prevent core meltdown. If these new uses are developed, increased production of thorium would be necessary (Hedrick, 1985; 1992a; 1992b).

Occurrences of radioactive elements in Hot Springs County, Wyoming

Summary

No uranium production has been reported from Hot Springs County. Tertiary sedimentary rocks of the Tepee Trail and Aycross (?) Formations, or their age equivalents, however, often contain more than 50 ppm uranium. All but one of the uranium occurrences reported in Tertiary rocks in Hot Springs County are in phosphatic rocks. Additional uranium occurrences are reported in the Jurassic Morrison Formation, at depth in the Triassic Chugwater Formation in the Grass Creek oil field, and in Precambrian granite. Cretaceous titaniferous black sandstones within the Mesaverde Formation also contain radioactive minerals at **Localities 2 and 3**, below.

Exposures of Tertiary sedimentary rocks on Lysite Mountain contain at least seven uraniferous phosphatic zones: four zones are in rocks equivalent to the Aycross (?) Formation and three zones are in rocks equivalent to the Tepee Trail Formation (**Figure 2**). The extent of these rocks is shown on **Figure 3**. These rocks, which are mapped as the Eocene Wagon Bed Formation (Twb) by Love and Christiansen (1985), contain most of the identified radioactive occurrences in the county. The lateral extent of the seven zones has not been determined because only eight sites have been sampled and analyzed (**Localities 6 through 12, and 14**, below). The Aycross (?) equivalent contains lacustrine oil shale, coal, and tuffaceous strata; the lower part of the Tepee Trail equivalent also contains these rock types. In contrast, the upper part of the Tepee Trail

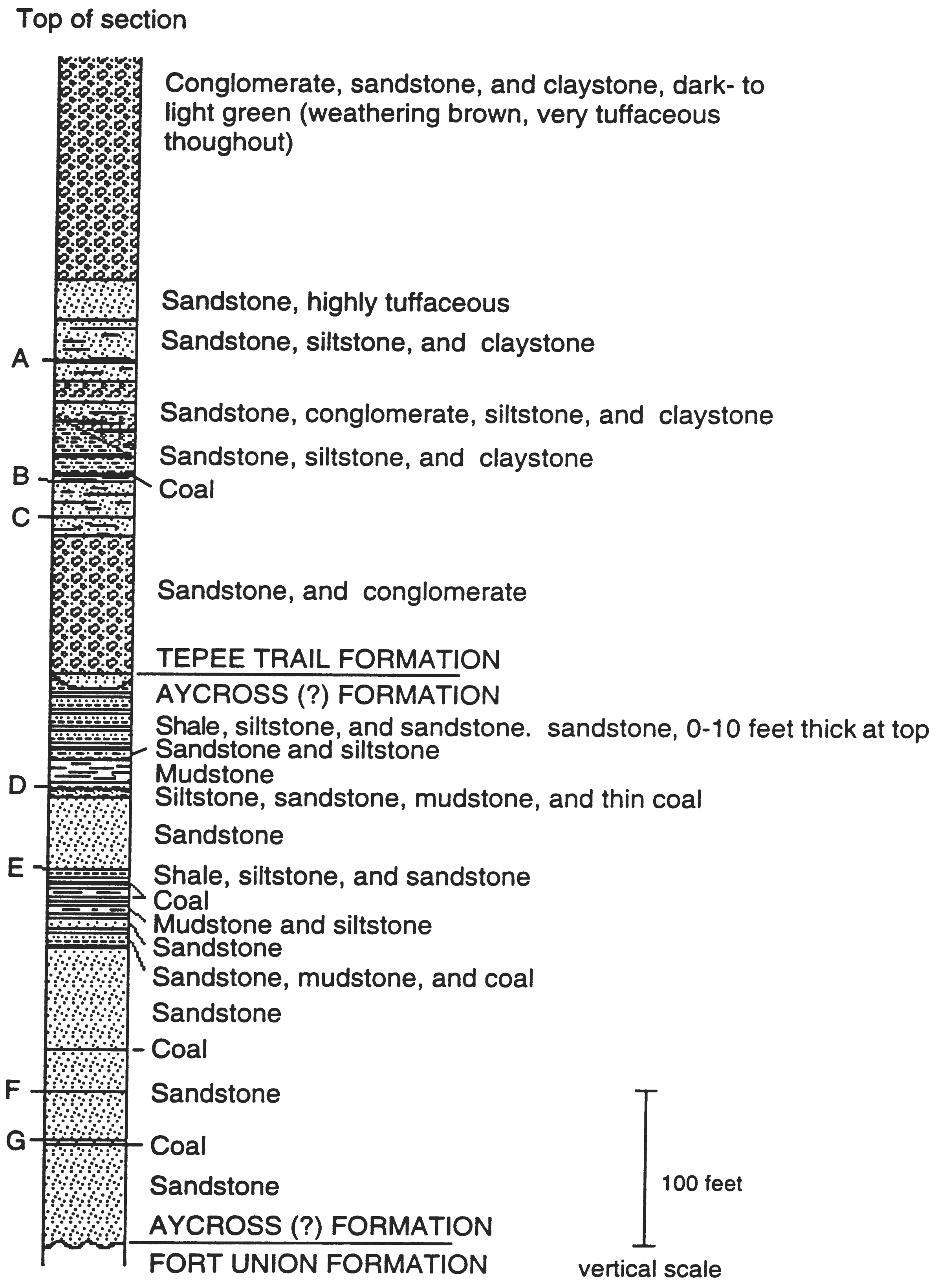

Figure 2. Stratigraphic section of the Tepee Trail Formation and Aycross (?) Formation equivalents on the northwest escarpment of Lysite Mountain (section 20, T42N, R90W), showing the position of uraniferous phosphatic zones (A through G). (After Love, 1964.)

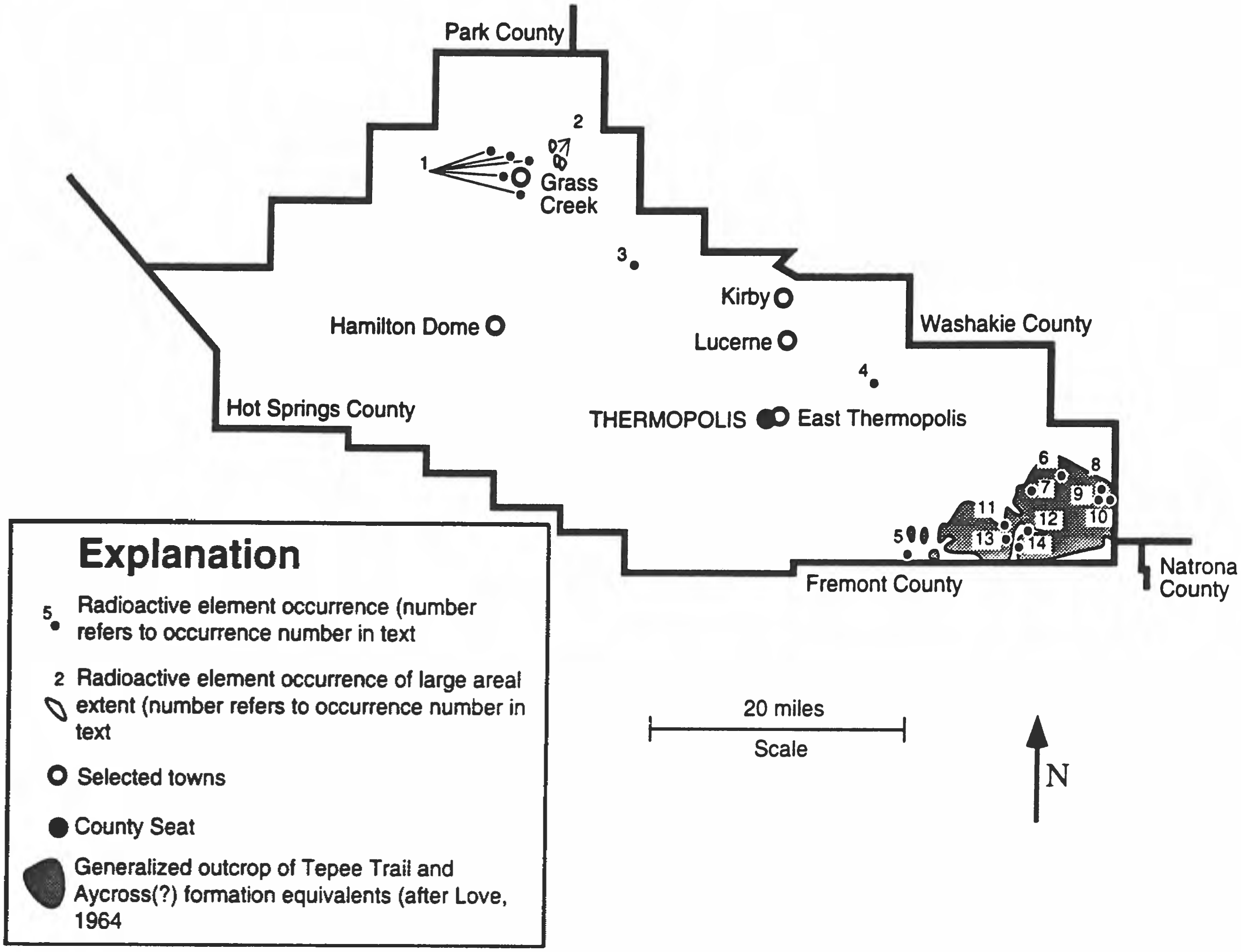

Figure 3. Index map showing the occurrences of radioactive elements and associated anomalies in Hot Springs County, Wyoming.

equivalent contains conglomerate and tuffaceous sandstone, siltstone, claystone, and limestone (Love, 1964).

The discovery of unconformity-related uranium deposits in Precambrian rocks beneath Tertiary sedimentary rocks in the Copper Mountain area immediately south in Fremont County (Yellich and others, 1978), suggests that additional deposits could be discovered in Hot Springs County through exploration in areas of similar geology. Unconformity-related uranium occurrences are also found in Precambrian rocks beneath the Cambrian Flathead Sandstone at many localities in the Bighorn Basin (Harris, 1986). There may be some potential for finding these deposits in southern Hot Springs County.

Description of occurrences

The alphanumeric notation that precedes each of the following descriptions is keyed to **Figure 3** and **Tables 2** through **5**: the number refers to the map location (**Figure 3**), the letter(s) before the parentheses refers to the elements/anomaly present at the site (**Table 3**). In the parentheses, the group(s) of two letters refers to the deposit type(s) (**Table 2**); in the brackets, the group(s) of letters refers to the formation name(s) or rock type(s) of the host rock(s) (**Table 4**). The lower case letters after the parentheses indicate the status of development and the type of data available for the occurrence (**Table 5**).

1. rad (UN) [TRc] rl. **Grass Creek oil field**; occurrences are located in NE SE NE section 13, T46N, R99W; NE SW SE section 18, NE SE SE section 18, NE NE NE section 19, NW SW NW section 29, and NW NE NE section 30, T46N, R98W. Three slightly radioactive zones reportedly occur in the Crow Mountain Sandstone Member of the Triassic Chugwater Formation (TRc) at depths from about 4,200 to 4,700 feet in some wells in this oil field. The uranium content of the zones is probably less than 0.01 percent uranium and might be related to petroleum accumulation in the sandstone (Love, 1953). The Crow Mountain Sandstone Member is a producing horizon in the oil field. Examination of gamma-ray well logs from holes drilled in the field showed more radioactivity in the Permian Phosphoria (Pp) and the Early Cretaceous Cloverly (Kcv) Formations than in the Chugwater Formation (TRc). The highest radioactivity in each formation was less than twice the full A.P.I. unit scale.

2. Th,U,Zr,V,Ti (BP) [Kmv] mn, mi, ca, ra. **Grass Creek area**; this occurrence consists of a northern segment located in sections 8, 9, and 16, T46N, R98W, and a southern segment located in sections 33 and 34, T46N, R98W. A radioactive, titaniferous, black sandstone occurs at the top of the lowermost sandstone of the Late Cretaceous Mesaverde Formation. The black sandstone represents heavy minerals that have been concentrated in lag deposits by wave action in a beach environment. This is "the largest high-grade black sandstone deposit in Wyoming" (Houston and Murphy, 1962). The heavy mineral fraction from a sample collected from the sandstone contained 1 percent monazite and 18 percent zircon. A niobium-bearing, radioactive, heavy, opaque mineral was also present in the heavy

Table 3. Chemical symbols for elements and radioactive anomalies.

Symbols	Element or anomaly
Ag	silver
Cu	copper
Fe	iron
Mn	manganese
Ra	radium
Th	thorium
U	uranium
V	vanadium
rad	radioactive material
ra	anomalous radioactivity

Table 4. Key to formation names or rock types used in the descriptions of the occurrences of radioactive elements in Hot Springs County, Wyoming.

Formation name	**Symbol**
CENOZOIC	
TERTIARY	
Tertiary, undivided	Tu
Eocene Aycross Formation	Ta
Eocene Tepee Trail Formation	Tt
Eocene Wagon Bed Formation	Twb
MESOZOIC	
Cretaceous Mesaverde Formation	Kmv
Cretaceous Cloverly Formation	Kcv
Jurassic Morrison Formation	Jm
Triassic Chugwater Formation	T̄Rc
PALEOZOIC	
Permian Phosphoria Formation	Pp
Cambrian Flathead Sandstone	Ꞓf
PRECAMBRIAN	
granitoid rocks	pꞒgr

Table 5. Status and/or type of occurrences of radioactive elements.

Symbol	**Status and/or occurrence**	**Symbol**	**Status and/or occurrence**
ALL RADIOACTIVE ELEMENTS		URANIUM OCURRENCES ONLY	
mn	minerals noted or observed	p	prospect
mi	minerals identified	pr	prospect—reserves delimited
ca	chemical analysis	ma[1]	mine (active)
ra	radiometric analysis	ms[1]	surface mine (inactive)
		mu[1]	underground mine (inactive)
rs	radiometric survey		
rl	radiometric down-hole log		
uo	unverified occurrence		
ia	in-situ operation (active)		
ir	in-situ operation (research)		

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[1] An occurrence is considered a mine (instead of a prospect) when the reported cumulative production of uranium ore exceeds 500 short tons.

mineral fraction. In 26 samples, the uranium content averaged 0.015 percent radiometric or equivalent uranium (eU) and 0.002 percent chemical uranium (cU). The concentrations varied from 0.001 to 0.056 percent eU (less than 0.001 to 0.009 percent cU). The northern segment of the black sandstone deposit (occurrence) is at least 5,600 feet long and is up to 16 feet thick. The southern segment of the deposit is exposed for 1,600 feet and is at least 5 feet thick (Houston and Murphy, 1962).

Early reconnaissance analyses of four samples from the black sandstones yielded 0.16 to 0.25 percent V_2O_5, and 0.01 to 0.03 percent cU_3O_8 (0.03 percent eU_3O_8) (Klosterman and Knaak, 1952; Barrett, 1953). Dow and Batty (1961) reported 0.06 to 0.12 percent equivalent thorium (eTh) from six samples.

More recently, five analyses reported from this area contained 39 to 252 ppm uranium, 282 to 781 ppm thorium, and 10,343 to 15,229 ppm zirconium (Hesse, 1982).

3. Th,U,Zr,Ti (BP) [Kmv] mi, ca, ra. **Cottonwood Creek**; located in SE section 26, T45N, R97W. A radioactive, titaniferous, black sandstone is present in the basal Mesaverde Formation (Kmv) as an erosional remnant 150 feet across. The black sandstone represents heavy minerals that have been concentrated in lag deposits by wave action in a beach environment. The heavy mineral fraction of a sample of this sandstone contains 18.5 percent zircon and 1.0 percent monazite (Houston and Murphy, 1962). The maximum thickness of the black sandstone is 9 feet. The average uranium content in four samples of the sandstone was 0.006 percent eU, with a range from 0.004 to 0.011 percent eU; all the samples had less than 0.001 percent cU (Houston and Murphy, 1962). A sample from the deposit reported in Dow and Batty (1961) contained 0.04 percent eTh. Hesse (1982) reported that a low-grade (buff colored) sample contained 29 ppm (or 0.0029 percent) uranium, 145 ppm (or 0.0145 percent) thorium, and 3,660 ppm (or 0.366 percent) zirconium.

4. U? (UN) [Jm] uo. **Red Rose claims**; located in sections 20 and 21, T43N, R93W. Uranium occurs in a carbonaceous shale of the Jurassic Morrison Formation (Jm) (Vine, 1962). Because this information has not been confirmed by another source, and because some of Vine's occurrences do not meet the occurrence criteria used in this report (0.005 percent or 50 ppm), this is an unverified occurrence.

5. U? (UN) [p€gr] ca, ra. **Anomaly 1**; located in SE section 31, T41N, R92W. A sample of Precambrian granite (p€gr) from just below the Flathead Formation (€f) at this anomaly contained 0.005 percent eU (0.001 percent cU)(Tourtelot, 1952).

6. U (LP) [Tu] ca, ra. **Lysite Mountain area**; located in center W2 section 20, T42N, R90W. A stratigraphic section of the Tepee Trail and Aycross (?) equivalents was measured at this locality by Love (1964) and is reproduced here as **Figure 2**. Samples of all seven uraniferous phosphatic zones in the Tertiary Tepee Trail and Aycross(?) equivalents (Tu) at this locality (**Figure 3**) were analyzed. From bottom to top (phosphatic zones G through A), they contained 0.023, 0.009, 0.006, 0.016, 0.005, 0.002, and 0.007 percent cU, respectively, between 0.008 and 0.02 percent eU, and from 1.11 to 5.18 percent phosphate content expressed as an oxide (P_2O_5). The lithologic units sampled, from bottom to top, were

carbonaceous shale, siltstone, mudstone, siltstone, carbonaceous siltstone, limy siltstone, and limy siltstone, respectively (Love, 1964).

7. U,P (LP) [Tt or Twb] ca, ra. **Bridger Pass road**; located in NE SE section 34, T42N, R91W. A sample of uraniferous phosphatic rock collected from a prospect pit in the Tepee Trail equivalent along the road contained 0.040 percent cU (0.037 percent eU) and 5.06 percent P_2O_5 (Love, 1964). The exact stratigraphic position of this sample is not known. The sample was of a brown, limey, carbonaceous mudstone. Damp and Brown (1982) reported that a sample of limestone from the Wagon Bed Formation from their partial measured section contained 77 ppm or 0.0077 percent eU [97 ppm or 0.0097 percent radiometric or equivalent thorium (eTh)]. They reported that the sample was from a uraniferous phosphorite, even though no phosphate analysis was presented.

8. U (LP) [Ta(?)] ca, ra. **Nowater Canyon**; located on center north line section 35, T42N, R90W. Samples of three uraniferous phosphatic zones in the Aycross (?) equivalent rocks near Nowater Canyon contained (from bottom to top) 0.004, 0.003, and 0.007 percent cU (0.005, 0.005, and 0.008 percent eU), respectively, with 1.52 to 2.21 percent P_2O_5.

   The lowest sample was from a pale green, tuffaceous limestone overlying a brown oil shale sequence. The middle sample was a tan, blocky tuff 40 feet stratigraphically above the lowest sample. The upper sample was of a hard, green, siliceous concretion 13 feet stratigraphically above the middle sample and 7 feet below a cliff of conglomerate (Love, 1964).

9. U (UN) [Twb] ca, ra. **Nowater Canyon area**; approximately located in center SW NE section 35, T42N, R90W. A sample of variegated, tuffaceous mudstone from the Wagon Bed Formation at this locality contained 57 ppm or 0.0057 percent eU (142 ppm or 0.0142 percent eTh). The exact stratigraphic position of this sample is not known. This occurrence was reportedly in a uraniferous phosphatic zone, even though a phosphate analysis was not given (Damp and Brown, 1982).

10. U (LP) [Ta(?)] ca, ra. **Hawks Butte**; located in SW NE NW section 36, T42N, R90W. The four uraniferous phosphatic zones in the Aycross(?) equivalent at this site were sampled. One sample was taken from each of the three lower zones and two samples were taken from the uppermost zone. From bottom to top, the samples contained 0.002, 0.023, 0.002, 0.002, and 0.008 percent cU (0.003 to 0.025 percent eU), with 0.36 to 2.33 percent P_2O_5. The thicknesses and lithologies of the four zones (from bottom to top) were 6 feet of carbonaceous shale, 3 feet of claystone, 3 feet of bentonitic claystone, and 3 feet of limestone, respectively. The total interval exposed at this locality is 160 feet thick (Love, 1964).

11. U,Th (UN) [Twb] ca, ra. **Kirby Creek**; located in NW section 21, T41N, R91W. A [composite ?] sample was taken from three rock units in the Wagon Bed Formation, including a lens of dark gray to black siliceous rock within a light brown to light gray, fine-grained to conglomeratic, arkosic sandstone; a bentonitic siltstone; and a gray siliceous concretion in an arkosic sandstone. The exact stratigraphic position of this sample is not known. This sample contained 532 ppm or 0.0532 percent cU_3O_8 (432 ppm or 0.0432 percent eU; 457 ppm or 0.0457 percent eTh), with 3.31 percent P_2O_5, 2.97 percent Fe, 1,892 ppm or 0.1892

percent Mn, and 130 ppm or 0.013 percent V. The sample was probably from a uraniferous phosphatic zone (Damp and Brown, 1982) on Lysite Mountain.

12. U,Th (LP) [Tu] ca, ra. **Jenkes Creek**; located in SE section 23 and NE corner section 26, T41N, R91W. Tuffaceous siltstone in section 23 and bentonitic mudstone in section 26 from either the Wagon Bed Formation or the Tepee Trail Formation were sampled very near the unconformity with the underlying Chugwater Formation. The exact stratigraphic position of these samples is not known. The samples contained 78 and 85 ppm or 0.0078 and 0.0085 percent cU_3O_8 (85 and 181 ppm or 0.0085 and 0.0181 percent eU) and 130 and 476 ppm or 0.013 and 0.0476 percent eTh, respectively. These samples were reportedly from a uraniferous phosphatic zone on Lysite Mountain, even though no phosphate analyses were presented (Damp and Brown, 1982).

13. rad (UN) [Twb?] ca, ra. **Nichols Ranch**; located in S2 SW section 28, T41N, R91W. No uranium minerals were visible at this locality, but radioactivity was 20 times background in a dozer cut in a limonite-stained, coarse-grained to pebble conglomeratic sandstone that contained petrified wood. The exact stratigraphic position of this occurrence is not known. The highest radioactivity and most intense limonite staining were related to fractures within the sandstone in the Wagon Bed Formation. A sample of highly limonite-stained material contained 110 ppm or 0.011 percent eU, 35 ppm or 0.0035 percent eTh, 3,102 ppm or 0.3102 percent Mn, and 5.44 percent Fe (Damp and Brown, 1982).

14. U,Th (UN) [Twb] ca, ra. **Bridger Creek (samples 313-314)**; located in N2 section 33-34 line,T41N, R91W. Samples of a black to red siliceous pod in a sandstone, and a light brown to light green bentonitic mudstone or siltstone taken at this locality contained 88 and 532 ppm or 0.0088 and 0.0532 percent cU_3O_8 (68 and 614 ppm or 0.0068 and 0.0614 percent eU) and 109 and 62 ppm or 0.0109 and 0.0062 percent eTh, respectively. The samples also contained 0.92 and 3.40 percent Fe, 0.87 and 1.61 percent P_2O_5, 320 and 170 ppm or 0.032 and 0.017 percent Mn, and 35 and 45 ppm or 0.0035 and 0.0045 percent V, respectively. The exact stratigraphic position of these samples is not known, except that all of these units are in the Wagon Bed Formation. According to Damp and Brown (1982), the mineralization is probably related to uraniferous phosphatic zones on Lysite Mountain.

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