GEOLOGICAL SURVEY OF WYOMING
Gary B. Glass, State Geologist

OPEN FILE REPORT
93-1

OCCURRENCES OF RADIOACTIVE ELEMENTS IN GOSHEN COUNTY, WYOMING

by

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

Laramie, Wyoming
1993

People with disabilities who require an alternative form of communication in order to use this publication should contact the Editor, Geological Survey of Wyoming at (307) 766-2286. TDD Relay Operator: 1(800) 877-9975.

This and other publications available from: The Geological Survey of Wyoming
Box 3008, University Station
Laramie, Wyoming 82071-3008
(307) 766-2286 • FAX (307) 766-2605

Table of Contents

List of Tables

List of Figures

Abstract

Although Goshen County has not been a producer of uranium, several different types of occurrences have been reported. These include redox (roll front and tabular) and chemical codeposition (marine black shale) occurrences in sedimentary rocks, redox occurrences in metamorphic rocks, fracture fillings, and unconformity-related occurrences. The recent development of a uranium mine in Tertiary rocks in northwestern Nebraska, 35 miles from Goshen County, may encourage exploration in similar aged rocks in Goshen County. Also, the large helium anomaly located in Goshen County is significant because helium can be an indicator of uranium. Should uranium again become an important economic fuel, it is likely that some uranium exploration could occur in Goshen County.

Introduction

This open file report is the first of a county-by-county series on uranium and other radioactive elements in Wyoming. Information for this report (which is 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 process.

Uranium, thorium, potassium-40 (^{40}K), and radium, and their daughter products, are the naturally-occurring radioactive elements. The first three elements and their isotopes commonly occur in nature. The element radium and its isotopes 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. Potassium-40 occurs in nearly every rock type and has no commercial use. 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.

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 to be 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 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**).

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	$U(SiO_4)(OH)_4$	widespread
uraninite-thorian uraninite	$(U,Th)O_2$	widespread
Oxidized forms (U^{6+})		
abernathyite	$K_2(UO_2)_2(AsO_4)_2 \bullet 8H_2O$	sedimentary redox
autunite	$Ca(UO_2)_2(PO_4)_2 \bullet 8\text{-}12H_2O$	igneous and metamorphic
bayleyite	$Mg_2(UO_2)(CO_3)_3 \bullet 18H_2O$	sedimentary redox
becquerelite	$CaU_6O_{19} \bullet 10H_2O$	sedimentary redox
carnotite	$K_2(UO_2)_2V_2O_8 \bullet 3H_2O$	sedimentary redox
liebigite	$Ca_2(UO_2)(CO_3)_3 \bullet 11H_2O$	widespread
meta-autunite	$Ca(UO_2)_2(PO_4)_2 \bullet 4\text{-}6H_2O$	igneous and metamorphic
meta-torbernite	$Cu(UO_2)_2(PO_4)_2 \bullet 8H_2O$	widespread
meta-tyuyamunite	$Ca(UO_2)_2V_2O_8 \bullet 3\text{-}5H_2O$	sedimentary redox
phosphuranylite	$(H_3O)_2Ca(UO_2)_3(PO_4)_2(OH)_4 \bullet 4H_2O$	widespread
rutherfordine	$(UO_2)(CO_3)$	various
sabugalite	$HAl(UO_2)_4(PO_4)_4 \bullet 16H_2O$	widespread
schoepite	$UO_3 \bullet 2H_2O$	sedimentary redox
schroeckingerite	$NaCa_3(UO_2)_2(CO_3)_3SO_4F \bullet 10H_2O$	widespread
sklodowskite	$(H_3O)_2 Mg(UO_2)_2(SiO_4)_2 \bullet 4H_2O$	widespread
torbernite	$Cu(UO_2)_2(PO_4)_2 \bullet 8\text{-}12H_2O$	widespread
tyuyamunite	$Ca(UO_2)_2V_2O_8 \bullet 8H_2O$	sedimentary redox
umohoite	$(UO_2)(MoO_2)(OH)_4 \bullet 2H_2O$	sedimentary redox
uranocircite	$Ba(UO_2)_2(PO_4)_2 \bullet 12H_2O$	various
uranophane	$(H_3O)_2Ca(UO_2)_2(SiO_4)_2 \bullet 3H_2O$	widespread
uranopilite	$(UO_2)_6(SO_4)(OH)_{10} \bullet 12H_2O$	widespread

Table 1 (continued).

Mineral	Chemical formula	Common occurrence
weeksite	$K_2(UO_2)_2Si_6O_{15}\bullet 4H_2O$	various
zellerite	$Ca(UO_2)(CO_3)_2\bullet 5H_2O$	sedimentary redox
zeuherite	$Cu(UO_2)_2(PO_4)_2\bullet 40H_2O$	various
zippeite	$K_4(UO_2)_2(SO_4)_3(OH)_{10}\bullet 16H_2O$	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	$Ca_5(PO4)_3(F,OH,Cl)_3$	carbonatites, phosphorites
brockite	$(Ca,Th,Ce)PO_4\bullet H_2O$	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	$Na_2Ba_4(Y,Ca,Sr,U)_3(CO_3)_9\bullet 5H_2O$	trona, phosphorite
rhabdophane	$(Ce,Y,La,Di)PO_4\bullet H_2O$	sedimentary, siliceous
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 of cryptocrystalline variety of uraninite that can contain thorium.

gummite: fine-grained, secondary, hydrous uranium minerals associated with uraninite that can be amorphous.

thucolite: uranium and thorium-bearing carbonaceous material.

[1]Apatite, fergusonite, fluorite, rhabdophane, xenotime, and zircon may sometimes contain either uranium or thorium in the interstitial spaces, but not always. 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.

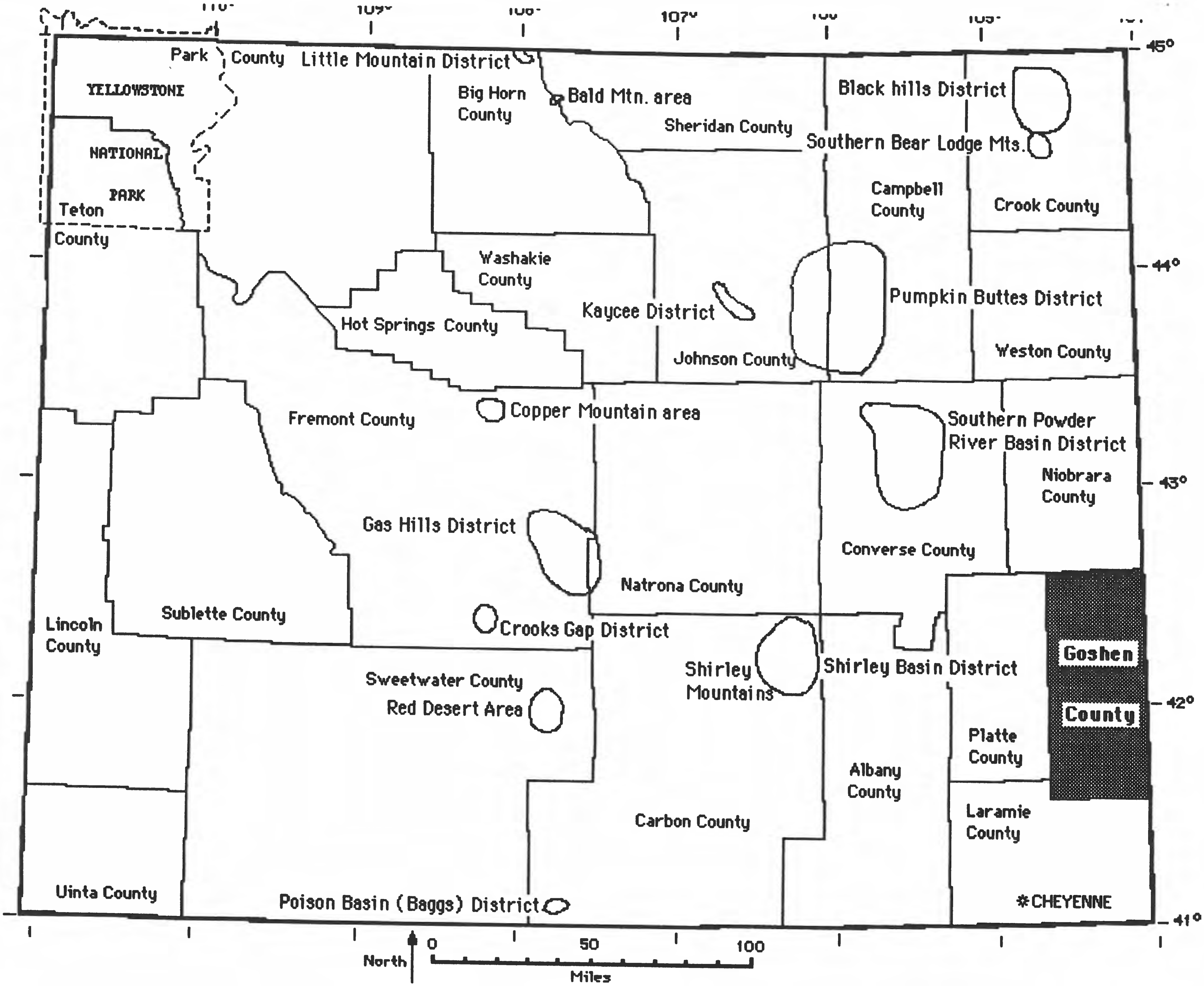


Figure 1. Index map of Wyoming showing major uranium districts and the location of Goshen County, Wyoming.

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

Potassium-40 occurs in all rocks in the State. It has no commercial use. Because potassium 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.

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).

Classification of deposits and occurrences

Uranium and thorium deposits and occurrences 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 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

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)

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

on the type of host rock and are also classified separately. Still other occurrences are classified as unknown due to insufficient data.

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(d) 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

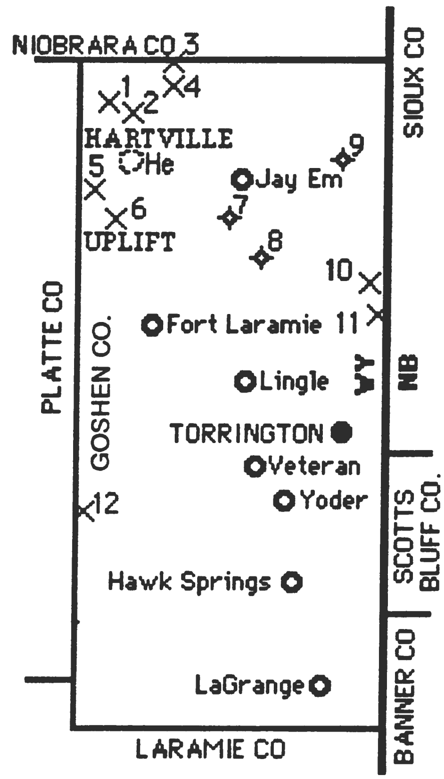
(Kirk, 1980), and recently, in armor plating itself (Bob Peck, personal communication, 1988).

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 deformation resistance 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 Goshen County, Wyoming

Summary

No uranium production has been reported in Goshen County, and reported radioactive occurrences are few (**Figure 2**). Some reported occurrences in the northwestern part of the county are associated with mineralized fractures in Precambrian rocks in the core of the Hartville uplift. Moderately radioactive Precambrian granites and gneisses (five to ten times background radiation levels) are also present in the Hartville uplift (**Figure 2**). Seeland (1982) reported that some of these rocks contain in excess of 50 parts per million (ppm) thorium, while an earlier analysis reported 0.01 percent U_3O_8 (Mallory, 1953). Uranium minerals and anomalous radioactivity are also found in the Ogallala Formation in the northeastern part of the county. This unit hosts a large deposit near Crawford, Nebraska, 35 miles northeast of the northeastern corner of Goshen County. Oil wells have encountered



EXPLANATION

6 — Radioactive element occurrence (numbers refer to occurrence number in text)

9 — Radioactivity occurrence in subsurface (numbers refer to occurrence number in text)

He — Helium anomaly

County Seat

Selected towns

Figure 2. Index map showing the occurrences of radioactive elements and associated anomalies in Goshen County, Wyoming.

radioactive black shales in the Minnelusa Formation (Permian-Pennsylvanian) at great depths.

There may be unconformity-related uranium mineralization in the Hartville uplift. One locality for this kind of mineralization is the very large (in areal extent) helium anomaly, which is located in T29N, R64W, northwestern Goshen County (**Figure 2**). Small concentrations of helium, which can be an indirect indication of uranium, were detected in an area of over six square miles in soil gas emanating from a thin layer of Miocene sedimentary rocks that unconformably overlie Precambrian rocks near the Hartville fault. Precambrian graphitic schists, amphibolites, metacarbonates, and gneisses are exposed one-half mile west of the anomaly, just west of the Hartville fault. The helium anomaly is also associated with a gravity and magnetic high. Graphitic schists are present in Precambrian rocks in the Hartville uplift and might occur beneath the overlying Miocene rocks. Exploration for uranium was conducted at the site of this anomaly in the mid-1980s, but no discovery was reported. A more thorough exploration drilling program is probably warranted.

Description of occurrences

The alphanumeric notation that precedes each of the following descriptions is keyed to **Figure 2** and **Tables 2** through **5**: the number refers to the map location (**Figure 2**), 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**).

Table 3. Chemical symbols for elements and radioactive anomalies.

Symbol	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 Goshen County, Wyoming.

Formation name	Symbol
CENOZOIC	
TERTIARY	
Chadron Formation	Tc
Ogallala Formation	To
PALEOZOIC	
Minnelusa Formation	PPm
Guernsey Limestone	MDg
PRECAMBRIAN	
undivided	p€
hematite schist	p€is
graphitic schist	p€gs

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--reserve delimited
ca	chemical analysis	ma[1]	mine (active)
ra	radiometric analysis	ms[1]	mine-surface (inactive)
		mu[1]	mine-underground (inactive)
rs	radiometric survey		
rl	radiometric down-hole log		
uo	unverified occurrence		
ia	in-situ operation (active)		
ir	in-situ operation-research		

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

1. U,Cu (MR?, FR) [MDg, p€] mi, rs. **Michigan mine area**; located in NW section 24, T30N, R65W. In 1982, the author identified torbernite (hydrated uranium-copper-phosphate) associated with copper carbonate and copper silicate

minerals in fractures and joints in Archean or Proterozoic quartzites and metacarbonates adjacent to iron formation. A zone of silicification south of the crest of a low hill contains gray carbonaceous streaks and veinlets. Anomalous radioactivity (five times local background radioactivity) is present 20 feet west of the zone of silicification in unaltered gray limestone of the Guernsey Formation (Mississippian-Devonian).

A grab sample taken from the mine dump in 1950 contained 0.056 percent equivalent uranium (eU) (Wilmarth and Johnson, 1950a). A sample of ore taken from the mine area in 1953 contained 0.03 percent U_3O_8 (Mallory, 1953). Samples of Guernsey Formation limestone and Precambrian talc schist (metacarbonate) from the area contained less than 11 ppm thorium and less than 11 ppm uranium, while a sample of copper bearing, silicified schist contained 56 ppm uranium and less than 17 ppm thorium (Seeland, 1982).

2. U,Cu (MR) [p€gs, p€is?] ra, ca. **Muskrat Canyon area**; located in NW section 19, T30N, R64W. A sample of copper carbonate-stained graphitic schist and a sample of dump material contained 0.02 and 0.005 percent eU, respectively (Roseboom, 1953). Another sample of copper-bearing material contained 0.03 percent U_3O_8 (Mallory, 1953).

   Samples of a quartz vein in schist and samples of graphitic schist that might be from this site contained 1 ppm or less uranium, and 12 ppm or less thorium (Seeland, 1982). Using the listed latitude and longitude for these samples, it appears they are from the SW section 18, and not from the mine site.

3. rad (UN) [p€] rs. **Western Rawhide Buttes**; located in T30N, R65W, and T31N, R64W. Radioactivity (level not stated) is mainly confined to fault zones in Precambrian rocks in these townships, although radioactivity is also reported from old copper mines (Wilson, 1960; Mallory, 1953).

4. U, Cu (MR?) [p€] rs, ra, ca. **Copper Belt-Lucky Henry mine**; located in center N2 N2 section 11, T30N, R64W. High radioactivity was noted on the dump of the South Copper Belt mine. At this mine, secondary copper minerals and base metal sulfides were present in Precambrian rocks. Samples contained up to 0.01 percent eU. The highest radioactivity was associated with fracture coatings of calcite, quartz, and secondary copper minerals. The mine workings consisted of approximately 300 feet of inclined shaft (King and Beroni, 1953; Ball, 1907). Another sample from the mine area contained 0.01 percent U_3O_8 (Mallory, 1953).

   A sample of sulfide vein material from an open cut located either on this property or the adjacent Omaha property in section 2 of this township contained 58 ppm uranium and less than 44 ppm thorium. Samples of limestone and schist in the area of these mines contained less than 4 ppm uranium and less than 4 ppm thorium while a granite contained 8 ppm uranium and 68 ppm thorium (Seeland, 1982).

5. U, Cu (MR?, UC?) [p€, MDg] ra, ca. **Greenhope mine**; located in NW section 26, T29N, R65W. A sample of an unspecified rock from the dump at this copper mine contained 0.012 percent eU. The mine was developed along the contact between a Precambrian amphibolite schist and a limestone in the Guernsey Formation (Mississippian-Devonian) (Wilmarth and Johnson, 1950b; Baker and Smith, 1952; and Ball, 1907), but the unit with the radioactivity anomaly was not identified. A sample of copper carbonate bearing limestone in the Guernsey Formation from an open cut in the area contained less than 2 ppm uranium and less than 2 ppm thorium (Seeland, 1982). A reconnaissance examination of the area yielded weak (five times background) anomalous gamma radiation emanating from zones in a Precambrian schist. No uranium minerals were found.

6. U?, Ra, Cu (UC?) [p€] rs. **South Twin Hill**; located in section 17, T28N, R64W. Anomalous radioactivity (11 to 17 times background) and copper carbonate minerals were found by the author in Precambrian biotite gneiss adjacent to the angular unconformity with the overlying Cambrian Flathead Sandstone. The Flathead is only 3 to 5 feet thick here, near its wedge edge. The Flathead does not exhibit mineralization away from the contact.

7. U (BS) [P₱m] ra, rl. **Ohio Oil Company, Waggoner No. 1**; located in section 14, T28N, R63W. In this well, five samples of black shales from the Minnelusa Formation (Permian-Pennsylvanian) contained from 0.005 to 0.019 percent uranium (0.005 to 0.022 percent eU). The samples were taken at depths of 2,230 to 2,323 feet (Love, 1951; Love and others, 1953).

8. rad (BS) [P₱m] rl. **Conoco Oil Company, Parsons No. 1**; located in NW NW NW section 35, T28N, R62W. According to Love's (1951) interpretation of gamma-ray logs, an aggregate total of 40 feet of radioactive black shales occurs at depths between 6,639 and 6,829 feet in the Permian-Pennsylvanian Minnelusa Formation in this well. The thickest shale is 9 feet thick.

   The author of this report interpreted a 1951 gamma-ray log of this well. Seven highly radioactive black shales are present between the depths of 6,636 to 6,830 feet. The top of the most highly radioactive shale is at a depth of 6,696 feet and has a deflection of 2.5 times the full A.P.I. unit scale.

9. rad (BS) [P₱m] rl. **Hanco Oil and Gas, Newman No. 1**; located in NE NE NE section 20, T29N, R60W. According to Love (1951), a total of 64 feet of radioactive black shales occurs at depths from 6,872 to 7,059 feet in the Permian-Pennsylvanian Minnelusa Formation, as determined from gamma-ray logs. An individual shale unit is up to 16 feet thick.

   The author of this report interpreted a 1952 gamma-ray log of this well. Six radioactive black shales are present between the depths of 6,869 to 7,058 feet. Each shale deflection on the log is at least twice the full A.P.I. scale, though no indication of the actual gamma-ray scale is given. The maximum radioactivity is not known.

10. U, V (RX?) [To?] ra, ca. **Spoon Buttes area**; approximately located in section 10, T27N, R60W. A chemical analysis of vertebrate fossils from a gravel [age not stated] at this locality yielded 0.028 percent (280 ppm) uranium (0.027 % eU), and 0.08 percent (800 ppm) vanadium. A sample of sandstone [probably from the Ogallala Formation] from the same area contained only 0.003 percent (30 ppm) uranium, (0.003 percent eU) and 0.05 percent (500 ppm) vanadium (Love, 1953). A sample of white massive sandstone from the Miocene Ogallala Formation in this area contained only 2.5 ppm uranium (Seeland, 1982).

11. U (RX) [To?] mn, rs. **Sheep Creek area**; located in SE SE section 34, T27N, R60W, and NE NE section 3, T26N, R60W. At these sites, the author found yellow uranium minerals that coat carbonaceous material and sand grains in a dark manganiferous sandstone that occurs below pebble conglomerate lenses in the Miocene Ogallala Formation. The individual occurrences are small, but are found over a length of at least one-half mile in the bluffs on the west side of Sheep Creek. Highly radioactive (30 to 60 times background) sandstones are found in this area at the base of the prominent rimrock of the Ogallala Formation and are partly covered by talus.

12. U (RX) [Tc] ca, ra. **Mars Hill (sample 216)**; located in NW NW SW section 15, T23N, R65W (Griffin and Warner, 1982). A sample of a sandstone in the Oligocene Chadron Formation at this site contained only 30 ppm U_3O_8 (determined by chemical analysis), but it contained 90 ppm eU (Griffin and Warner, 1982). This disequilibrium indicates that some uranium has been removed.

References cited

Baker, K.E., and Smith, L.E., 1952, U.S. Atomic Energy Commission Preliminary Reconnaissance Report TEB-258, 1 p.

Ball, S.H., 1907, Copper deposits of the Hartville uplift, Wyoming: U.S. Geological Survey Bulletin 315-B, p. 93-107.

Beckmann, P., 1976, The health hazards of not going nuclear: Boulder, Colorado, Golem Press, 190 p.

Borrowman, S.R., and Rosenbaum, J.B., 1962, Recovery of thorium from a Wyoming ore: U.S. Bureau of Mines Report of Investigations 5917, 8 p.

Chenoweth, W.L., 1991, A summary of uranium production in Wyoming: Wyoming Geological Association 42nd [Annual] Field Conference Guidebook, p. 169-179.

Energy Information Administration, 1990, Uranium industry annual-1989: U.S. Department of Energy Report DOE/EIA 0478(89), p. 5 - 39.

Griffin, J.R., and Warner, A.J., Jr., 1982, National Uranium Resource Evaluation-Cheyenne Quadrangle, Wyoming, Colorado, and Nebraska: U.S. Department of Energy Open-File Report PGJ/F-115(82), 63 p.

Hedrick, J.B., 1985, Thorium: U.S. Bureau of Mines Mineral Commodity Summaries-1985, p. 162-163.

Hedrick, J.B., 1992a, Thorium: U. S. Bureau of Mines Mineral Commodity Summaries-1992, p. 182 - 183.

Hedrick, J.B., 1992b, Thorium: U. S. Bureau of Mines Annual Commodity Report-1992, 5 p.

Houston, R.S., 1979, Introduction to the second uranium issue and some suggestions for prospecting: University of Wyoming Contributions to Geology, v. 17, no. 2, p. 85-88.

Houston, R.S., and Murphy, J.F., 1970, Fossil beach placers in sandstones of Late Cretaceous age in Wyoming and other Rocky Mountain states: Wyoming Geological Association 22nd Annual Field Conference Guidebook, p. 241-247.

King, R.U., and Beroni, E.P., 1953, Regional reconnaissance for uranium and thorium in the United States, Colorado-Wyoming district: U.S. Atomic Energy Commission Report TEI-330, p. 208-213.

Kirk, W.S., 1980, Depleted uranium, *in* Mineral facts and problems: U.S. Bureau of Mines Bulletin 671, p. 997-1003.

List, J.E., and Coleman, R.B., 1979, Current U.S. methods of yellowcake precipitation: Engineering and Mining Journal, v. 180, no. 2, p. 78-82.

Love, J.D., 1951, Uranium content of Middle Pennsylvanian black shales penetrated in wells in southeast Wyoming: U.S. Atomic Energy Commission Report TEM-122, 14 p.

Love, J.D., 1953, Uranium in sandstone-type deposits, Wyoming, reconnaissance, Gas Hills area, Mayoworth area, East Tabernacle Butte area, Marshall area, Split Rock area, and other localities: U.S. Atomic Energy Commission Report TEI-390, p. 63-67.

Love, J.D., Henbest, L.G., and Denson, N.M., 1953, Stratigraphy and paleontology of Paleozoic rocks, Hartville area, eastern Wyoming: U.S. Geological Survey Oil and Gas Investigations Chart OC-44.

Mallory, N.S., 1953, Airborne radiometric survey of Lusk area, Niobrara, Platte, and Goshen Counties, Wyoming: U.S. Atomic Energy Commission Report RME-46, 11 p.

Mickle, D.G., and Mathews, G.W., 1978, Geologic characteristics of environments favorable for uranium deposits: Bendix Field Engineering Company, Report GJBX-67 (78), Grand Junction, Colorado, 78 p.

Peck, Roy, 1969, History of uranium in Wyoming: Mines Magazine, v. 59, no. 1, p. 4-5.

Roseboom, E.H., 1953, Untitled: U.S. Atomic Energy Commission Preliminary Reconnaissance Report USGS PRR D-731, 1 p.

Seeland, David, 1982, National Uranium Resource Evaluation-Torrington Quadrangle, Wyoming and Nebraska: U.S. Department of Energy Open-File Report PGJ/F-67(82), 60 p.

Staatz, M.H., 1983, Geology and description of thorium and rare-earth deposits in the southern Bear Lodge Mountains, northeastern Wyoming: U.S. Geological Survey Professional Paper 1049-D, 52 p.

Stuckless, J.S., 1979, Uranium and thorium concentrations in Precambrian granites as indicators of a uranium province in central Wyoming: University of Wyoming Contributions to Geology, v. 17, no. 2, p. 173-178.

Wilmarth, V.R., and Johnson, D.H., 1950a, Untitled: U.S. Atomic Energy Commission Preliminary Reconnaissance Report USGS RR 63, 1 p.

Wilmarth, V.R., and Johnson, D.H., 1950b, Untitled: U.S. Atomic Energy Commission Preliminary Reconnaissance Report USGS RR 64, 1 p.

Wilson, W.H., 1960, Radioactive mineral deposits of Wyoming: Geological Survey of Wyoming Report of Investigations 7, 41 p.