RADIOACTIVE MINERAL OCCURRENCES IN SUBLETTE COUNTY, WYOMING

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ABSTRACT

Uranium is the primary radioactive mineral of economic value with reported occurrences in Sublette County. Only one occurrence in Sublette County has produced small amounts of uranium. A few types of occurrences (having over 50 parts per million uranium) have been reported. Several uranium occurrences in the county are in Tertiary age rocks in the Green River Basin. Additional uranium occurrences are reported in Precambrian granitic rocks and in the Permian Phosphoria Formation.

Although no unconformity-related uranium occurrences have been reported from Sublette County, the potential for these exists at the unconformity between Tertiary units and underlying Precambrian rocks. This type of occurrence is probably of the greatest potential for future development in Sublette County. The one producing property, though the production was from a Tertiary sandstone, exhibits geologic characteristics similar to unconformity-related occurrences, since the sandstone is adjacent to Precambrian granite. The remaining occurrences reported in the county to date are too low grade and small in reserves to be produced in the future.

INTRODUCTION

Uranium, thorium and potassium-40, and their daughter products are the commonly-occurring radioactive elements and isotopes. The element radium and its isotopes are rare in nature. Isotopes are atoms of an element that have different numbers of neutrons in their nucleus, and therefore have a different atomic mass.

The importance of uranium is based on the ability of uranium to undergo fission, a process in which uranium atoms release energy and particles, and form other atoms. The energy released is used to produce steam for electricity generation.

Thorium, another radioactive element, though never produced in Wyoming or in large amounts anywhere, is used in refractory materials and aerospace alloys.

Radium, which is only found in nature in any abundance in uranium ores, was produced from the Silver Cliff Mine near Lusk, in Niobrara County, in the years just after World War I. Present radium demands, mostly for medicinal purposes, are met by recycling and as a by-product of reactions in nuclear reactors.

Information for this report was gathered and compiled over a period of 12 years through library research, permit examinations and reconnaissance field examinations. In addition to the author, Jon K. King and W. Dan Hausel have compiled information for the report. William L. Chenoweth and J. D. Love have been valuable sources of information throughout this process.

Because uranium has been reported in nearly every time-rock unit in the State, Wyoming is often considered to be an uranium metallogenic province (Stuckless, 1978; Houston, 1979). In the United States, Wyoming ranks second to New Mexico in cumulative uranium production and estimated resources, though ranking first in economic (mineable) reserves Wyoming currently (1997) produces more uranium than any other state, and all of its current production is by in-situ mining methods (Energy Information Administration, 1997). Many uranium minerals have been identified in Wyoming. These are listed in Table 1.

The largest and most important uranium deposits discovered to date in Wyoming occur in Paleocene and Eocene sedimentary rocks in Tertiary basins. Large amounts of uranium have been mined from and are still present in what are called roll-front deposits in the Gas Hills, Shirley Basin, Crooks Gap, Southern Powder River Basin, and Pumpkin Buttes uranium districts

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 in the Black Hills of northeastern Wyoming (Hulett Creek and Carlile uranium districts). 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.

Thorium is abundant at several locations in Wyoming. These locations include large potential thorium resources in Tertiary peralkaline igneous rocks in the southern Bear Lodge Mountains of northeastern Wyoming and in fluvial Cambrian paleoplacers at Bald Mountain in north-central Wyoming. Thorium is also abundant in other Cambrian paleoplacers and in Cretaceous, marine, beach paleoplacer deposits (black sandstones) scattered about central and western Wyoming.

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 potassium-40.

Uranium deposits and occurrences are of many different types, based upon their method of formation. The classification scheme used in this report is modified by the author from Mickle and Mathews (1979), and is presented in Table 2. This classification is based on type of host rock (sedimentary, igneous, metamorphic) and suspected origin. Unconformity-related occurrences are separated because they are found in Wyoming in all types of host rocks. Other occurrences are unclassified, because the characteristics of classes often overlap and the differences between classes are gradational. Other occurrences are classified as unknown due to insufficient data. Because radioactive sedimentary occurrences have been intensively studied in Wyoming, the classification system reflects this with more and better defined classes of occurrences in sedimentary rocks. Redox occurrences comprise by far the most common class in Wyoming, and all of the large mines in the state produced uranium from deposits of this type. Because most uranium production outside of the United States is from other classes of deposits, particularly unconformity-related and the Precambrian quartz-pebble conglomerate deposits, information on these classes are also presented.

USES OF URANIUM AND THORIUM

Uranium is used as a fuel in nuclear power plants for the production of electricity. Minor uses include the manufacture of detonators for nuclear weapons, armor-piercing projectiles, reactor shielding, chemical catalysts, and some counterweights (Kirk, 1980).

Yellowcake (U_3O_8) from Wyoming's mills is purchased by electric utilities. 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 to 3 percent for use in nuclear power plants. Nuclear weapons require more than 90 percent ^{235}U (Beckmann, 1976). The uranium remaining after the fissionable isotope has been removed is called depleted uranium metal and is used in armor-piercing projectiles, counterweights, chemical catalysts, reactor shielding (Kirk, 1980) and, recently, in armor plating itself (Bob Peck, personal communication, 1988).

Thorium is used in refractory materials (57 percent), the light-producing material in gas lantern mantles (17 percent), aerospace alloys (10 percent), electronic components, and in chemical catalysts. 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. This gives 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. The development of breeder reactors which use thorium for fuel, and experimental applications using thorium in fuel rods and core retention beds in conventional reactors in order to prevent core meltdown would require increased production (Hedrick1985, 1994).

URANIUM IN SUBLETTE COUNTY

Sublette County has not been prospected as actively for uranium as other areas in Wyoming. The occurrences of radioactive mineralization in the county are few and relatively small (see Figure 2 for locations). Tertiary sedimentary rocks in the Wasatch Formation and other Eocene rocks in the Green River Basin are marginally favorable host rocks for uranium mineralization and do contain radioactive occurrences. Rocks of similar age have produced uranium in Sweetwater and Fremont Counties. However, these Eocene rocks in Sublette County tend to be finer-grained with less well developed fluvial systems (Lease and others, 1977). The unconformity between Tertiary sedimentary rocks and Precambrian rocks along the southeast margin of the Wind River Range is also a favorable site for uranium mineralization (see for example the Pard mine; occurrence #20). Enrichment of uranium and other metals is present in the Permian Phosphoria Formation in the Overthrust Belt along the western edge of the county, and in the Gros Ventre Range in the northwestern part of the County. See the overview of Lincoln County for more information regarding uranium in the Phosphoria Formation (Harris and others, 1993).

Exploration in the Precambrian terrains within the Wind River Range has been slowed by the rugged topography and wilderness designations. However, most of the bedrock is high-grade metamorphic rocks that probably do not contain much uranium. The fact that only one uranium occurrence is present in these rocks (occurrence #1) supports this conclusion. In contrast with this minimal uranium content, the Fremont Butte area contains thorium and rare-earth enrichment that seems to be unique (occurrences #12-#13).

Only one property in Sublette County has produced any uranium ore, the Pard mine (occurrence #20).

RADIOACTIVE MINERAL OCCURRENCES IN SUBLETTE COUNTY
(numbers refer to the index map, Figure 2)

1 U(UN,PC) **Longshot #4 claim--Union Peak**; approximately N1/2 sec. 2, T.40N., R.108W, on the east flank of Union Peak. (Norton, 1955); mineral noted and radiometric survey. A yellow, radioactive mineral was associated with a black mineral as fracture coatings in a Precambrian granite-gneiss or pegmatite. The granitic rock was about 10 times more radioactive than background, (Norton, 1955;) The yellow mineral might have been uranophane (Gruner and others, 1956).

2 U(MP,Pp) **Tosi Creek**; SE 1/4 sec. 17, T.39N., R.110W. (Sheldon and others, 1953); chemical and radiometric analysis. In the Phosphoria Formation, a single sample of phosphorite about 2.3 feet thick from this stratigraphic section (28.6 % P2O5) contained 0.010 percent uranium (0.008 % eU), while six samples of phosphate rock all contained less than 0.005 percent uranium (Sheldon and others, 1953; Sheldon, 1963).

3 U(MP,Pp) **West Tosi Creek area** (sample #319); approximately center W1/2 sec. 15, T.39N., R.111W. (Simons and others, 1981); chemical analysis. Simons and others (1988) report 68 ppm uranium in a sample of phosphorite from the Phosphoria Formation.

4 U(MP,Pp) **Triangle Peak area** (sample #290); approximately center sec. 2, T.39N., R.112W., unsurveyed. Chemical analysis. Simons and others (1981) report 87 ppm uranium in a sample of phosphorite from the Phosphoria Formation.

5 U(MP,Pp) **Wilderness boundary** approximately N1/4 sec. 13-14 line, T.39N., R.112W., unsurveyed. Simons and others (1981) report 72 and 95 ppm uranium in two samples of phosphorite from the Phosphoria Formation.

6 U(MP,Pp) **Dell Creek** (sample #306); approximately N1/4 sec. 20-21 lime, T.39N., R.112W., unsurveyed (Simons and others, 1981); analysis. Simons and others (1981) report 71 ppm uranium in a sample of phosphorite from the Phosphoria Formation.

7 U(MP,Pp) **Bartlett Creek**; SE 1/4 sec. 23, T.38N., R.111W. (Sheldon and others, 1953); chemical and radiometric analyses. In the Phosphoria Formation, two samples of phosphorite from two units, each about 1 foot thick contained 20.5 and 26.5 percent P2O5, and 0.006 and 0.007 percent uranium (0.006 and 0.008 % eU), respectively (Sheldon, 1963; Sheldon and others, 1953; *TEI-363*).

8 U(UN,Thb) **unnamed--Jack Creek area**; NE 1/4 NW 1/4 sec. 28, T.38N., R.113W. (Love, 1964); chemical and radiometric analyses. A sample of carbonaceous shale in the type section of the Hoback Formation (Paleocene) contained 0.012 percent uranium (0.011 % eU) (Love, 1964).

9 U?(UN) **unnamed "mine"**; approximately sec. 26-27 line, T.37N., R.107W. (Osterwald and Dean, 1958); unverified. A uranium mine is plotted at this location by Osterwald and Dean (1958). An occurrence is not even known in this area, so the site is probably mislocated due to a typographic error. The site is near Fremont Peak, and therefore might be a mislocation of the Fremont Butte localities in T.32N., R.107W. (12, 13).

10 U?(UN) **Fremont Ridge**; approximately sec. 2, T.34N., R.109W. (Osterwald and Dean, 1958; Elevatorski, 1976); unverified occurrence. A uranium occurrence or sample containing at least 0.1 percent uranium is plotted by Osterwald and Dean (1958), while Elevatorski (1976), probably relying on their plate, reported an occurrence. This site is on Pleistocene glacial moraine deposits, and a mineral occurrence or above background radioactivity was not found by Gebhardt and others (1982). The original location by Osterwald and Dean (1958) might have been a mislocation of Fremont Butte.

11 Th(UN,PCgr) **unnamed** (sample 142); SW 1/4 SE 1/4 sec.19, T.33N., R.108W. (Gebhardt and others, 1982); radiometric analysis. A sample of Precambrian granite from this site contained 212 ppm eTh with 6 ppm cU3O8 (5 ppm eU) (Gebhardt and others, 1982).

12 Th,U?(IM?,PCgr) **John Paul #5 claim--Fremont Butte area**; N1/2 SE 1/4 sec. 17, T.32N., R.107W. (Love, 1954a); radiometric survey, and chemical and radiometric analysis.

A Precambrian, coarse-grained, brown granite on the property contained an abundant black crystalline mineral. Radioactivity was up to about 30 times background over an area reported as 10 foot [square ?] (Love, 1954a). A highly radioactive granite sample contained 0.002 percent uranium (0.015 % eU) (Love, 1954a). Two months later on the claim, though mislocated in section 16, a test hole had been drilled Maximum radioactivity was less than the maximum surface radioactivity (7 vs. 10 times background) in the hole (Meehan-Papulak, 1954a). Gebhardt and others (1982) report that a sample of Precambrian granite from the center of section 17 contained 366 ppm eTh with only 13 ppm cU3O8 (4 ppm eU).

13 Th?,REE,U?(UN,PCsc,PCgr) **Fremont Butte claims**; NW 1/4 sec. 21, T.32N., R.107W. (Love, 1954b); radiometric survey, and chemical and radiometric analyses. Iron-stained fractures along the contact of a Precambrian mica schist and foliated granite contain a greenish-yellow, non-fluorescent mineral, and a greenish-yellow fluorescent mineral. The contact trends about N60°E with a dip of 80°NW. Radioactivity up to about 50 times background occurs along the contact. A sample of mica schist from the most radioactive zone in a pit (Love, 1954b) contained 0.002 percent uranium (0.030% eU) with greater than 0.1 percent each cerium, lanthanum and neodymium (a, 1954). A vertical, 1-2 foot wide, N50°W trending, fine-grained granite dike in the granite was located 200 yards southeast of the sampled pit. This dike was about 30 time more radioactive than background (Love, 1954b). The dike was later mislocated, though radioactivity was reported as 15 times background and a sample contained 0.04 percent eU3O8 (Meehan-Papulak, 1954b).

14 U(MP,Pp) **Middle Piney Lake**; NE 1/4 NW 1/4 sec. 8, T.30N., R115W. (Sheldon and others, 1953); chemical and radiometric analyses. In the Phosphoria Formation, six samples of phosphorite from 6 units (20.0 to 34.4 % P2O5; 0.4 to 1.5 feet thick) contained 0.004 to 0.011 percent uranium (0.006 to 0.019 % eU) with two high phosphate rock units (15.1 and 18.7 % P2O5; 5.0 and 0.4 feet thick) containing 0.005 percent uranium (0.009 and 0.012 % eU).(Sheldon and others, 1953, Sheldon, 1963). In later

sampling of the same area, two samples of pellet phosphorite from the Meade Peak Member of the Phosphoria Formation contained 0.004 and 0.012 percent uranium (0.006 and 0.011 % eU) with 28.9 and 25.0 percent P2O5, 2.92 and 3.10 percent F, and minor rare earth element enrichment (less than 100 ppm) (Gulbrandsen, 1966).

15 U(UN,Tgf) **Green--New Fork Rivers confluence** (sample 159); NE 1/4 NW 1/4 sec. 14, T.30N., R.110W. (Gebhardt and others, 1982); chemical and radiometric analysis. A sample of shaly mudstone from the Fontenelle member of the Green River Formation that contained no visible uranium mineralization assayed 289 ppm cU3O8 (178 ppm eU) (Gebhardt and others, 1982).

16 Th(UN,PCgr) **unnamed** (sample 75); NW 1/4 NW 1/4 sec. 14, T.31N., R.103W. (Gebhardt and other, 1982); radiometric analysis. A sample of Precambrian granite contained 121 ppm eTh and 5 ppm eU (Gebhardt and others, 1982).

17 Th,U(UN,PCgr) **Prospect Mountains** (samples 35-39); NW 1/4 NW 1/4 and NE 1/4 SE 1/4 sec. 21, and SW 1/4 SW 1/4 and SW 1/4 NW 1/4 sec. 22, T.29N., R.103W. (Gebhardt and others, 1982); chemical and radiometric analyses. Three samples of Precambrian granite contained 103 to 250 ppm eTh, with 7 to 37 ppm cU3O8 (4 to 29 ppm eU). Two other samples of Precambrian granite, only assayed for uranium, contained 86 and 63 ppm cU3O8 (Gebhardt and others, 1982).

18 U(UN,Tsp) **unnamed** (sample no. 16570); center sec. 26, T.29N., R.103W. (Lease and others, 1977); chemical and radiometric analysis. A sample of the South Pass Formation contained 83 ppm cU3O8 (191 ppm eU3O8) (Lease and others, 1977). This is in the vicinity of the Pard mine (20).

19 U(UN,Tw?) **unnamed** (sample no. 16128); center sec 27, T.29N., R.103W. (Lease and others, 1977); chemical analysis-unverified. A sample of Wasatch Formation (?) from this site reportedly contained only 8.3 ppm eU as shown in appendix A. Yet a sample with the same number in appendix B of the same publication contained 326.5 ppm eU (392 ppm cU3O8; 385 ppm eU3O8) (Lease and others, 1977).

20 U,Th(RX?,Tu,PCgr?) **Pard 1-4 mine**; property--sec. 34-35 line; mine--center W1/2W1/2 sec. 35, T.29N., R.103W. [Wyoming Ad Valorem (1966) and Elevatorski (1976) mislocate this mine 1 township to the south]. (Gebhardt and others, 1982); mine-surface. The Pard 1-4 mines reported production for two years. In 1959, South Pass Mining, Inc., produced about 309 tons of uranium ore (AEC) and, in 1966, Federal American Partners produced 117 tons of ore (Ad Valorem). Meta-autunite is reported in a weathered, limonite-stained Eocene sand, gravel and conglomerate derived from adjacent Precambrian granite. Four samples were taken on the property. A sample of conglomerate contained 883 ppm cU3O8 (14 ppm eU) and 550 ppm eTh. Two samples of Precambrian granite contained 1581 and 13 ppm cU3O8 (577 and 6 ppm eU) with 20 and 30 ppm eTh. A sample reported to be an Eocene sand and gravel was identified by a petrologist as a granodiorite that contained 2 percent allanite with epidote rims (Gebhardt and others, 1982; see also Lease and others, 1977).

21 rad(UN,Twr) **unnamed**; approximately NE 1/4 sec. 25, T.28N., R.105W. (after Winterhalder, 1953; Love and others, 1979); radiometric survey. A north-south trending, vertical fault breccia in the White River Formation had radioactivity of 5 to 10 times background, but contained no visible uranium minerals. The 1/2 to 1 foot-wide breccia zone was composed of fragments of tuffaceous White River Formation, and contained botryoidal chalcedony and black veining (manganese oxide ?) Winterhalder (1953) places the locality in sec. 24(?). But his description of access to the locality, with the map of Love and others (1979), places this locality in sec. 25.

22 U(UN,Tw) **Sandy Gal no. 2 claim**; sec. 29, T.27N., R103W. (); radiometric survey, and analysis. Despite the absence of visible radioactive minerals, radioactivity was 10 to 30 times background on pebble to boulder sized remnants of a hard silica and carbonate cemented sandstone. This sandstone is in the Eocene Wasatch Formation (Holmquist, 1955). Bromley (1957) reports an assay from this property of greater than 0.1 percent U3O8.

23 U(MP,Pp) **Deadline Ridge**; sec. 8, T.27N., R.114W. (after Sheldon and others, 1953; Lake Mountain 7-1/2 minute Quadrangle map); rock and radioactivity samples. Six samples of phosphorite and phosphate rock (12.6 to 25.3 % P2O5) from the Phosphoria Formation in this stratigraphic section contained 0.005 to 0.009 percent chemical uranium (0.006 to 0.012 % eU), with the six units being 0.5 to 3.5 feet-thick (Sheldon, 1963; Sheldon and others, 1953-*378*).

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

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 $K_2(UO_2)_2(AsO_4)_2 \cdot 8H_2O$ 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 $NaCa_3(UO_2)_2(CO_3)_3SO_4F \cdot 10H_2O$ evaporites, 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

Table 1 (continued).

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.

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[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.

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	
RX	Redox[1]	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	Moonstone Formation, central Wyoming

OCCURRENCES IN METAMORPHIC ROCKS

CM	Contact metamorphic	uncertain
AN	Anatectic	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)

UNCONFORMITY RELATED

UC	Unconformity Related	Arrowhead prospect (Fremont County)

UNKNOWN

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.

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

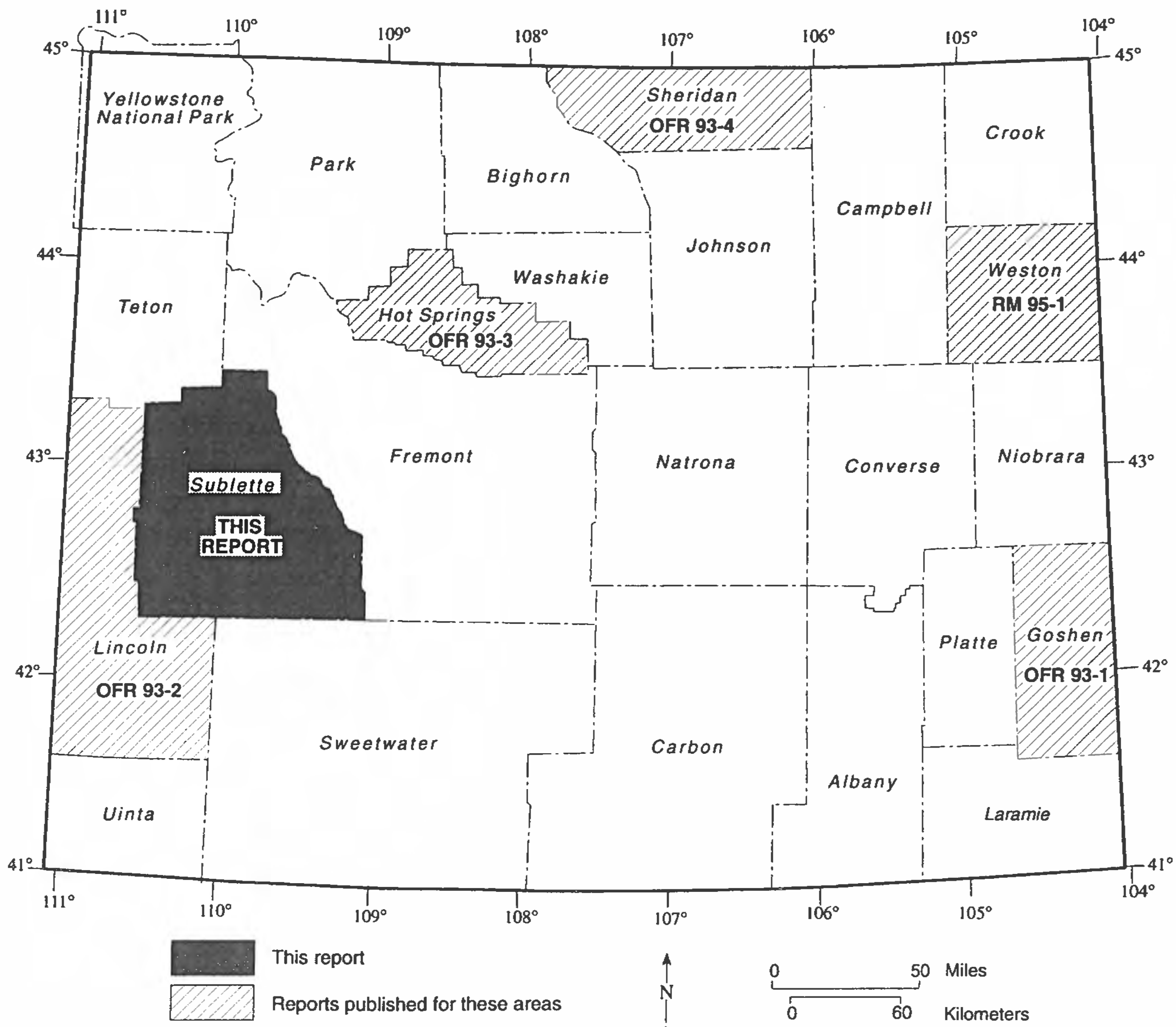
Table 4. Key to formation names or rock types used in the descriptions of the occurrences of radioactive elements in Sublette County, Wyoming.

Formation name	Symbol
CENOZOIC	
TERTIARY	
Eocene Green River Formation	Tg
Eocene Wasatch Formation	Tw
PALEOZOIC	
Permian Phosphoria Formation	Pp
PRECAMBRIAN	
Precambrian GRANITE	pCG

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.



Yellowstone National Park
Park
Bighorn
Sheridan
OFR 93-4
Johnson
Campbell
Crook
Weston
RM 95-1
Washakie
Hot Springs
OFR 93-3
Teton
Fremont
Natrona
Converse
Niobrara
Sublette
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Lincoln
OFR 93-2
Platte
Goshen
OFR 93-1
Sweetwater
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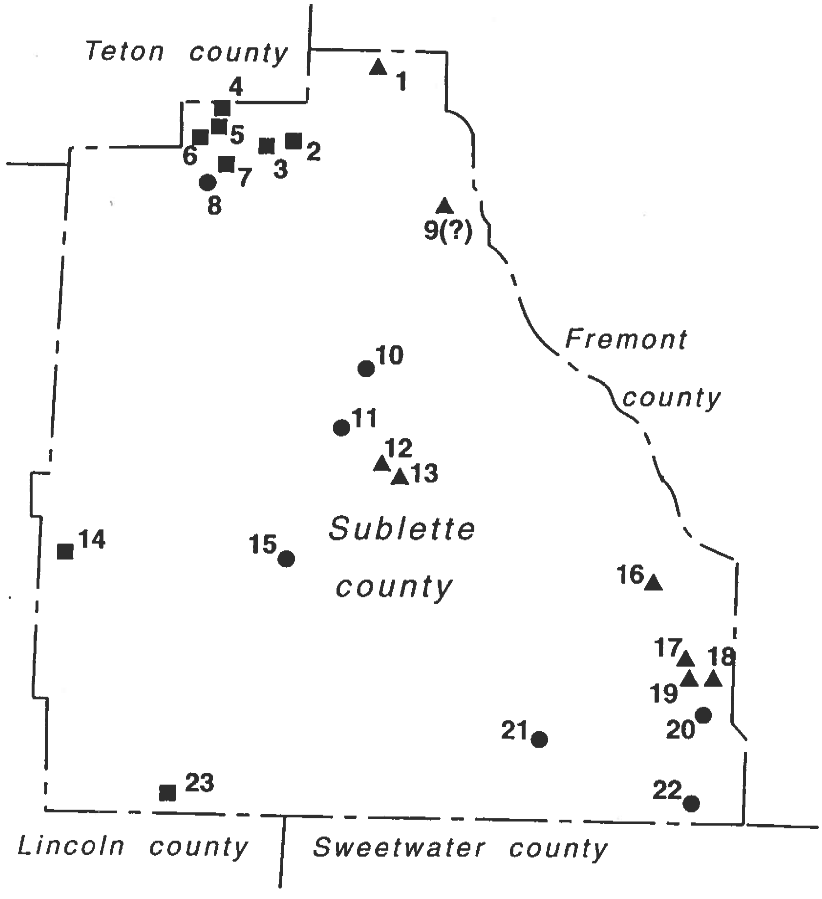

● Occurrences in Tertiary rocks of the Green river Basin

■ Occurrences in the Permian Phosphoria Formation

▲ Occurrences in Precambrian rocks