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RARE EARTH ELEMENTS AND YTTRIUM IN WYOMING

by

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This report has not been reviewed for conformity with the editorial standards of the Geological Survey of Wyoming.

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Introduction

Rare earth elements (REE) are also known as the lanthanides. Because these 15 elements and the element yttrium often occur together in nature they are discussed as a unit. These elements are listed in Table 1. As shown in Table 1, the rare earth elements can be divided into two groups: the cerium group or light rare earth elements (LREE), and the yttrium group or heavy rare earth elements (HREE). The light rare earth elements, and yttrium and terbium have commercial applications. The exception to this generalization is the element promethium which is almost nonexisting in nature. Commercial applications of heavy rare earth elements are not common (Hedrick, 1985).

Minerals that contain rare earth elements and are reported in Wyoming are listed in Table 2. The composition of these minerals is variable and radioactive elements in the minerals often destroy the physical structure of the minerals creating metamict minerals. This means the exact mineralogy of the rare earth-bearing minerals is often uncertain.

Minerals containing rare earth elements are present in greater abundances in alkaline igneous rocks, carbonatites, pegmatites, veins, and breccias of uncertain origin, and in both fossil and Quaternary placers. Production of rare earth-bearing minerals has come from (1) Quaternary stream placers (Malaysia, Thailand, Idaho), (2) Quaternary beach placers, (Australia, India, Sri Lanka, Brazil, Georgia, Florida), (3) veins of uncertain origin (South Africa), (4) carbonatites (USSR, China, Burundi, California), and (5) alkaline igneous rocks (USSR -- might be related to carbonatites) (After Hedrick, 1985; Neary and Highley, 1984; Roberts and Hudson, 1983, 1984; Youles, 1984).

Table 1. Chemical symbols for rare earth elements and yttrium.

Element	Chemical symbol
cerium group - light rare earth elements (LREE)	
lanthanum	La
cerium	Ce
praseodymium	Pr
neodymium	Nd
promethium	Pm
samarium	Sm
europium	Eu
gadolinium	Gd
yttrium group - yttrium and heavy rare earth elements (HREE)	
yttrium	Y
terbium	Tb
dysprosium	Dy
holmium	Ho
erbium	Er
thulium	Tm
ytterbium	Yb
lutetium	Lu

Table 2. Minerals reported in Wyoming that contain rare earth elements and(or) yttrium.

minerals in which rare earths and yttrium are basic constituents

Mineral	Chemical formula[1]	Common occurrence[2]
allanite	$\mathrm{(Ce,Ca,Y)_2(Al,Fe_2)_3(SiO_4)_3OH}$	carbonatites, veins
bastnaesite	$\mathrm{(Ce,La)(CO_3)F}$	carbonatites
brockite	$\mathrm{(Ca,Th,Ce)PO_4 \cdot H_2O}$	carbonatites
burbankite	$\mathrm{(Na,Ca,Sr,Ba,Ce)_6(CO_3)_5}$	trona, phosphorite, carbonatites
calkinsite	$\mathrm{(Ce,La)_2(CO_3)_3 \cdot H_2O}$	trona, phosphorite, carbonatites
ewaldite	$\mathrm{Ba(Ca,Y,Na,K)(CO_3)_2}$	trona, phosphorite
euxenite	$\mathrm{(Y,Ce,U,Th,Ca)(Nb,Ta,Ti)_2O_6}$	pegmatites
fergusonite	$\mathrm{(Y,Er,Ce,Fe)(Nb,Ta,Ti)O_4}$	pegmatites
mckelveyite	$\mathrm{Na_2Ba_4(Y,Ca,Sr,U)_3(CO_3)_9 \cdot 5H_2O}$	trona, phosphorite
monazite	$\mathrm{(Ce,La)PO_4}$	placers, carbonatites, veins
samarskite	$\mathrm{(Y,Fe,Ca,U,Ce,Th)(Nb,Ta,Ti)_2(O,OH)_6}$	pegmatites
xenotime	$\mathrm{YPO_4}$	placers, veins(?)

minerals in which rare earths and yttrium are relatively abundant accessory constituents, but are not required to form the mineral

Mineral	Chemical formula[1]	Common occurrence[2]
apatite	$\mathrm{Ca_5(PO_4)_3(F,OH,Cl)_3}$	carbonatites, phosphorite
fluorite	$\mathrm{CaF_2}$	carbonatites, veins
pyrochlore-microlite	$\mathrm{(Na,Ca)_2(Nb,Ta,Ti)O_6(OH,F)}$	placers, pegmatites(?)
columbite-tantalite	$\mathrm{(Fe,U,Ca)(Nb,Ta)O_4}$	pegmatites
zircon	$\mathrm{ZrSiO_4}$	placers

[1] Clark (1984); Felsche and Herrman (1978).
[2] Hedrick (1985); Neary and Highley (1984).

Rare earth elements (REE) and yttrium have a myriad of uses and many of these elements go into "high-tech" components like the new higher temperature superconductive materials (Table 3). The manufacture of synthetic zeolites, used as catalysts in petroleum distillation, consumes 59 percent of all rare earths and yttrium. In order of consumption, REE and yttrium are also used in metal alloys (23 percent), glass and ceramics (15 percent), and in electronic components, other catalysts and diverse applications (three percent) (Hedrick, 1986). Because of the increasing use of high technology materials, the demand for rare earth elements and yttrium was increasing at a rate of about ten percent per year from 1982 through 1985. The trend in this increased demand is away from consumption of mixtures of REE and towards using the individual elements (Hedrick, 1985, 1986). For example, lanthanum and yttrium are used in superconductive materials that perform at higher temperatures than presently used materials. This new application should increase the demand for individual rare earth elements.

Table 3. Uses of rare earth elements and yttrium (Hedrick, 1985; Neary and Highley 1984).

Metal alloys...iron alloys (structural steel), super alloys (corrosion resistant, impact resistant, hydrogen-cracking resistant, and(or) heat resistant), non-ferrous alloys, lighter flints.

Glass and ceramics...polishing compounds, decolorizers, colorizers, color stabilizers, light absorbers, fiber optics, lasers, high temperature refractories, metal substitutes.

Electronic components...permanent magnets, lights, capacitors, phosphors (color televisions, x-ray intensifying screens, and data displays), carbon arc lamps, superconductors, semiconductors, computer memories and substrates, radar guidance systems.

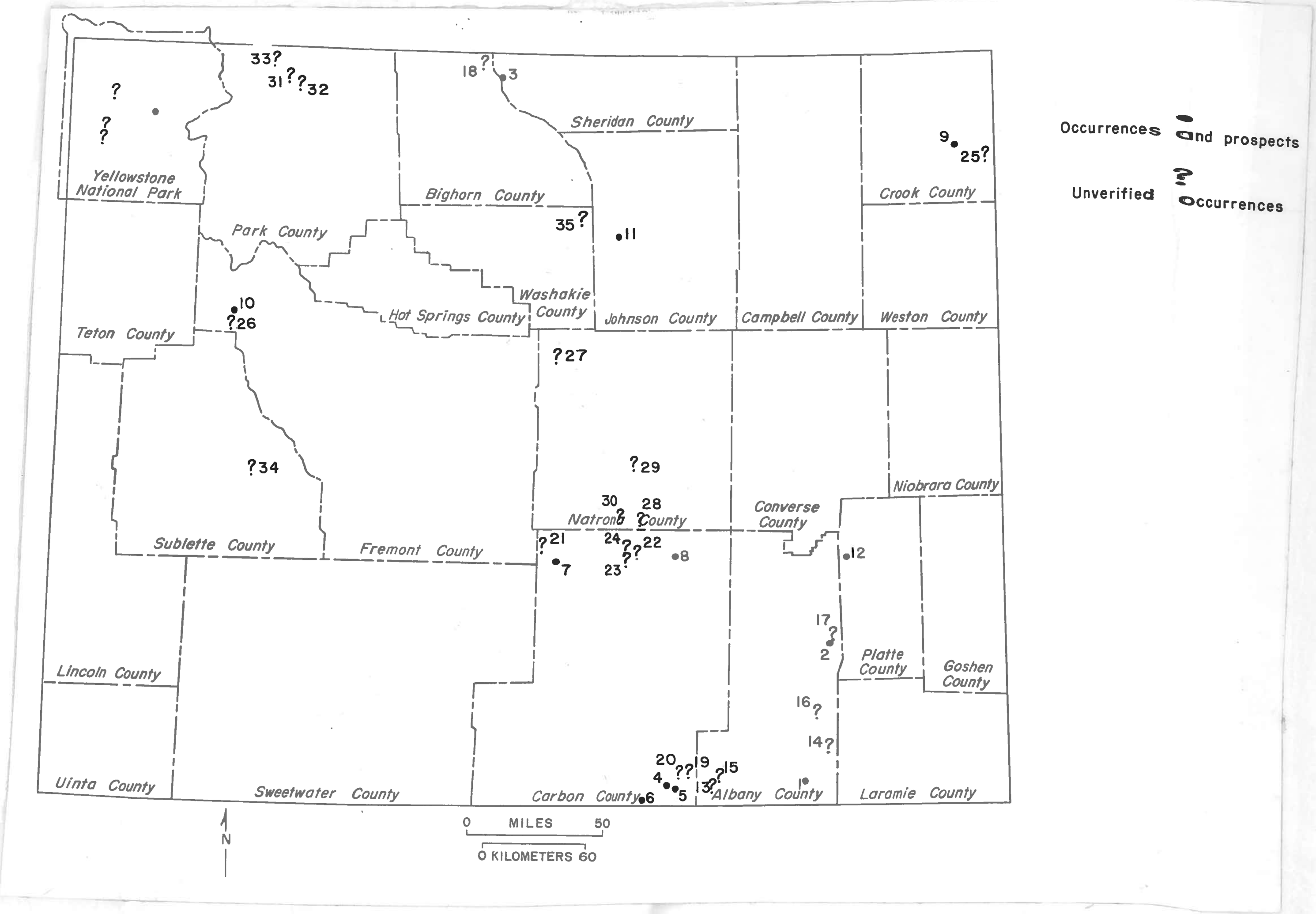
Catalysts...petroleum, ammonia, gas sweetening, auto pollution control.

Other...Nuclear reactor components, hydrogen fuel storage.

Rare earth elements are being produced in the United States at two locations. Bastnaesite is mined by Molycorp at Mountain Pass, California, and accounts for most domestic production. Monazite is recovered with ilmenite and zircon from Quaternary black sand beach deposits in Florida. Rare earths, yttrium, and thorium are co-products from the processing of monazite (Hedrick, 1986).

Production of rare earths and yttrium in Wyoming was almost entirely from the Platt mine. Ten thousand pounds of a rare earth-bearing mineral was shipped from the Platt mine in Carbon County (page 13). Most of the production from this mine was for uranium (Wyoming State Board of Equalization, 1957-1958).

Many occurrences of minerals containing rare earth elements are present in Wyoming. (Figures 1, 2, 3, and 4). Additional sites shown on these figures contain abundant rare earths determined from chemical analyses, but rare earth-bearing minerals have not been reported. Potential economic sources of rare earths are (1) Tertiary veins and disseminations in igneous rocks related to carbonatites, (2) Mesozoic black sandstone beach placers, (3) Cambrian fluvial placers, and (4) Precambrian metacarbonate rocks of uncertain origin. Other mineral occurrences are in veins(?) and pegmatites in Precambrian metamorphic rocks, syenite in the Laramie Anorthosite complex, thermal areas in Yellowstone National Park, and in trona in the Eocene lacustrine Green River Formation. Even though rare earth-bearing minerals have not been identified, rare earth elements are at least locally abundant in uraniferous phosphatic zones in Eocene lacustrine rocks along the Beaver Divide and on Lysite Mountain, in uraniferous phosphatic zones in the Eocene lacustrine Green River Formation, and in phosphorite in the Permian Phosphoria Formation. The rare earth elements in the phosphorite and trona might be recovered as by-products from mining and processing. The occurrences in (1) Mesozoic black sandstones, (2) Eocene lacustrine rocks (trona and uraniferous phosphatic rocks), and (3) in phosphorite in the Phosphoria Formation are discussed in separate sections following the other prospects, occurrences, and sites of rare earth enrichment.



1. Tie Siding area
2. Red Mountain Syenite
3. Bald Mountain monazite deposit
4. Platt pegmatite
5. Big Creek pegmatite area
6. Blackhall Mountain
7. Ferris Mountains
8. Bates Hole area
9. Bear Lodge Mountains
10. Warm Springs Creek placer
11. Beaver Creek allanite prospect
12. Richard Riley claims
13. Mary Values prospect
14. Middle Lodgepole Creek area
15. Albany station area
16. Laramie Range
17. Elmers Rock area
18. Rainbow claims
20. Hubbell Ditch area
21. Emigrant Trail thrust area
22. Omega claims
23. Poe Mountain no. 2
24. Pyramid Peak
25. Mineral Hill
26. Uranium claim no. 1
27. Allie claims
28. Little Basin area
29. Ranger no. 1 claim
30. Wood Lode claims
31. Dilworth Bench
32. Bald Ridge(?)
33. Sawtooth Lake area(?)
34. Fremont Butte area
35. Prospect Creek area

Figure 1. Location of rare earth prospects and occurrences other than those in Mesozoic black sandstone, Eocene lacustrine rocks, and the Permian Phosphoria Formation.

Rare earth analyses up to only 200 ppm have been reported form Wyoming coal ash (Glass, 1975; Glass and Roberts, 1984: Glass and Roberts, 1986), indicating that rare earth elements are not abundant in organic sediments. Although no studies have been performed regarding the economics of extracting rare earth elements from coal ash, it appears that such a study may not be worthwhile since coal contains less rare earth concentrations than average crustal rock (Felsche and Hernman, 1978).

Prospects and occurrences

(exclusive of Mesozoic beach placers, Eocene lacustrine rocks,
and Permian phosphorite localities)

The Mesozoic beach placers, Eocene lacustrine rocks, and Permian phosphorite occurrences are discussed in specific sections following the information on other prospects, occurrences, and unverified occurrences.

Albany County

Tie Siding area T.12N., R.71W.; T.12N., R.72W.; and T.13N., R.72W.

Many pegmatites are present in the Precambrian Sherman Granite near Tie Siding. Crytolite (impure zircon) and pyrochlore, both containing minor yttrium, are reported in one pegmatite in this area (Smith, 1954). Smith's (1954) map implies this pegmatite is in the west half of the southwest quarter of Section 29 (T.13N., R.72W.). During an examination in 1978 by Griffin and Warner (1982), a trace of allanite was noted in the Holiday Place pegmatite on Dale Creek in Section 32 (T.13N., R.71W.). This pegmatite contained more than 500 ppm lanthanum and more than 200 ppm yttrium. Rare earth-bearing minerals were not noted at any other pegmatites during this examination, but high radioactivity reportedly was associated with biotite. Given the association of rare earth elements and radioactive elements, rare earths might be present in fine grained minerals that are obscured by the dark biotite. Three other pegmatites sampled during the 1978 examination contained more rare earths than others in the area. These pegmatites contained (1) over 200 ppm yttrium, but only 50 ppm lanthanum (SW1/4NE1/4 sec. 6, T.12N., R.71W.), (2) 500 ppm lanthanum and 150 ppm yttrium (SE1/4SW1/4 sec. 2, T.12N., R.72W.), and (3) 1,000 ppm lanthanum and 200 ppm yttrium (SE1/4SE1/4NW1/4 sec. 6, T.12N., R.72W.) (Griffin and Warner, 1982).

Red Mountain Syenite roughly E1/2 T.22N., R.71W.

Carl Anderson (personal communication, 1987) a doctoral candidate in the Department of Geology and Geophysics at the University of Wyoming reports that one minor phase of the Red Mountain Syenite contains more than one percent allanite. The syenite is part of the Precambrian Laramie Anorthosite Complex. From his preliminary mapping and point-counting, Anderson has determined that an olivine-absent but clinopyroxene-bearing phase of the syenite contains between 1.5 and 3.6 percent allanite. The allanite is both pristine and metamict. This clinopyroxene phase makes up less than five percent of the syenite, and at present this phase has not been completely mapped. To date allanite is most abundant in the north half of the center of Section 36 (Anderson, personal communication, 1987).

Big Horn and Sheridan Counties

Bald Mountain monazite deposit

S1/2 sec. 21, sec. 22, W1/2 sec. 23, S1/2 sec. 30, and sec. 31, T.56N., R.91W.

The locations given encompass sites where samples of the basal Middle Cambrian Flathead Formation (Deadwood conglomerate) contain two or more pounds of monazite per ton of rock (after Kline and Winkel, 1952; McKinney and Horst, 1953a, 1953b). The exact extent of these monazite-rich placers in the basal Flathead Formation is not known. Monazite-rich rocks might be present between sample locations, and extend in the subsurface under thicker overburden to the east and north of the sample sites. Extensive areas of monazite-rich rock might underlie Bald Mountain and Rooster Knob and possibly Burnt Mountain. This paleoplacer also contains gold and ilmenite. Because Precambrian tantalum-columbium-bearing mafic dikes are present in the area (Harris, 1987), the paleoplacer might contain these elements as well. Wilson (1951) mentions that Quaternary monazite placers are present in the area.

In the Bald Mountain area, the basal Flathead Formation is a poorly-sorted arkosic sandstone that contains irregularly distributed, lenticular conglomerates. Low angle bedding is quite visible in these rocks. The basal Flathead Formation is heterogeneous; it has (1) variable textural maturity, (2) varies in color from pale buff to brown and deep red, (3) is poorly to well cemented, and (4) is from 10 to 50 feet thick. The conglomerates contain subrounded quartz clasts that are usually pebble-sized and that appear to be derived from quartz veins. These clasts are in a matrix of sand-sized, angular to subangular feldspar grains with minor sand-sized, rounded to subangular quartz grains. The arkosic sandstones enveloping the conglomerates are very similar to the matrix material, except that the grain size in the enveloping sandstones may become coarser higher in the stratigraphic section (after Wilson, 1951; Cardinal, 1958; McKinney and Horst, 1953a; Middleton, 1980).

Regionally, the source of the arkosic and conglomeratic material was probably to the east. Recently, the unit has been interpreted to be the result of fluvial deposition in a braided stream system during major flooding episodes (Middleton, 1980). The basal Flathead Formation was previously interpreted as being beach or nearshore marine deposits (Lochman-Balk, 1971). Preliminary, dip-corrected elevations of the conglomerates and elongation directions of the conglomerates, from data in McKinney and Horst (1953b) and from the Bald Mountain 7 1/2-minute Quadrangle map, imply local transport directions in a stream system that flowed to the southwest and southeast. This is probably a local perturbation in the regional westward transport direction in a multitude of streams.

In detail, zones of monazite enrichment within the basal Flathead Formation are not specifically confined to any lithology or horizon. The best clue to the monazite-rich rocks is their radioactivity. Monazite is usually most abundant in poorly cemented, iron stained, irregularly distributed, lenticular, 2.5 to 10 feet thick conglomerates that are on or near the underlying red or gray Precambrian granitic rock (Wilson, 1951; McKinney and Horst, 1953a). Isopach, elevation contour, and monazite-content contour maps of zones of monazite enrichment, based on the data in McKinney and Horst (1953b) and from the Bald Mountain 7$^{1}/_{2}$-minute Quadrangle map, support the irregular distribution and lenticular nature of the conglomerates as first noted by Wilson (1951). These data also indicate that these conglomerates might be stacked upon each other. Wilson (1951) described the monazite concentrations as being pepper-sized, reddish-brown monazite grains at various locations within conglomerates cemented by limonite. McKinney and Horst (1953a) thought most monazite was restricted to poorly cemented, deep red or yellowish red conglomerates that were overlain by well cemented sandstones and finer grained conglomerates. However, monazite concentrations greater than five pounds per ton of rock were shown by Kline and Winkel (1952) to be present in these "barren" overlying sandstones and well-cemented conglomerates. Rapid lateral changes are further demonstrated by samples from adjacent drill holes and test pits in the same horizon that do not contain anywhere near the same amounts of monazite (compare Kline and Winkel, 1952, with McKinney and Horst, 1953a, 1953b).

McKinney and Horst (1953a, 1953b) had apparently assumed a sheet-like configuration for a zone of monazite enrichment because the basal Flathead Formation was then considered to be a beach deposit. As shown later, recognition of the more complex fluvial nature of this monazite placer precludes any accurate determination of monazite resources from the extensive data in McKinney and Horst (1953b).

The Bald Mountain paleoplacer deposit has been extensively prospected for monazite and gold, but production figures for monazite or gold have not been reported. The paleoplacers were first examined for gold, but gold concenterations proved to be unprofitable. Gold concentrations of about 0.1 oz/ton were reported (Darton, 1906; Darton and Salisbury, 1906). McKinney and Horst (1953b) reported much lower gold concentrations of 0.001 to 0.005 oz/ton. These are probably lower than actual concentrations because they used composite samples from the entire depth of dry rotary-drilled holes. Dense minerals like gold, monazite, and ilmenite are incompletely recovered during air drilling at low pressures, and the holes were not entirely in conglomerate. Because dense minerals such as monazite commonly accumulate at the bottoms of drill holes during air drilling, this may also explain the small monazite grain size in the cuttings as reported by McKinney and Horst (1953a). In the early 1950s, the deposit was examined for monazite as a source of thorium. At this time numerous pits and trenches were dug, and holes were drilled (about 2,000 feet). Numerous samples of drill cuttings were taken (about 27 tons) and analyzed. The potential resource of by-product ilmenite was also noted at this time (Kline and Winkel, 1952; McKinney and Horst, 1953a, 1953b). Results of these examinations define the extent of the monazite-rich rocks and potential resources as presented in the following paragraphs.

In the Bald Mountain area, monazite abundances, as calculated from the radioactivity of samples concentrated on a Wilfley table (with a correction for Wilfley table losses), vary from less than two pounds monazite per ton up to about 30 pounds of monazite per ton. Zones in which all samples contain greater than five pounds monazite per ton are often ten feet thick and vary from less than 2.5 feet thick up to 15 feet thick. From microscopic examinations of 114 samples, having a wide range in monazite grades, ilmenite contents of concentrates are 4.5 to 5 times greater than the monazite contents (McKinney and Horst, 1953b).

Within the Bald Mountain deposit, the potential high-grade monazite resources are in a 48.3-acre area in the center of the eastern half and western half of Sections 22 and 23, respectively. A less well defined area of high monazite content is located in Section 31.

The potential monazite resources in Sections 22 and 23 are in a zone that was estimated to be about six feet thick and overlain by 0 to 30 feet of overburden. This potential resource contains an estimated 4,447 tons of monazite in 674,160 tons of rock that averages 13.2 pounds of monazite per ton of rock. The rock also contains about 22,000 tons of ilmenite. Lower grade resources are far more extensive and abundant. For example, the area in section 31 at the base of Bald Mountain contains about 7,800 tons of monazite in 3,500,000 tons of rock that averages about 4.45 pounds of monazite per ton of rock (McKinney and Horst, 1953b).

As presented in this report, the extent and potential resources of monazite-rich rocks at Bald Mountain are poorly defined. At present it is not even possible to tell if the resources are overestimated or underestimated, let alone the amount of error. The major problems are (1) the ill-defined lateral extent under thicker overburden, (2) the need to reexamine the deposit in terms of the rapid lateral and vertical changes in the new fluvial depositional model, and (3) inaccurate sampling and analyses in previous investigations. A reexamination could proceed in several increasingly costly steps.

The first step would be to determine if drilling and lithologic logs are available for the holes drilled in 1952 (McKinney and Horst, 1953a, 1953b). These might enable an investigator to determine if the holes were really drilled to Precambrian rocks, if and when well cemented sandstones and conglomerates were encountered, and if there are any lithologic differences between these well cemented sandstones and conglomerates and the poorly cemented sandstones and conglomerates.

Step two would be a field geologic investigation of the area. This would include taking surface samples and measuring radioactivity to determine the nature and extent of the paleoplacer as well as the underlying and overlying rock. It must be determined whether there are any indicators of monazite abundance. For example, as an approximation, which is a better guide to ore, the poorly cemented conglomerates or high radioactivity? The investigation would have to be extensive with a secondary goal being the determination of whether the fluvial paleoplacer had been previously sampled in an effective manner, even though sampling was designed for a beach placer. This would determine if holes were drilled deep enough and(or) close enough, and if samples were taken often enough.

In step three, <u>if</u> sampling has been done in an effective manner, some new samples must be obtained. Because the holes drilled in the 1950s were drilled with air, which causes homogenization of samples and incomplete recovery of heavy minerals, some new holes must be drilled next to the old ones and sampled with a more effective drilling medium. Core drilling might be necessary to ensure complete sample recovery. It might then be possible to recalibrate the old data by analyzing these new samples. Microscopic point counting is recommended along with radiometric analyses of bulk samples and downhole radiometric analyses. If some holes are cored, the rare earth content of the core can be compared to the radiometrics of the core and in the drill hole to see if radiometrics alone can be used to determine the concentrations of rare earth elements. Radiometric analyses of crushed drill core after concentration on a Wilfley table are not recommended because the monazite can have various thorium concentrations, and a great deal of monazite was lost off the Wilfley table (25 to 40 percent according to McKinney and Horst, 1953b).

Step four would be a complete subsurface resampling of the area if needed. If earlier steps indicate radioactivity is an ore guide, downhole radiometric analyses could be used.

Carbon County

Platt pegmatite (Platt, Uranium King mine) SW1/4SE1/4SW1/4 sec. 3, T.13N., R.81W.

This zoned pegmatite cross-cuts the foliation of the Precambrian gneissic country rock. The pegmatite is 70 feet wide, 160 feet long, and was mined to a depth of 75 feet (Houston, 1961a). Rare earth-bearing minerals ("euxenite" and monazite) are most abundant in the center of the pegmatite and in gash veins. In order of abundance, minerals present in the pegmatite are "euxenite", monazite, and columbite. The "euxenite" is metamict so the x-ray identification is suspect. The "euxenite" is most probably samarskite or a columbium-rich, yttrium-bearing tantalite based on its chemical composition and x-ray pattern. X-ray fluorescence showed that the only element examined in this report that was present in major amounts in the "euxenite" was yttrium. The same kind of analysis on monazite indicated the presence of the following rare earth elements and yttrium, in order of decreasing abundance, cerium, neodymium, yttrium, and lanthanum. Some crystals of "euxenite" and monazite reportedly exceeded three inches in length. Ten thousand pounds of "euxenite" were produced from this mine (after Houston, 1961a, 1961b; Platt, 1986). At present, the mine has been sealed with a concrete cap, in which small metal grates may permit access.

Samarskite is reported from a granite on the King claims in Section 32 of the same township (Gruner and Knox, 1956). This occurrence probably refers to the Platt pegmatite because (1) there are no granites in Section 32, (2) the claim names are similar, (3) the localities are in the same township, (4) only one digit in the section number is different, and (5) the reported minerals are similar.

Big Creek pegmatite area T.13N., R.80W. and T.13N., R.81W.

Houston (1961b) states that four pegmatites in these two townships, in addition to the Platt pegmatite, contain one or more of the following minerals: euxenite, columbite, and monazite. Houston (personal communication, 1987) stated more rare earth-bearing pegmatites are probably present in the area since all the pegmatites were not examined. A sketch map by Houston (1961b) showed columbium-bearing pegmatites in Section 19, T.13N., R.80W. and near Section 22, T.13N., R.81W. Houston (personal communication, 1987) could not remember the exact location of the pegmatite in Section 19, but confirmed the presence of a columbium-bearing pegmatite in the section. He marked the three remaining pegmatites on his map published in 1961. The largest pegmatite is a north-south elongate body in the center of the south half of Section 13 (T.13N., R.81W). Two small pegmatites are located along a road in the center of the east half of Section 14 (T.13N., R.81W). He added that the columbium-bearing mineral in these four pegmatites was metamict and might be euxenite (samarskite) or fergusonite.

Blackhall Mountain secs. 2, 3, and 11, T.12N., R.83W.

DeNault (1967) reports that a pegmatite on the ridge crest of Blackhall Mountain contains a metamict rare earth-bearing mineral in two of the four thin sections that he examined. The ridge crest is actually three crests, and he maps a pegmatite along each ridge. Therefore, the exact location of his discovery is not certain. As mapped, the pegmatites are 200 to 800 feet wide and 0.5 to 1.5 miles long. X-ray fluorescence of the mineral showed one percent or less each of cerium, lanthanum, praseodymium, neodymium, and thorium, leading DeNault (1967) to conclude the mineral might be allanite.

Ferris Mountains approximately T.27N., R.88W; NW1/4 T.26N., R.86W.; SW1/4 T.27N., R.87W.; N1/2 T.26N., R.87W.

Master (1977) reported up to three percent allanite as an accessory mineral in Precambrian granitic intrusive rocks in the Ferris Mountains. The abundance of allanite in Precambrian pegmatites in the mountains was not mentioned, but samples from the pegmatites do not contain more lanthanum and yttrium than the enclosing granitic rocks. The highest values of lanthanum and yttrium that Master (1977) found in samples of granitic rock in this area are 200 and 100 ppm, respectively. Concentrations of lanthanum and yttrium reported in another study covering a slightly larger area in the Ferris Mountains (Neubert, 1985) do not even approach those reported by Master (1977). In a short report on the Cherry Creek prospect, a property that is the Babbs mine of Master (SE1/4 sec. 26, T.27N., R.88W.), Wilson (1955) notes that a mineral in the adit that might be allanite is present with copper-bearing minerals. The relatively low values of lanthanum and yttrium coupled with the lack of higher concentrations of allanite imply that this area is probably not rich in rare earths. However, an examination directed towards finding rare earths, rather than other metals, is needed to prove this tentative evaluation.

Bates Hole area T.27N., and T.28N., R.79W., R.80W., and R.81W.

Harshman (1972) states that several areas of high radioactivity that were detected during aerial surveys are present within this area on the south rim of Bates Hole. From surface examinations, these radioactive zones are attributable to monazite in sandy and conglomeratic beds in the Wind River and White River Formations, and monazite in Quaternary alluvium derived from these formations. The monazite content in these coarse-grained beds is reportedly quite variable. Reported concentrations of monazite vary from a few hundredths to 1.43 pounds of monazite per ton of sand, with most samples containing less than one pound of monazite per ton of sand (Harshman, 1972). Roehler (1958) states that John Schulte discovered that most of the radioactivity in the area was from thorium in monazite. These occurrences are probably fluvial placers.

Within this large area, three specific sites have been examined. Griffin and Milton (1982) report that samples from Holocene gravels in the northeast quarter of Section 5 (T.27N., R.81W.) contain 700 to 1,000 ppm elemental lanthanum and 70 to 200 ppm elemental yttrium. Much earlier, Love (1954a) reported high surface radioactivity, but no uranium minerals, in the Wind River or White River Formations in Sections 9 and 29 (T.27N., R.80W.). These sites of high radioactivity were called the Gafco claims and designated as rare earth occurrences by Olson and Adams (1962).

Crook County

Bear Lodge Mountains Roughly T.52N., R.63W.

The southern portion of these mountains contains Tertiary trachytes, phonolites, and carbonatites which intrude lower Paleozoic sedimentary rocks. These igneous and sedimentary rocks are enriched in rare earths, thorium, uranium, fluorine, barium, strontium, and columbium. These rocks have not been analyzed for tantalum. The rocks are notably enriched in the commercial light rare earths (LREE) (Staatz, 1983; Staatz and others, 1980). This area has only been evaluated for its thorium, uranium, and by-product rare earth potential. These elements apparently occur in a porphyry deposit that is physically similar to porphyry copper deposits. In these porphyry-type mineral deposits, minerals are disseminated in extensive systems of microfractures. The rare earths, uranium, and thorium in the Bear Lodge deposit are concentrated in veins and veinlets that contain manganese and(or) iron oxides. Minor quartz, crystobalite, and sometimes altered trachyte and phonolite, fluorite, and(or) calcite are also present in the veins and veinlets. The veins and veinlets are soft and porous to hard and highly siliceous. Exploration has been confined to these fractured areas (after Jenner, 1984; Staatz, 1983; Wilkinson, 1982; Staatz and others, 1980; Wilmarth and Johnson, 1953; Brown, 1952).

The igneous complex and surrounding sedimentary rocks have not been completely explored. There are many factors that were overlooked in previous examinations. The rare earth concentrations apparently have no correlation with the thorium, uranium, potassium, columbium, manganese, sodium, strontium, barium, calcium, or iron concentrations. Rare earths are most abundant on the perimeter of areas with the greatest potassium abundances (after Staatz, 1983; Staatz and others, 1980; Wilmarth and Johnson, 1953). Rare earths are often associated with fluorine, but rocks in the igneous complex have not been analyzed for fluorine. Also, the fluorite occurrences in sedimentary rocks surrounding the igneous complex have not been analyzed for rare earths. High rare earth concentrations do not coincide with areas of high total radioactivity, more abundant fracturing or brecciation, any recognizable alteration, or the locations of carbonatites (after Jenner, 1984; Staatz, 1983; Wilkinson, 1982; Staatz and others, 1980; Wilmarth and Johnson, 1953). Jenner (1984) described what may be carbonatites in the Ogden Creek area, south of those previously examined, but reports no analyses for rare earths. Gold mineralization is present in this porphyry deposit (Jenner, 1984; Wilmarth and Johnson, 1953; Brown, 1952; Jamison, 1912; Jenny and Newton, 1880; Hall, 1910). At present (1987) at least one mineral company is conducting detailed exploration for gold, with rare earth elements being considered as possible by-products.

The preceding information about this district coupled with the common association of rare earths with alkalic rocks and carbonatites, and poor exposures in the area means the Bear Lodge Mountains are an incompletely explored, potentially economic source of rare earth elements. A study that evaluates the combined value of gold, thorium, uranium, rare earths, strontium, fluorine, barium, columbium, and tantalum in the Bear Lodge igneous complex and surrounding sedimentary units is needed.

The information on the following pages covers the characteristics of mineralization within and on the margins of the igneous complex. Mineralized features within the complex include: (1) the geochemically demonstrated zone of rare earth enrichment, (2) rare earth-bearing veins, (3) rare earth-bearing fractures, and (4) carbonatites. The Ogden Creek area has characteristics of mineralization in the complex (veinlets in igneous rocks) and mineralization on the margins of the complex (fluorite in carbonate rocks). The mineralization on the margins of the complex is in fluorite-bearing sedimentary rocks that should be analyzed for rare earths. Fluorite abundance might be indicative of rare earth abundance, and is therefore described in the following subsections. These mineralized sites, counterclockwise from the west, are: (1) Royal Purple fluorspar claims, (2) Petersen fluorite lode claims, and (3) the Lytle Creek area. As noted in these subsections on the richest fluorite occurrences, fluorite-bearing sedimentary rocks are not restricted to these sites.

The concentrations of rare earths in fluorite-bearing sedimentary rocks around the margins of the intrusive complex are essentially unstudied. One analysis has been reported, and it implies rare earth concentrations are low, in the tens of ppms (Wilmarth and Johnson, 1953). The color of the fluorite cannot be used as an indirect indicator of rare earth mineralization. Deep purple fluorite is commonly thought to contain abundant radioactive elements, such as those associated with rare earths in the intrusive complex. However, Wilmarth and Johnson (1953) have shown that in the Bear Lodge Mountains purple fluorite contains both high and low amounts of radioactive elements. No analyses are available for lighter colored fluorites in these mountains. More analyses are needed at various locations around and distances from the intrusive complex in order to determine if any pattern of rare earth distribution exists.

Zone of rare earth enrichment as demonstrated by geochemical sampling

center W1/4 sec. 16, sec. 17, center E1/4 sec. 18, N1/2 sec. 20, T.52N., R.63W.

Rocks within this zone contain more than 5,000 ppm total elemental rare earths. The boundaries of the zone of enrichment are defined by limited geochemical sampling (see Staatz and others, 1980; Staatz, 1983). This zone encompasses the disseminated deposits as described by Staatz (1983). Rare earth bearing-minerals are quite scarce in these disseminated deposits. In these disseminated deposits, mineralization is in veinlets and microfractures. The boundaries of the disseminated deposits cannot be defined by visual examination or radiometric measurement (Staatz, 1983). The boundaries of the zone of enrichment are imcompletely defined because few samples have been analyzed from the west half of Section 18, and in Sections 19, 22, 27, 28, 29, and 33 (see Staatz, 1983; Staatz and others, 1980), where indicators of rare earth mineralization such as manganese and iron oxide stained veinlets and veins, and fluorite mineralization are present (after Staatz, 1983; Wilkinson, 1982; Jenner, 1984; Wilmarth and Johnson, 1953; Haff, 1944b; Cox, 1945).

The area within the known zone of rare earth enrichment is about 1.2 square miles, and data from drill holes indicates mineralization extends to a depth of about 1,200 feet in some areas (after Staatz, 1983). More sampling and analyses of rocks from outside the known zone of enrichment, and on a closer spaced surface and subsurface pattern within the zone of enrichment are required to define a potential reserve (see also carbonatite subsection).

Rare earth-bearing veins

SE1/4 sec. 7, NW1/4 sec. 16, sec. 17, center E1/4 sec. 18, center sec. 19, N1/2 sec. 20, NW1/4 sec. 22, center sec. 21, N1/4 sec. 27-28 line, T.52N., R.63W.

These are the veins of Staatz (1983) that by definition exceed two inches in average width; he calls smaller features veinlets. Staatz (1983) maps and describes 26 veins and presents chemical data for 20. Except for seven veins (number 1, 2, 10, 21, 22, 23, and 24), these veins are within the zone of rare earth enrichment. Vein color is controlled by the kind and abundance of iron and manganese oxides. The veins are sinuous, pinch and swell along strike and dip, and have variable dip along strike. No pattern is apparent in the strike of these veins except for a lack of veins that strike N45°-75°E, perpendicular to the long axis of the igneous complex. The veins are usually steeply dipping, but dips vary from 25° to vertical, both into and away from the center of the complex. The veins are often only exposed in pits and trenches. Exposed dimensions are from about one to 100 inches in width and 1.5 to 400 feet in length. The extensive cover in the area means the veins could be larger, and more veins are probably present in the complex (after Staatz, 1983).

Rare earth-bearing minerals are not common in the veins and are fine grained. In order of abundance, the major rare earth-bearing minerals in the veins are monazite, brockite, and bastnaesite (Staatz, 1983). The most abundant rare earth-bearing mineral in the carbonatites is bastnaesite. For more details see carbonatite section.

The rare earth content of the veins within the zone of enrichment varies from about 5,400 to 98,000 ppm total elemental rare earths. Veins outside the zone of rare earth enrichment contain less but still abundant rare earths, 2,300 to 71,530 total elemental rare earths. These veins represent additional high grade rare earth resources within the zone of rare earth enrichment and a potential resource outside the zone of enrichment (after Staatz, 1983; Wilmarth and Johnson, 1953). Staatz (1983) concludes that only two of the veins contain mineable inferred reserves; these total reserves are 3,140 tons of rare earth oxides. Staatz (1983) does not state which veins are mineable or how he arrived at the reserve estimate.

Previous work on these veins provides additional information about them. Wilmarth and Johnson (1953) describe the northwest-trending vein 22 of Staatz (1983), and name it the Sunrise lode. This vein and vein 21 of Staatz (1983) are the only veins that are in contact with sedimentary rocks. Wilmarth and Johnson (1953) also provide additional information about the Home Fire no. 43 claim, also known as the Old Clark lode. This claim is on vein 24 of Staatz (1983), or is northwest of and adjacent to this vein (after Wilmarth and Johnson, 1953; Staatz, 1983). Veins might be present in igneous rocks in the Ogden Creek area, but only the presence of veinlets has been positively established (after Haff, 1944b; Cox, 1945; Hagner, 1943; Wilkinson, 1982). Chenowith (1954) noted fluorite fissure fillings up to one-foot wide in igneous rocks in the northwest quarter of Section 8 (T.52N., R.63W.), but he did not mention iron or manganese oxide staining. Wilkinson (1982) mentioned what may be the same fluorite occurrence in a breccia in the same general area (center SE1/4NW1/4 section 8), but he also mapped rare earth-bearing fractures in the same general area (SW1/4SW1/4NW1/4 section 8).

Rare earth-bearing fractures

center N½ sec. 7-8 line, sec. 17, NW¼ sec. 18, SE¼ sec. 18,
N½ sec. 20, SE¼NW¼ sec. 33, T.52N., R.63W.

Wilkinson (1982) maps these as extensive fractures containing thorium and rare earths. He describes them as radioactive, iron and manganese oxide stained veinlets and veins with secondary silica and features indicative of open-space filling. The presence or absence of rare earths in all of Wilkinson's (1982) fractured areas has not been determined. Wilkinson's (1982) fractured areas are far more widespread than the disseminated deposits of Staatz (1983). A comparison of the locations of these fractured areas with geochemical studies by Staatz and others (1980) indicates that many of these fractured areas have not been analyzed for rare earths or other elements, while others do not contain abundant rare earths.

In addition to these fractured areas, White (1980), O'Toole (1981), Wilkinson (1982), Staatz (1983), and Jenner (1984) map and describe intrusive breccias at various and sometimes contradictory locations. These intrusive breccias are apparently extensively fractured, iron oxide stained, altered igneous and metamorphic rocks where additional new material has been emplaced as a matrix. This new matrix material is mostly altered igneous rock and siliceous material (Staatz, 1983; Wilkinson, 1982; Jenner, 1984); fluorite, calcite, gold, and pyrite have been reported in the matrix (Wilkinson, 1982; Jenner, 1984). Locations of these breccias have not been presented because some breccias contain rare earths while others do not (compare breccia mapping to the zone of rare earth enrichment). The differences between rare earth-bearing and barren breccias need to be determined, as well as the differences and similarities between breccias and fractured areas.

Carbonatites

surface: S1/8 sec. 7-8 line, NW¼NW¼NE¼ sec. 20, T.52N., R.63W.
subsurface: NW¼ sec. 17, NE¼ sec. 18, T.52N., R.63W.

Carbonatite dikes and stringers in the Bear Lodge igneous complex contain rare earths. Some dikes and stringers are outside the zone of rare earth enrichment. All the carbonatites are notably enriched in strontium and also contain abundant barium in barite (Wilkinson, 1982; Staatz, 1983; Jenner, 1984). Because the carbonatites are only exposed in trenches with no visible float (Wilkinson, 1982), the exact extent and size of the carbonatites is not known. The surface exposures are about 15 by 80 feet (Staatz, 1983) or about 4.5 by 160 feet (Wilkinson, 1982) on the Section 7-8 line, and about 20 feet by 330 feet in Section 20 (Wilkinson, 1982). In subsurface, the carbonatites are tenths of an inch to about eleven feet thick and are steeply dipping (Staatz, 1983). These are apparently actual thicknesses in angled (non-vertical) drill holes because Jenner (1984) reports thicknesses in drill cores of tenths of an inch to several tens of yards. The color of surface exposures and altered subsurface carbonatite is controlled by iron oxide staining. In subsurface, fresh carbonatites are usually light gray.

Surface and fresh subsurface carbonatite contain different mineral suites. The only mineral common to both suites is fluorite. Powdery bastnaesite with minor intergrown powdery sychysite are the rare earth-bearing minerals in surface exposures of carbonatite. In subsurface, the fresh carbonatites contain streaks and lenses of the rare earth-bearing mineral ancylite with smaller amounts of burbankite, carbocerianite, and two other incompletely identified minerals (after Staatz, 1983; Jenner, 1984). Fresh subsurface samples also contain streaks and lenses of strontianite, chalcopyrite, galena, sphalerite, pyrite, and pyrrhotite (Staatz, 1983); the sulfides are also present as fine disseminated grains (Jenner, 1984).

Total rare earth content in the carbonatites varies from about 5,800 to 66,000 ppm rare earth elements. This is less than that in some veins. Ninety-five percent of the rare earths are the commercially viable light rare earths (Staatz, 1983). The effects of surficial oxidation of sulfides on rare earth distribution is not known because Staatz (1983) does not discriminate between surface and fresh subsurface samples. The effect of surface oxidation and sulfuric acid production on rare earth mobility needs to be determined. Otherwise all rocks in the complex must be sampled by core drilling in order to determine resource potential.

Jenner (1984) maps additional strontium-poor carbonatites in the Ogden Creek area, south of other carbonatites and the zone of rare earth enrichment. The origin of these carbonate rocks is uncertain (see Ogden Creek subsection).

Ogden Creek area (Allen-Wright fluorspar deposits)

SW1/4 sec. 27, SE1/4 sec. 28 and possibly in NW1/4 sec. 34, T.52N., R.63W.

This area merits further examination because of the presence of fluorite, intrusive breccia, and possibly carbonatite, which are similar to the zone of rare earth enrichment. These Ogden Creek rocks have not been analyzed for rare earths. As with most of the Bear Lodge igneous complex, rocks in this area are poorly exposed. The rocks are trachytes and phonolites that surround recrystallized carbonate rocks (marble) (Jenner, 1985; Wilkinson, 1982; Staatz, 1983). The carbonate rocks have been variously interpreted as Precambrian limestone (Chenoweth, 1955), Paleozoic limestone (Haff, 1944b; Staatz, 1983; Wilkinson, 1982), and, on the basis of physical, chemical, and isotopic analyses, melted Paleozoic limestone (Jenner, 1984). How the limestone was melted remains a problem. The carbonate rocks do not exhibit the strontium enrichment that is present in the rare earth-bearing carbonatites to the north (after Jenner, 1984; Wilkinson, 1982; Staatz, 1983).

The fluorite claims are on and near the ridge crest between Ogden and Tent Creeks, mostly in Sections 27 and 28. Within these claims, the so called limestones were the most extensively prospected areas (Haff, 1944b) prior to exploration for radioactive rocks. Fluorite is relatively abundant in these carbonate rocks, particularly at their margins, but is also present in the trachytes and phonolites. Limonite stained, vuggy, siliceous masses that contain fluorite and fluorite-bearing intrusive breccias are present in the trachyte-phonolite (Haff, 1944b). Intrusive breccias have been mapped in both Sections 28 (Wilkinson, 1982) and 27 (Haff, 1944b). The concentrations of fluorite are greatest in the western carbonate exposure in a trench that straddles the Section 27-28 line. A zone 100 feet long and tens of feet wide in this exposure contains five to ten percent fluorite with smaller zones containing even higher percentages (Cox, 1945). The presence or absence of veins has not been established (after Haff, 1944b; Cox, 1945; Hagner 1943; Wilkinson, 1982).

The nonweathered fluorite in all the occurrences is lavender to deep purple, and is irregularly distributed. When weathered, the fluorite is greenish white (Haff, 1944b; Hagner, 1943). Fluorite is present as fine grains in veinlets in and in disseminations throughout the trachyte-phonolite and intrusive breccia, and as more coarsely crystalline disseminations, aggregates, and masses in the carbonate rocks (Haff, 1944b). Chenoweth's (1955) observations of larger fluorite crystals contradict statements by Haff (1944b). Chenoweth (1955) also reports that insoluble residues of the carbonate rocks only contain fluorite. This does not preclude rare earth mineralization because surface samples that contain rare earth-bearing minerals are uncommon in the igneous complex. The report of apatite and alteration (Hagner, 1943) has not been verified.

Royal Purple fluorspar claims

roughly W1/2 sec. 30, T.52N., R.63W., E1/2 sec. 25, T.52N., R.64W.

The location given for these claims is inferred from the description of Cox (1945) using Darton (1905) and Staatz (1983). Brown (1952) does not depict or mention these claims. The geology and topography at the claim location given by Haff (1944c) (section 5, T.51N., R.63W. and section 32, T.52N., R.63W.) do not match the geology and topography as described by Cox (1945) and Haff (1944c).

The Royal Purple claims are on roughly northwest-trending ridges on both the north and south banks of Bear Den Canyon (middle fork of Houston Creek). The fluorite mineralization is in pockets and lenses, and disseminated in the Minnelusa Formation. The mineralization is near a northwest-southeast elongate exposure of phonolite-trachyte with an undetermined intrusive form (after Haff, 1944c; Staatz, 1983).

South of Bear Den Canyon, deep purple and black fluorite is present in sandstone as disseminated grains and crystal aggregates up to three inches across. Ten to 15 percent fluorite was reported in some prospect pits (Haff, 1944c).

North of Bear Den Canyon, fluorite is more abundant and is apparently restricted to the west margin of the phonolite-trachyte intrusion. Prospect pits in the host Minnelusa sandstone and limestone reportedly contain 20 to 30 percent fluorite with rich pockets containing as much as 50 to 90 percent fluorite. In the prospect pits, dark purple to almost black fluorite was present in veinlets and blebs that form five to six vuggy lenses. The lenses are from one to three feet wide and at least eight to ten feet long. The prospect pits did not completely expose the length of these lenses, but they are elongate northwest-southeast. The fluorite is associated with brown calcite, quartz, and siderite(?). Disseminated fluorite and scattered veinlets of fluorite are also present north of Bear Den Canyon in limestone and well-indurated sandstone (after Haff, 1944c; Cox, 1945). Cox (1945) also reports fluorite mineralization in a fault contact between the phonolite-trachyte intrusion and a limestone in the Minnelusa Formation.

Fluorite mineralization on the west side of the intrusive complex is probably more widespread than just these claims. Fluorite has been reported at other sites near Bear Den Canyon, and disseminated fluorite could easily be overlooked in this heavily vegetated terrain which has few exposures. In Bear Den Canyon, Cox (1945) describes fluorite-calcite veinlets and low-grade fluorite boulders in the Pahasapa Limestone east of the Royal Purple claims. Fluorite has also been reported north of the Royal Purple claims, probably along strike, in section 24 (T.52N., R.64W.) (Hilton *in* Osterwald and others, 1966). However, Staatz (1983) does not show any claims in this area. Staatz (1983) does show claims in the Pahasapa Limestone north of Bear Den Canyon in Section 30 (T.52N., R.63) and north and east of Jim Wayne Spring in both the Pahasapa Limestone and Minnelusa Formation in the western quarter of Section 19 (T.52N., R.63W.).

Petersen fluorite lode claims (Bear Lodge fluorite property)

roughly center S1/4 sec. 15, center E1/2 sec. 22, T.52N., R.63W.

Fluorite is present in the Mississippian Pahasapa Limestone on these claims. Pits and trenches have also revealed altered porphyritic igneous rocks on the claims, but only Hagner (1943) mentions fluorite mineralization in the igneous rocks. Exploration has been hampered by a mantle of gravel (Haff, 1944a; Cox, 1945; Dunham, 1946). Jenner (1984) maps exposures of Cenozoic igneous rocks near these claims. Replacement and vein fluorite mineralization, and gradations in between, are present on the property. The deep or dark purple fluorite is associated with calcite, quartz, chert, and feldspar. Samples of material from trenches, shafts, and drifts contain about 20 to 85 percent fluorite (after Haff, 1944a; Cox, 1945; Dunham, 1946). Hagner (1943) also reports colorless fluorite. The report of feldspar implies some inclusion of porphyritic igneous rock.

Replacement deposits follow bedding in the limestone. Replacement mineralization varies from widely disseminated fluorite grains to bands as much as one foot thick that are mostly fluorite. The full extent of the replacement deposits has not been determined. In workings, they have been followed to a depth of 24 feet, are up to five feet thick where bands are stacked, and are probably up to 50 feet long (after Haff, 1944a; Cox, 1945).

Smaller fluorite veins are narrow and appear to be in joints while larger fluorite-bearing veins are actually brecciated zones. The breccia zones contain clay and limestone clasts with cherty masses and vuggy masses of fluorite. These breccia zones have irregular shapes, and the entire lengths have not been excavated. In workings, the zones are up to nine feet thick, two extend to depths of 28 and 44 feet, and most are probably less than 20 feet long. Vein mineralization is both parallel to and crosscuts bedding in the limestone. The breccia zones are often elongate parallel to the strike and dip of bedding, but apparently dip at steeper angles (25° to 60°) than bedding (after Haff, 1944a; Cox, 1945). Bedding in this area has a northwest strike and dips about 25° to the northeast (Staatz, 1983).

Wilmarth and Johnson (1953) looked at fluorite mineralization in the Pahasapa Limestone on these claims as well as those in the Lytle Creek area. The information they present contradicts some preceding information by Haff (1944a) and Cox (1945). This implies these divergent features are confined to the Lytle Creek area. The sizes of fluorite mineralization as reported by Wilmarth and Johnson (1953) are smaller than those presented in the previous paragraph (vein-breccia zones up to one-foot wide and six feet long, and disseminated replacement deposits up to two feet wide and ten feet long). Wilmarth and Johnson (1953) state: (1) colorless fluorite is interbanded with deep purple fluorite, (2) iron and manganese oxides are present in fractures in fluorite grains in veins, and (3) chert and feldspar are not associated with the fluorite. Colorless fluorite has only been reported in the Ogden Creek area and in the igneous complex. Interbanded fluorite coloration has not been reported in the igneous complex by any other investigator. The iron and manganese oxides have only been reported in veins within the igneous complex.

Fluorite mineralization in the Pahasapa Limestone is probably more extensive on the eastern and southern margins of the igneous complex that just the Petersen claims. A few additional prospect pits and trenches are located on these margins, and the northeastern portion of the margin is covered by an extensive gravel (Brown, 1952; Staatz, 1983). Also, Chenoweth (1955) reports finely disseminated fluorite in numerous exposures of Pahasapa Limestone on these margins of the igneous complex.

Lytle Creek area

E1/4 sec. 13, T.52N., R.64W.; NW1/4 sec. 7, W1/4 sec. 18, T.52N., R.63W.

Wilmarth and Johnson (1953) visited at least four claims in this area that they state contain fluorite in the Pahasapa Limestone. These claims are the James Walter, Baker lode, Nichols lode, and Nichols No. 1 lode (see Wilmarth and Johnson, 1953; and Everett, 1951 for exact locations). Brown (1952) depicts two fluorite prospects in this area. Staatz (1983) shows prospect pits in the Permian Minnelusa Formation near Lytle Creek. Mapping by Staatz (1983) shows that the Pahasapa Limestone in this area has been more thoroughly invaded by igneous rocks than on the northeastern margin of the complex.

As noted in the subsection on the Petersen fluorite lode claims, Wilmarth and Johnson (1953) combined their observations on the Lytle Creek claims with those for the Petersen claims. The characteristics of fluorite mineralization in the Lytle Creek claims are apparently like those for the Petersen claims in (1) the presence of deep purple fluorite, (2) the association of fluorite with calcite and quartz, (3) the presence of vein-breccia and replacement deposits, and (4) mineralization is usually nearly parallel to bedding in the Pahasapa Limestone. Other than size, the differences that may be exclusively in the Lytle Creek area are the presence of colorless fluorite, iron and manganese oxide staining, and the absence of chert and feldspar (see the Petersen subsection). These divergent characteristics may be a function of zoning, related to the greater invasion of igneous rocks.

Fremont County

Warm Spring Creek Placers   Secs. 28, 29, 32, 33, and 34, T.42N., R.108W.

Monazite-bearing black sands are reported by Love (personal communication, 1987) and Dunnewald (1958) in terrace deposits along Warm Springs Creek and in alluvial material in and adjacent to the creek. The locations given are for alluvial and terrace deposits as mapped by Keefer (1957). Love (personal communication, 1987) believes the monazite placers are also present downstream along Wind River. The highest known terraces are more than 100 feet above Warm Springs Creek. The alluvial deposits on Warm Springs Creek are from 1/4 to 5/8 of a mile in width and are about 1 2/3 mile long. In the summer of 1957, the placers were tested by the Little Jim Mining Company using a portable sluice. A small amount of gold was recovered along with monazite-bearing black sands (Dunnewald, 1958).

Dunnewald (1958) implies that he did not see monazite in the terrace deposits, but he accepted the word of a Mr. Robertson of the Little Jim Mining Company. However, Love (personal communication, 1987) confirmed the existence of monazite in alluvium along the creek. Monazite-bearing placers might also be present in alluvium along the South Fork of Warm Spring Creek, but the description on the extent of the placers is contradictory (after Dunnewald, 1958).

Johnson County

Beaver Creek allanite prospect (Lyle Ramsbottom property)

NW1/4 sec. 5, NE1/4 sec. 6, T.46N., R.83W.; S1/2 sec. 31, T.47N., R.83.W.

Allanite is present in metamorphosed calc-silicate rocks at this site in the southern Bighorn Mountains. Allanite is ubiquitous in the calc-silicate rocks with both a homogeneous distribution and as small decussate masses. Individual allanite crystals are up to one or two inches long. The calc-silicate rocks occur as lenses, bands, layers, and pods that are concordant with the foliation in the enclosing quartz-feldspar gneiss (N60°W). These discontinuous calc-silicate bodies apparently form a zone 3,750 feet long and a few inches to six feet wide. The exact extent of the bodies and zone is not known because excavation is needed in order to further delimit these non-resistant calc-silicate rocks. Bodies of calcitic marble are also present in this zone, both adjacent to and isolated from calc-silicate rocks. Allanite is apparently more abundant in calc-silicate rocks adjacent to marble. In addition to the uranium, thorium, and rare earth elements in allanite, high values of columbium have also been reported from samples of calc-silicate rock. The exact origin for the enrichment of these elements is not known, but it is thought to be related to regional amphibolite-grade metamorphism during Precambrian time (Sargent, 1960; Arbrustmacher and Sargent, 1982; Hose, 1955; Wilson, 1952; Magleby, 1952). Alternatively, the marble is a carbonatite.

Prior to 1960, the zone of calc-silicate rocks had been prospected by excavating pits and trenches. The size of the pits and trenches was from a few feet to ten feet deep and a few feet across to 54 feet long and several feet across. The sizes of most of the workings were at the small end of the range. In 1955, 300 tons of allanite-bearing rock was shipped from workings in Section 31 to Casper, Wyoming. This ore was never processed (after Sargent, 1960).

These allanite-bearing calc-silicate rocks are a potential source for rare-earth elements. Uranium, thorium, and columbium might be produced as by-products. From four samples, it has been estimated that calc-silicate rocks average 4.44 percent total rare earth elements, 0.03 percent uranium, and 0.06 percent thorium. It has been estimated that the zone of calc-silicate rock contains about 400,000 tons of mineable allanite-bearing material. Values for the potential products range from 30 to 1,000 ppm elemental columbium, 0.01 to 0.12 percent thorium, 0.004 to 0.090 percent radiometric equivalent uranium, and 1.27 to 7.68 percent light rare earth elements (the commercial rare earth elements) (Armbrustmacher and Sargent, 1982).

Platte County

Richard Riley claims sec. 29, T.27N., R.70W.

Allanite was reported in a pegmatite in Precambrian rocks fourteen miles northwest of Wheatland in 1954. The allanite was associated with biotite. The pegmatite exposure is 350 feet long and trends northeasterly (Smith, 1954). This is probably the locality reported by Wells (1934) in which the allanite contained 14.64 percent Ce_2O_3 and 7.34 percent $(La,Dy)_2O_3$.

Yellowstone National Park

The only information pertaining to rare earth elements in the Park is from drill cores from holes in the geothermal areas at the Mud Volcano area, and in the Norris, Upper, and Lower Geyser Basins. The mineral bastnaesite was seen lining a few fractures at three depths in core from the Mud Volcano hole. Rare earth-bearing minerals have not been reported in cores from the Norris, Upper, and Lower Geyser Basins (Bargar and Beeson, 1984; Keith and others, 1978a, 1978b; Bargar and Beeson, 1985; Honda and Muffler, 1970; Barger and Beeson, 1981; Keith and Muffler, 1978; Bargar and Muffler, 1982). Some of the samples from the cores drilled in all the geothermal areas contain high chemical concentrations of rare earth elements. High concentrations of one rare earth element are usually accompanied by high concentrations of others in the same sample. Sample spacing is so wide that it is impossible to tell if there are zones of rare earth enrichment in the cores or if the high concentrations of rare earths are just local phenomena (after Beeson and Bargar, 1984). Beeson and Bargar (1984) report high concentrations of rare earth elements in samples of core from three holes for which the information on hydrothermal alteration has yet to be published. Examination of core from these three holes might reveal more rare earth minerals and(or) a greater abundance of rare earth minerals.

UNVERIFIED OCCURRENCES

(exclusive of Mesozoic beach placers, Eocene lacustrine rocks, and Permian phosphorite occurrences)

Unknown Location

Eight hundred pounds of samarskite were reportedly shipped to California from an undisclosed location in Wyoming in 1930 (Marzel, 1933).

Albany County

Many Values (George-Funk Mica, Muscovite) prospect

W1/2NE1/4SE1/4 sec. 32, T.13N., R.78W

This tantalum prospect is developed in a poorly exposed pegmatite in Precambrian schists and gneisses. The location is from Beckwith (1937). Beckwith estimated that the pegmatite is 600 feet long with a maximum width of 70 feet and an average width of 40 feet. The pegmatite was exposed in shafts and pits for a length of 140 feet, a width of 15 feet, and a depth of 20 feet in 1942 (Hanley and others, 1950). Minor tantalite and possibly fergusonite were identified in the pegmatite in 1942 (Hanley and others, 1950; Beckwith, 1937, see also Hagner, 1942).

Middle Lodgepole Creek area (Weddle claims) Sec. 2, T.15N., R.71W.

A 75-feet wide euxenite(?)-bearing pegmatite that cuts Precambrian granite is reported at this location (Wilson, 1960). In 1978, euxenite was not seen by Griffin and Warner (1982). High radioactivity is reportedly associated with biotite in this pegmatite. This means this pegmatite is like those near Tie Siding (page 7). A sample of the Weddle pegmatite contained 700 ppm lanthanum but only 70 ppm yttrium (Griffin and Warner, 1982).

Albany station area Sec. 3-10 line, T.14N., R.78W.

Sanford and Stone (1914) report allanite in a pegmatite at this site. The occurrence has never been confirmed. Mussard (1982) reported that a sample of Sherman Granite in this area contained about 2.8 percent (by volume) allanite. Unfortunately he did not give the sample location. From his sample numbering scheme, it would appear to be somewhere in the north half of T.14N., R.78W. (see also Dribus and Nanna, 1982).

Laramie Range Sec. 2, T.18N., R.72W.

A four-inch allanite crystal was reported in Precambrian pegmatite at this site, and was described as highly radioactive by Osterwald in Wilson, (1960). The mineral was never positively identified as allanite and therefore might not contain rare earths.

Elmers Rock area roughly center SE1/4 sec. 19, T.23N., R.71W.

Graff and others (1981) report that a rock sample from this site contained 1,600 ppm lanthanum but only 16 ppm yttrium. Other abundant elements in the sample (#105238) included 33 ppm uranium, 350 ppm thorium, 1,200 ppm cerium, and 280 ppm zirconium. From the location given in Graff and others (1981), the rock sample is probably from either of two Archean quartz veins in an Archean granite (Snyder, 1984; Bull Camp Peak 71/2-minute Quadrangle) gneiss. These quartz veins and others mapped by Snyder (1984) in the central Laramie Mountains warrant further sampling.

Big Horn County

Rainbow claims Location estimated as T.58N., R.82W., unsurveyed

Parker (1963) reports euxenite in a pegmatite on these claims in the northern Bighorn Mountains. His location is just east of Cookstove Basin where radioactive pegmatites are present. The location given is for the Cookstove Basin.

Carbon County

Mullen Creek mafic complex Center W1/2NW1/4 sec. 11, T.14N., R.80W.

McCallum and Kluender (1983) reported that a sample of vein material in this mafic complex contained 1,000 ppm lanthanum. The sample as located was from a fault in gabbroic rocks (McCallum and Kluender, 1983). Because younger granitic rocks were intruded into the mafic complex (Hills and Houston, 1979), the high lanthanum values might be related to these granitic rocks rather than to the mafic complex. Mussard (1982) reports one percent by volume allanite is present in a sample of this granitic rock near or at this site, and three other samples of this granitic rock in the mafic complex contained elevated levels of rare earths and(or) one-half to one percent allanite.

Hubbell Ditch area Center S1/2 sec. 11, T.14N., R.81W.

A sample of chlorite schist taken at this site near Mullen Creek contained 500 ppm lanthanum. Stream sediment samples taken both up and down stream from this site (center N1/2 sec. 11, center S1/2 sec. 14) contained at least 150 ppm lanthanum (McCallum and Kluender, 1983). From existing geologic maps (Houston and others, 1968), it is difficult to determine if the high lanthanum concentrations are from an Archean quartzofeldspathic gneiss or from the Early Proterozoic Heart Formation.

Emigrant Trail thrust area NE1/4 sec. 32, T.28N., R.89W.

Griffin and Milton (1982) report a sample of a vein in Precambrian granite at this site contained 700 ppm lanthanum and 100 ppm yttrium. This may be the same site as locality 24 of Love (1970) since the location is the same. But Love (1970) reports lead, silver, and uranium mineralization in nodules in prospect pits in highly fractured Precambrian granite of the Emigrant Trail thrust block. Griffin and Milton (1982) concur with the uranium mineralization, but report lead levels of less than 0.01 percent, and they did not analyze for silver.

Many Precambrian dikes, pegmatites, and epidotized zones are present in the Pedro, Shirley, and Seminoe Mountains. Many dikes and epidotized zones contain uranium and(or) thorium mineralization, but only a few have been analyzed for rare earths. Sites with abundant rare earth elements are reported for the following three localities. Other sites contain small amounts of rare earths (after Griffin and Milton, 1982). Since few rare earth analyses have been performed, other rare earth occurrences might be present in the area.

Omega Claims SW1/4SE1/4SE1/4 sec. 17, T.27N., R.83W.

These claims are on shattered Precambrian biotite-rich zones in quartz monzonite. A rock sample contained 700 ppm lanthanum but only 30 ppm yttrium. No rare earth-bearing minerals have been reported (Griffin and Milton, 1982).

Poe Mountain no. 2 (Rainer no. 1) Center E$^{1/2}$ sec. 12, T.26N., R.84W.

This claim is on a Precambrian epidote-rich dike in quartz monzonite. A sample from the claim contained 500 ppm lanthanum but only 20 ppm yttrium. No rare earth-bearing minerals were reported (Griffin and Milton, 1982).

Pyramid Peak area roughly center T.28N., R.84W.; T.27N., R.84W. line

The exact location of this sample site is not given by Griffin and Milton (1982). They show the location on their plate 5, but many of the locations on plate 5 are not accurate. From petrographic examinations, Griffin and Milton (1982) report a trace of allanite and four percent epidote in this sample of Precambrian granitic rock. The allanite is probably the reason for the 700 ppm lanthanum and 20 ppm yttrium in the sample. This site is therefore another of the rare earth enriched epidotized zones in the Pedro Mountains and adjacent areas.

Crook County

Mineral Hill (Tinton, Negro Hill) area, Wyoming and South Dakota

In Wyoming roughly T.51N., R.60W. and N$^{1/2}$ T.50N., R.60W.

This area encompasses a Tertiary alkalic intrusive complex, with carbonatitic affinities and possibly carbonatites, which was intruded into Precambrian schists and lower Paleozoic sedimentary rocks. The schists contain Precambrian pegmatites that are elongate roughly parallel to the foliation in the schists. Rare earth-bearing minerals have not been reported in the area (Welch, 1974; Smith and Page, 1940). However, four of twenty stream sediment samples from the area contained elevated levels of rare earths (after Warren, 1980). These data plus the common association of rare earth elements with carbonatites and pegmatites means the area merits further examination for rare earth-bearing minerals. Gold is present in both the Precambrian schists and Tertiary intrusive complex (Norby, 1984; Welch, 1974). Concentrations of rare earths and columbium were low in the single reported analysis of rock (less than 30 ppm). Gold values vary from 0.5 to 10's of ppm (Welch, 1974). Considering the possible presence of carbonatite, and a gold- and columbite-tantalite-bearing Precambrian basement, the intrusive complex could contain resources of columbium, tantalum, rare earths, and gold.

Fremont County

Uranium claim no. 1 (Dubois claims) Sec. 24, T.41N., R.108W.

Gruner and Knox (1957) report the minerals uraninite, allanite, and uranophane at the Uranium claim no. 1 in a granite(?), and give the location. Granger and others (1971) locate the Dubois claims in the center of Section 24. Granger and others (1971) state these claims are for pitchblende in a breccia zone cutting Precambrian gneiss and pegmatites, and do not mention allanite. Therefore the presence of allanite has not been confirmed.

Laramie County(?)

Allanite is reportedly associated with a feldspar deposit in Precambrian rocks on the east flank of the Laramie Range (Osterwald in Wilson, 1960).

Natrona County

Allie claims — Secs. 12 and 13, T.39N., R.88W.; Secs. 7 and 18, T.39N., R.87W.

Russell and Devore (1948) reported allanite in and at the margins of pegmatites at the southern end of the Bighorn Mountains. The lenses of granitic pegmatites are generally parallel to the regional northwest-trending foliation in the enclosing Precambrian gneiss. Twenty-three claims mostly encompass scattered outcrops of pegmatite and pegmatitic float. Due to the scatter of pegmatitic materials, the number and extent of pegmatites is not certain. Allanite was reported on the basis of hand specimen and microscopic examinations. The radioactive allanite grains are from 1/4 to three inches in length. No estimates of the percentage of allanite were reported, and only geiger counter surveys of radiation were performed (after Russell and Devore, 1948).

The mineralogical characteristics reported by Russell and Devore (1948) for their allanite do not conform with those for allanite in Roberts and others (1974). Therefore the presence of rare earth elements in Russell and Devore's (1948) dark radioactive mineral is not certain.

Little Basin area — SW1/4SW1/4 sec. 22, NW1/4NW1/4NW1/4 sec. 27, T.29N., R.83W.

Griffin and Milton (1982) report high thorium levels in the Flathead Formation at these sites. They believe the thorium was concentrated in a paleobeach placer. The amount of rare earths at these sites should be determined because fluvial paleoplacers in the Flathead Formation at Bald Mountain contain abundant rare earths, and they were once considered to be beach paleoplacers.

Ranger no. 1 claim — SW1/4 sec. 22, T.34N., R.84W.

This might be the location of a fossil beach placer in the Cretaceous Lance Formation. The rocks on this claim are described as an arkosic sandstone and a conglomerate with heavy minerals, local iron oxide staining, and minor carbonaceous material (Griffin and Milton, 1982). The description raises the possibility that a roll front could be present. For example, chemical analyses demonstrate thorium is 30 times as abundant as uranium, which can occur in a remnant roll front or fossil placer. Rare earth abundances are from 500 to 1,000 ppm lanthanum and 70 to 500 ppm yttrium.

Clarence Wood Lode claims — center SE1/4 sec. 5, T.29N., R.85W.

These claims are on Precambrian, epidote-rich, irregularly shaped dikes in granite. A sample of the dike contained 700 ppm lanthanum and 100 ppm yttrium, but no rare earth-bearing minerals were reported (Griffin and Milton, 1982).

Park County

Dilworth Bench NE1/4 T.56N., R.104W.

Garrand and others (1982) reported that a sample of Flathead Sandstone obtained along Barrus Creek on the Dilworth Bench contained 1,000 ppm lanthanum. This site might be a paleoplacer in the Middle Cambrian basal Flathead Sandstone.

Bald Ridge(?) Sec. 25, T.56N., R.104W.

A radioactive pegmatite in Precambrian rocks has been reported at this site. The pegmatite is reportedly allanite- and rare earth-bearing (Wilson, 1960; Olsen and Adams, 1962). This location is in Cambrian sedimentary rocks (Pierce, 1965), so the information appears erroneous.

Sawtooth Lake area(?) SE1/4 T.57N., R.105W. unsurveyed

This location is reported in latitude and longitude by Olsen and Adams (1962). They state gadolinite (beryllium- and rare earth-bearing mineral) and possibly other rare earth minerals are present in a pegmatite at this site on the Beartooth Plateau. The plateau is dominantly Precambrian gneiss. Some beryl-bearing pegmatites have been reported four miles north of the Sawtooth Lake area (Harris, 1959), so the exact location is even uncertain.

Sublette County

Fremont Butte area NW1/4 sec. 21, T.32N., R.107W.

Love (1954b) reports that a sample of Precambrian granite from this site contained greater than 0.1 percent (1,000 ppm) each of cerium, lanthanum, and neodymium. No rare earth-bearing minerals were reported (Love, 1954b). If confirmed, these rocks contain more neodymium than any other rocks in the State, and they might be a source of rare earths (greater than 3,000 ppm total REE).

Washakie County

Prospect Creek area W1/2 sec. 26, T.48N., R.86W.

Damp and Jennings (1982) report high thorium concentrations in a paleoplacer in the Flathead Formation at this site. Lanthanum and yttrium concentrations in the conglomerate are reportedly low (215 ppm and 40 ppm, respectively) but zirconium concentrations are high (1,650 ppm) (Damp and Jennings, 1982). Wilson (1960) reports high radioactivity in the Flathead Formation in this area. This area warrants further examination because of its similarity to the rich rare earth paleoplacers in the Flathead Formation on Bald Mountain.

Occurrences in Mesozoic beach placers

Radioactive, titaniferous, black sandstones of Late Cretaceous age are present at many locations in Wyoming (Figure 2 and Table 4). These black sandstones have been interpreted as fossil placers and are known to contain columbium and rare earth elements. Rare earth elements are present in monazite, in an unidentified opaque mineral, and probably in zircon. Zircon makes up about 5 to 17 percent of the black sands while the monazite content ranges from zero to four percent. The abundances of the unidentified opaque mineral have not been reported (Houston and Murphy, 1962), but are probably less than one-half percent. X-ray diffraction patterns from the columbium-bearing opaque mineral do not match those for columbite, tantalite, or euxenite, but the mineral contains cerium and lanthanum (Houston and Murphy, 1962). Eighteen reliable analyses for lanthanum have been done on 15 sandstones (Table 3); the results vary from 50 to 1,687 ppm lanthanum and do not correlate with monazite content. Eight analyses on eight sandstones have been done for yttrium (Table 4); the results vary from less than ten ppm to 500 ppm yttrium (Madsen, 1982; Morris and Stanley, 1982; Garrand and others, 1982; Griffin and Milton 1982; Madsen and Reinhart, 1982).

None of the black sandstones have been systematically examined as a source for rare earths, columbium, and tantalum. A systematic sampling program and chemical analyses are needed in order to determine the potential value of the black sandstones. Occurrences of columbium, tantalum, and rare earths in unreported black sandstones of Late Cretaceous age cannot be ruled out either.

Site 25 (Figure 2 and Table 4) is a Late Jurassic titaniferous, black sandstone of uncertain origin. It is not known if this black sandstone contains columbium, tantalum, or rare earth elements (Houston and Love, 1956). The existence of this Jurassic black sandstone means additional black sandstones that are not Late Cretaceous in age may be present in Wyoming.

The information in Table 4 and on Figure 2 is from Houston and Murphy (1962, 1970); Houston and Love (1956); Dow and Batty (1961); Madsen (1982); Morris and Stanley (1982); Garrand and others, (1982); Griffin and Milton (1982); and Madsen and Reinhart (1982).

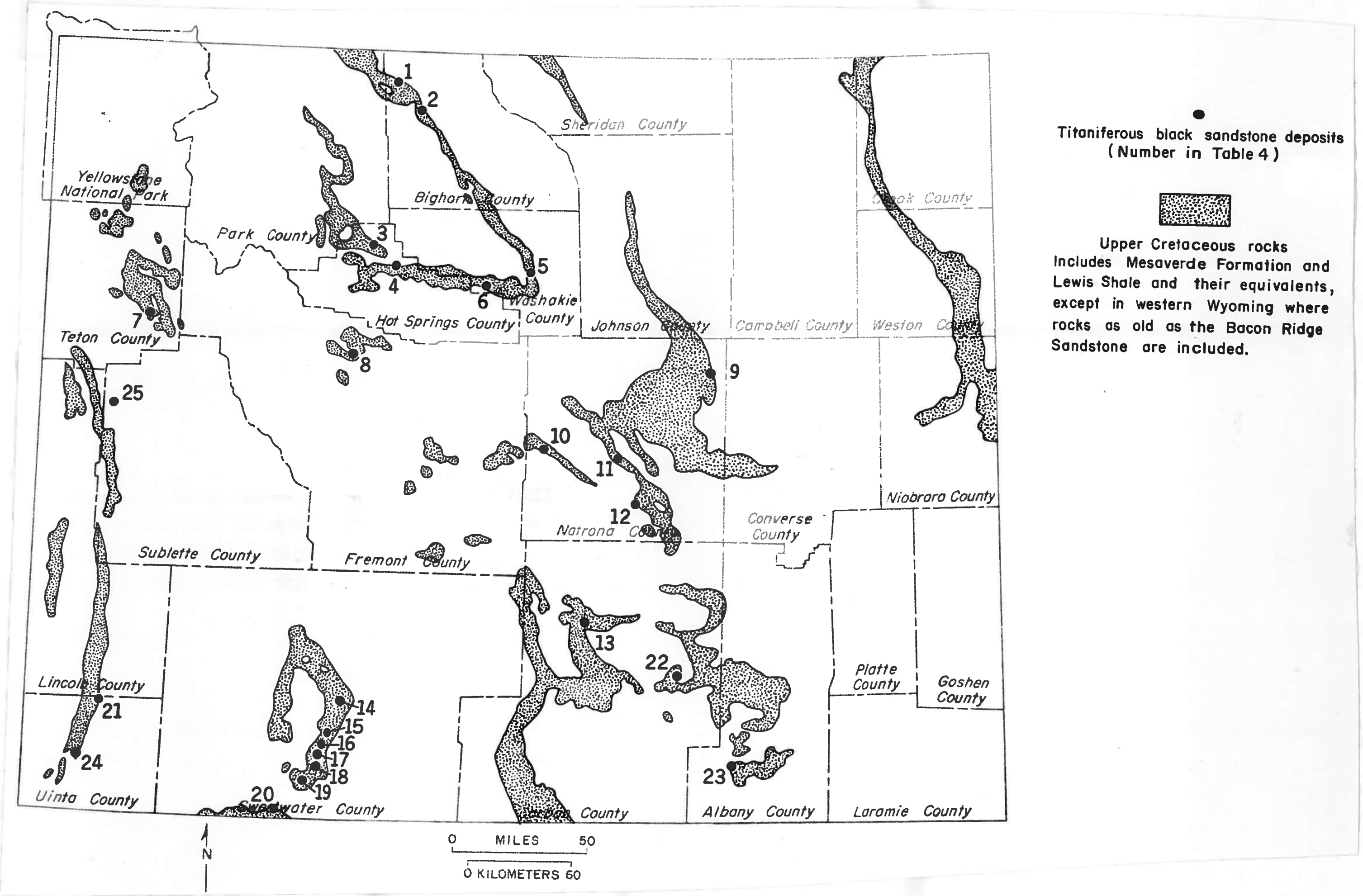


Figure 2. Locations of Mesozoic black sandstone (beach placer) deposits and outcrops of host formations in Wyoming. Numbers refer to listing in Table 4.

Table 4. Mesozoic black sandstone (beach placer) deposits in Wyoming.

Area	No.*	Location			Extent (feet)		Thickness (feet)		Lanthanum content (ppm)	Yttrium content (ppm)
		Section	T.N.	R.W.	Length	Width	Maximum	Average		
Cowley	1	1, 4	56	97	900+	Unknown	3.5	1	135- 400	<10
Lovell	2	7	55	95	5,000+	Unknown	4.0	3	50- 316	<10
		12	55	96						
Grass Creek	3									
Northern segment		8, 9, 16	46	98	5,600+	680+	16.0	11	1,374	
Southern segment		33, 34	46	98	Unknown	1,600	5.0	Unknown	1,020	
Cottonwood Creek	4	26	45	97	150	150	9.0	Unknown	1,687	
Dugout Creek	5	34, 35	45	89	14,256	1,500+	25.0	11	312	
		2, 11	44	89						
Mud Creek	6	19	44	91	1,500+	100+	7.5	Unknown	500	
Dry Cottonwood Creek	7	27	42	112	Unknown	Unknown	Unknown	Unknown		
Shotgun Bench	8	18	5	1E.	Unknown	300	5.0	Unknown		
Salt Creek	9									
Northern Segment		24, 25, 36	39	78	8,976+	Unknown	Unknown	Unknown		
		31	39	77						
Southern Segment		19, 30	38	77	5,280+	750	Unknown	Unknown		
Coalbank Hills	10	5	34	88	1,400+	Unknown	5.0	Unknown		
Poison Spider	11	1	33	84	300+	Unknown	7.0	Unknown	300-1,000	70-300
		36	34	84						
Clarkson Hill	12	20	31	82	150+	20+	5.6	Unknown		
Seminoe	13	25	25	85	Unknown	Unknown	Unknown	Unknown		
		15, 28	24	85						
Beacon	14	19	19	101	2,700	150	Unknown	7	700	300
Black Butte Creek	15	30	18	101	1,500+	Unknown	4.0	Unknown	1,500	500
Honnes Ranch	16	11	17	102	2,500	50-100	Unknown	4	1,000	100
Pretty Water Creek	17	8	16	102	450+	Unknown	Unknown	3		
Dans Creek	18	13	15	103	Unknown	250	Unknown	5.5		
Salt Wells Creek	19	7	14	103	250	Unknown	3.0	Unknown	500	100
Red Creek	20	22	12	105	800	Unknown	6.0	5	700	
Cumberland Gap	21	25	18	117	13,200+	200	Unknown	Unknown		
		18, 19, 30	18	116						
Fiddler's Green	22	21	21	80	2,600	Unknown	13.0	Unknown		
Sheep Mountain	23	10	15	77	1,900	50	17.0	Unknown	706	
Spring Gap	24	8, 17, 30	16	117	900+	30	Unknown	2.5	1,000	80
Cliff Creek	25	33	38	114	Unknown	Unknown	Unknown	4		

* = number on Figure 2.

Rare earths in Eocene lacustrine rocks (trona and phosphatic zones)

Rare earth-bearing carbonate minerals, burbankite, mckelveyite, and ewaldite have been found in the Eocene Wilkins Peak member of the Green River Formation, an evaporitic lacustrine unit (Figure 3). The abundances of these minerals are described as extremely scarce to never abundant (Milton, 1971). In most samples, the minerals are dark green to black due to admixed organic material (Milton and others, 1965); therefore, these minerals could be overlooked in most examinations, and could be more abundant. The locations of the reported occurrences of these minerals are shown in Table 5 and Figure 3. Most are in the lowermost Wilkins Peak member (uraniferous phosphate zone 1, trona bed 1). These rare earth-bearing carbonate minerals are apparently in and associated with trona beds (trona beds 17 and 1) and uraniferous phosphatic zones (zones 1 and 2a) (Love, 1964). No geochemical analyses for rare earth elements are available for any trona bed. Semiquatitative analyses from ten surface samples indicate a rare earth enrichment in uraniferous phosphatic zone 1 of over 1,000 ppm total rare earths, with some enrichment in zone 2a that is less than 1,000 ppm total rare earths (Table 5 and Figure 3) (after Love, 1964). Mott's (1978) analyses show no evidence of rare earth enrichment, so lateral changes are probable.

The extent of rare earth-bearing trona and uraniferous phosphatic rock is probably larger than that encompassing the localities shown in Figure 3, but it is not known which other trona beds or portions of trona beds are mineralized. The outline of the U.S. Geological Survey's trona resources area is shown on Figure 3 (Culbertson, 1971). An outline for uraniferous phosphatic rocks is not shown because lateral changes are quite common (Love, 1964).

It might be possible to obtain rare earths as a by-product from trona mining and processing. Rare earth-bearing carbonate minerals have been reported in trona bed 17 (Love, 1964) which is presently being exploited, as well as in waste from soda ash production (Milton and others 1965). Also of possible economic importance is the fact that yttrium and HREE are selectively enriched in intimately intergrown mckelveyite-ewaldite while LREE are selectively enriched in burbankite. Additional information on the mineralogy of these minerals is in Milton and others (1965), Donnay and Donnay (1971), Donnay and Preston (1971) and Fitzpatrick and Pabst (1977); their information on mineral localities is different than Love's (1964). Love's (1964) locations have been used for all but one site (Table 5).

Exposed lacustrine Eocene uraniferous phosphatic zones along the Beaver Divide and on Lysite Mountain are also enriched in rare earths, but no rare earth-bearing minerals have been reported (Figure 3). The lone sample from Beaver Divide appears to contain more than 2,000 ppm total rare earths and is in Aycross equivalent rocks (sec. 34, T.32N., R.95W.). The five samples from the Lysite Mountain area (sec. 20, T.42N., R.90W.; sec. 34, T.42N., R.91W.; sec. 10, T.40N., R.91W.) are not notably enriched in rare earths, except for cerium (after Love, 1964). These Lysite Mountain surface samples are from the Tepee Trail and possibly Aycross equivalent rocks (Love, 1964). As with the other Eocene uraniferous phosphatic rocks, rare earth mineralization might be more widespread than just the localities shown in Figure 3.

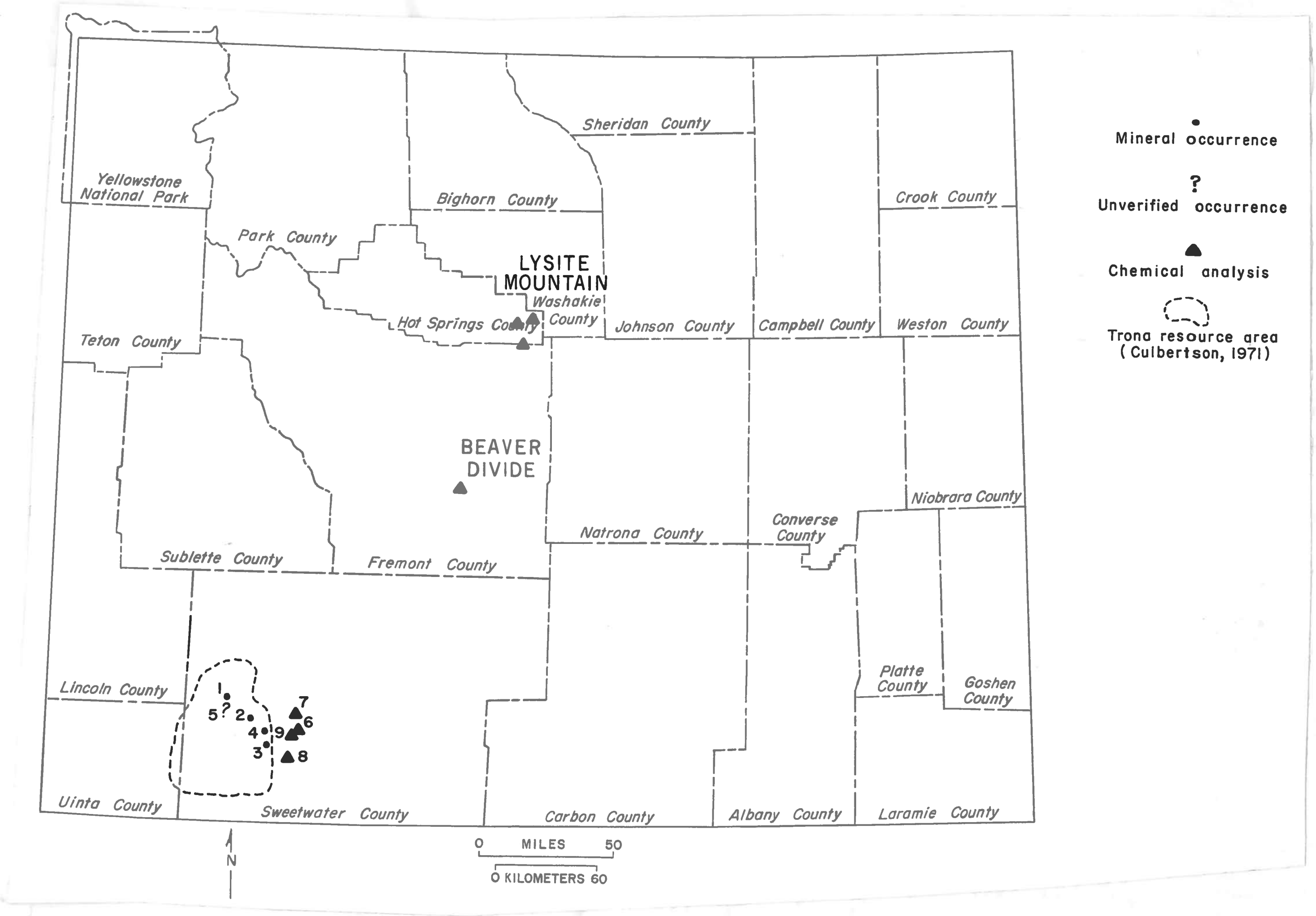


Figure 3. Locations of rare earth-bearing Eocene lacustrine rocks. Numbers refer to listing in Table 5.

Table 5. Locations of occurrences of rare earth-bearing carbonate minerals and sites of rare earth enrichment in the Wilkins Peak member of the Green River Formation.

Name	No.*	Location	Comments
Confirmed Occurrences[a]			
FMC Westvaco mine	1	Sec. 15, T.19N., R.110W in trona bed 17; shaft location	also green minerals in soda ash waste
Diamond Alkali Company Daco No. 3	2	NW1/4NW1/4 sec. 17, T.18N., R.108W. Basal Wilkins Peak, near trona bed 1	at 1,369 feet deep in lean uraniferous phosphatic rock (zone 1)
Diamond Alkali Company Reid No. 2	3	SE1/4SE1/4 sec. 32, T.17N., R.107W. Basal Wilkins Peak; near trona bed 1	at 1,422.5 feet deep in zone 1
JM Perkins Green River No. 3	4	SW1/4 sec. 8, T.17N., R.107W. Basal Wilkins Peak; near trona bed 1	at 1,784 feet deep in zone 1
Unverified Occurrence[b]			
Mountain Fuel Supply Company John Hay Jr., No 4	5	SW1/4NW1/4 sec. 2, T.18N., R.100W. near trona bed 17	at uncertain depth, trona bed 17 at 1,590 feet deep
Sites of rare earth enrichment (all in uraniferous phosphate)[a]			
Oro and Lulu claims and both Ridge sections	6	secs. 10, 11, 14, T.17N., R.106W. Basal Wilkins Peak	5 surface samples, zone 1
Old Log Inn and Northeast areas	7	secs. 12, 25, T.18N., R.106W. Basal Wilkins Peak	2 surface samples, zone 1
Diamond Alkali Reid No. 2	8	sec. 32, T.17N., R.107W.	at 1,331 feet deep, zone 2a
South Firehole Canyon Area	9	sec. 20, T.16N., R.106W.	surface sample, zone 2a

[a] Love, 1964.

[b] Milton and others, 1965; Fahey, 1962.

* Number on Figure 3.

Rare earths in phosphorite of the Phosphoria Formation

The phosphorite in the Phosphoria Formation in western Wyoming is a potential source for various metals as by-products from phosphate production. Because rare earths are often relatively abundant accessory elements in apatite, an important phosphate mineral in phosphorite (Gulbrandsen, 1966), rare earths might also be recovered during phosphate production (see, for example, Lounamaa and others, 1980). To date, the number of analyses for rare earth elements in phosphorite in the Phosphoria Formation in Wyoming is limited, and abundances of all the rare earths have never been reported. The sample locations are scattered and include lean phosphorite so regional trends in rare earth concentrations cannot be determined (Figure 4, Table 6). However, rare earth concentrations are higher in rocks with higher phosphorous contents because more apatite is present. Therefore, the best phosphate ores are probably the richest rare earth ores. In Wyoming, a potential resource of about 700-1,000 ppm total rare earths probably exists in phosphorite (after Altschuler and others, 1967; Vine, 1966; Gulbrandsen, 1966; Motooka and others, 1984).

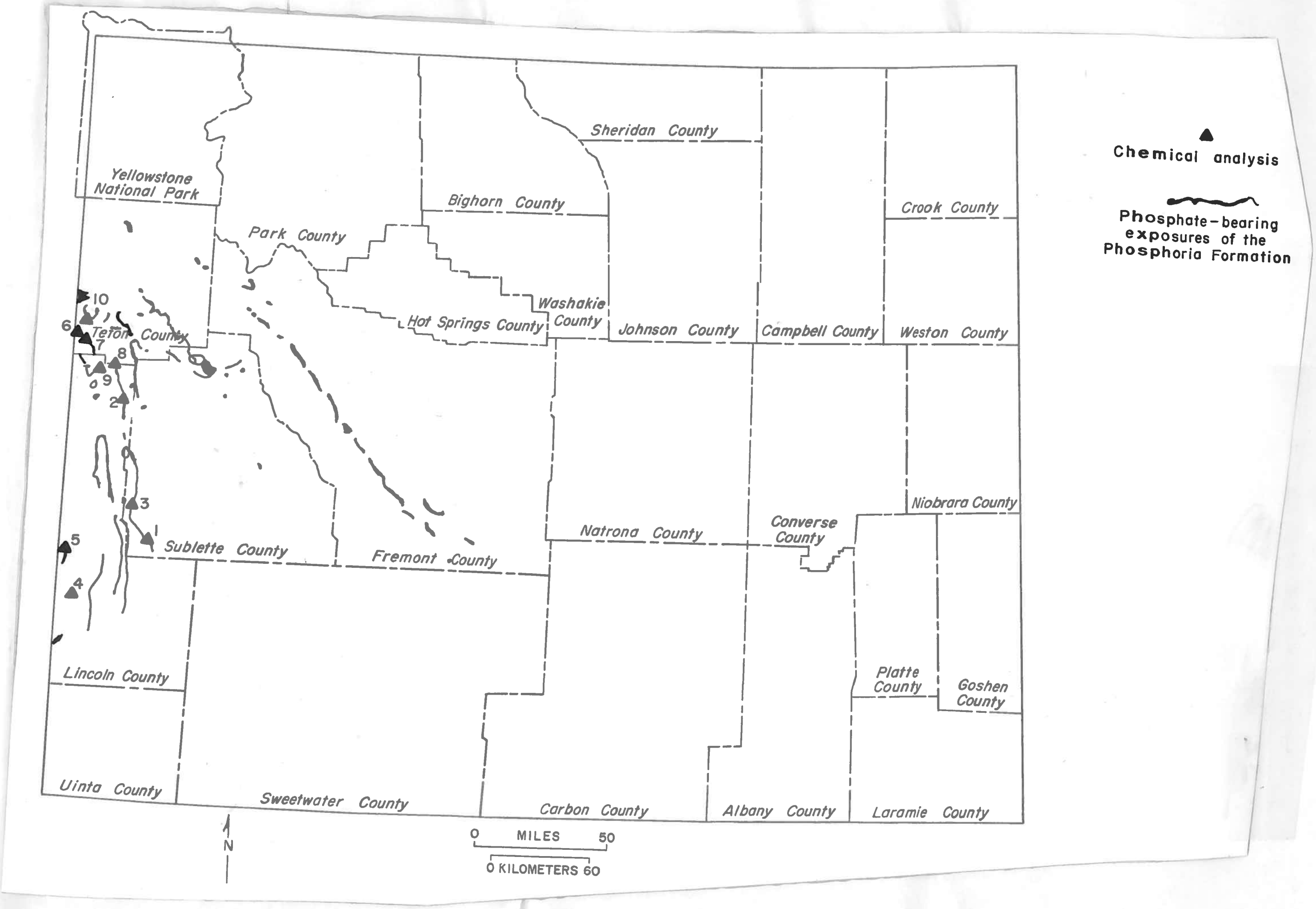


Figure 4. Locations of samples from phosphorite in the Phosphoria Formation that have been analyzed for rare earths. Numbers refer to listing in Table 6.

Table 6. Locations of sample sites of phosphorite in the Phosphoria Formation, with results of rare earth analyses.

		Location			Part per million				
Name	No.*	Section	T.N.	R.W.	La	Y	Yb	Nd	Ce
Deadline Ridge Section 2 samples (a, d)	1	7	27	114	100-300	300	3	nd	-
Steer Creek Section 2 samples (a, d)	2	9	36	116	100-300	300	10	nd-300	-
Middle Piney Lake Section 2 samples (a, d)	3	8	30	115	300	100-300	10	nd-300	-
Cokeville Section 2 samples (a, e)	4	4	24	119	100	300	3-10	300	-
Raymond Canyon Section 31 samples (b, e)	5	6	26	119	50-700	50-1,000	-	nd-700	-
Siddoway fork trench 3 samples (c)	6	uns	40	118	130-180	150-200	-	-	28-44
North Fork Big Elk Creek trench 7 samples (c)	7	uns	39	118	130-520	160-520	-	-	34-140
Astoria Hot Springs trench 2 samples (c)	8	32	39	116	79-300	100-410	-	-	20-86
Wolf Creek trench 9 samples (c)	9	uns	38	117	140-320	170-440	-	-	48-90
Teton Pass west pit 1 sample (c)	10	uns	41	118	170	220	-	-	36

uns = unsurveyed; nd = not detected; - = no analysis performed.

* Number on Figure 4.

References: a, Gulbrandson, 1966; b, Vine, 1966; c, Motooka, 1984: d, Sheldon, 1963; and e, Sheldon and others, 1953.

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