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STATE OF SOUTH DAKOTA
Joe Foss, Governor

STATE GEOLOGICAL SURVEY
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REPORT OF INVESTIGATIONS

NO. 79

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A PRELIMINARY REPORT ON THE URANIUM IN SOUTH DAKOTA

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by

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INTRODUCTION

Since the advent of the atomic bomb, nation-wide attention has been focused on atomic energy as a source of industrial power. At present, uranium, the basic raw material, is the only naturally occurring substance found in sufficient quantities to be used in the large-scale production of atomic energy. Consequently, the United States Atomic Energy Commission is offering an attractive bonus and a guaranteed price schedule to stimulate exploration, discovery, and production of uranium.

Purpose of Report

Many inquiries have been received by the Survey from uranium-conscious people who wish to obtain information concerning the uranium deposits in South Dakota and the general occurrence, mineral identification, and sale of uranium-bearing ores. Therefore, the first part of this report is designed to provide some of the basic fundamentals and general information which may be useful to the prospector as a guide in his search for uranium. The second portion of this report is concerned with the uranium deposits in South Dakota.

Acknowledgements

The author gratefully acknowledges the kind cooperation and helpfulness of those who were instrumental in the successful culmination of this report. Mr. John W. King, Chief of the Atomic Energy Commission's sub-office at Hot Springs, South Dakota, and Atomic Energy Commission geologists Ralph Hall, Harry Young, and Parker Davies provided considerable data concerning uranium and uranium deposits in the State. The author has drawn freely from available literature and appreciates the use of this material, thus claiming no originality for the utilization of such material. Special thanks are extended the Survey publications department. The writer is indebted to Mrs. Pat Rist for her excellent drafting of many illustrations.

I PROSPECTING FOR URANIUM

URANIUM-BEARING MINERALS

Uranium-bearing minerals are radioactive as they spontaneously emit energy in three different types of radiation: (1) alpha particles which are helium nuclei, (2) beta particles which are electrons, and (3) gamma rays which are short-wave radiations, resulting from the bombardment of matter by electrons which are formed in radioactive decompositions. Geiger and scintillation counters detect gamma rays.

Chemically and mineralogically, the element uranium does not occur as a pure element in nature, but does unite with other elements to form compounds. Over 100 uranium-bearing minerals are known in which uranium may constitute a relatively large or small percentage of the minerals.

Prospectors should have a knowledge of the diagnostic mineral characteristics to help identify the chief uranium-bearing minerals or those which have been found in commercial quantities or offer commercial possibilities. Several of the important uranium-bearing minerals which occur in South Dakota are discussed in a later chapter, and their chemical compositions and principal physical characteristics are listed in Table 1, pp. 8-11.

Classification of Uranium Minerals

Geologists classify uranium-bearing minerals as primary and secondary. Primary uranium minerals were formed as a result of ascending molten solutions, originating deep within the earth, which solidified on or near the earth's crust. Secondary uranium minerals are alteration products of the primary minerals as a result of surface or near surface weathering processes. In many instances, secondary minerals enter solution and are transported and deposited elsewhere. This sequence of events may be repeated with the formation of new secondary uranium minerals. While some secondary uranium minerals are intimately associated with their parent primary minerals, others may be transported and deposited miles away from the provenance or source areas.

Primary Uranium Minerals

Primary uranium minerals usually occur in veins or pegmatites. They are generally steel to velvety black or grayish or greenish black in color, pitch-like, greasy, glassy, or sub-metallic in luster, and higher in uranium content, specific gravity, and hardness than most secondary uranium minerals. Detailed descriptions of pitchblende and uraninite, the chief primary minerals, follow:

Pitchblende UO_2 (uranium oxide)

Pitchblende is the most important uranium mineral and is the source of major uranium production in the Belgian Congo, Canada, and Czechoslovakia. It has been reported in non-commercial amounts in Lawrence and Pennington Counties, South Dakota. It usually occurs in metalliferous veins and may be associated with sulphides and arsenides of nickel, cobalt, silver, lead, iron, copper, and bismuth. Pitchblende has a steel to grayish black color, pitch-like, greasy, or dull luster, conchoidal fracture, found in dense massive, rounded, and irregular forms, and is heavier than iron and about as hard as steel. The mineral contains 50 to 80 percent U_3O_8.

Uraninite UO_2 (uranium oxide)

Uraninite occurs in veins and rarely in pegmatites. It has been reported in Custer, Lawrence, and Pennington Counties, South Dakota. This mineral and pitchblende have nearly identical chemical and physical characteristics. However, uraninite occurs in aggregates of small, distinct, cube-shaped crystals. The mineral contains 65 to 85 percent U_3O_8.

Secondary Uranium Minerals

Many secondary uranium minerals are found principally in sandstones and shales, although they may occur in almost any type of rock. These minerals exhibit vivid colors, ranging from brilliant canary yellow and bright orange to emerald green. They may be in the form of powdery and earthy masses, thin crusty coatings, or groups of thin tabular, platy crystals. Secondary minerals contain smaller percentages of uranium than pitchblende and uraninite. The secondary minerals that are being mined for uranium or have been reported to contain commercial percentages of uranium oxide in South Dakota are summarized as follows:

Carnotite $K_2(UO_2)_2(VO_4)_2 \cdot 3H_2O$ (potassium uranium vanadate)

Carnotite is found in Butte, Custer, Fall River, Harding and Pennington Counties, chiefly in sandstones, lignite coal, shale, and chalcedony veins. Carnotite ore has been mined in Fall River County since 1951. The mineral displays a bright canary yellow color, making a sharp color contrast with the enclosing country rock, except in a few instances where iron and/or organic stain alters the color. The luster is dull when earthy and silky to pearly when finely crystalline. It occurs commonly in earthy masses or finely crystalline powder. The hardness is 2 to 3, and the specific gravity is about 4. The mineral contains 50 to 55 percent U_3O_8.

Tyuyamunite $Ca(UO_2)_2(VO_4)_2 \cdot 7\text{-}10\frac{1}{2}H_2O$, Metatyuyamunite $Ca(UO_2)_2(VO_4)_2 \cdot 5\text{-}7H_2O$ (calcium uranium vanadate)

Tyuyamunite is intimately associated with carnotite in the Lakota and Dakota sandstones in Fall River, Custer, Harding, and Pennington (?) Counties. Metatyuyamunite is tentatively identified from a sandstone in the White River Badlands, Pennington County. Tyuyamunite is termed "calcium carnotite" because of the close resemblance. Tyuyamunite and metatyuyamunite are yellow to greenish yellow (turns green on exposure to sunlight), pearly to waxy in luster, massive to finely crystalline scales and flattened laths with perfect micaceous cleavage, hardness of 2, and specific gravity of 3.3 to 4.3. These minerals contain 48 to 57 percent U_3O_8.

Uranocircite $Ba(UO_2)_2(PO_4)_2 \cdot 8H_2O$ (barium uranium phosphate)

It is found in sandstone in the White River Badlands, Pennington County. Uranocircite has a yellowish green color, pearly luster, mica-like crystals, hardness of 2 to $2\frac{1}{2}$, and specific gravity of $3\frac{1}{2}$. The mineral contains 55 percent U_3O_8.

Autunite $Ca(UO_2)_2(PO_4)_2 \cdot 10H_2O$ (calcium urainum phosphate)

Autunite occurs in siltstone, limestone, and igneous rocks in the Black Hills, Lawrence, Custer, and Pennington Counties and in some coals, clinker beds, and carbonaceous materials in Harding County. The mineral is identified by a lemon-yellow or apple-green color, a vitreous, silky, or pearly luster, a hardness of 2 to $2\frac{1}{2}$, and a specific gravity of about 3. It is generally found as thin micaceous coatings or thin tabular crystals in rock fractures or along bedding planes. Notably, it fluoresces a brilliant apple-green or yellow under ultraviolet light. The mineral contains about 58 to 61 percent U_3O_8.

Other uranium-bearing minerals have been reported in the State, but as yet they do not contain 0.1 percent U_3O_8, the marketable minimum. An unidentified "organo-uranium complex" mineral is presently being mined in the South Cave Hills, Harding County.

The State Geological Survey and the Atomic Energy Commission at Hot Springs do not have samples of radioactive ores and minerals available for distribution to the public. However, the State Geological Survey does have a number of ore specimens on display. Persons wishing to obtain such samples may purchase them from the following mineral dealers:

Greiger's
1633 East Walnut Street
Pasadena 4, California

V. D. Hill
Route 7, Box 188
Salem, Oregon

A. D. Mackay
Suite 503-504
198 Broadway
New York 7, New York

Schortmann's Minerals
6 and 10 McKinley Ave.
Easthampton, Massachusetts

Plummer's
2183 Bacon Street
San Diego 7, California

Ward's Natural Science Est.
P. O. Box 24, Beechwood Sta.
Rochester 9, New York

Thorium Minerals

Thorium is a radioactive element, and it may occur in sufficient quantities to affect radiation detection instruments. Thorium minerals such as thorianite and thorite contain up to 33 percent U_3O_8. However, monazite, which has been reported in Custer, Lawrence, and Pennington Counties, carries only up to 1 percent U_3O_8 and from 2 to 15 percent ThO_2 (thorium oxide). The principal identifying characteristics of thorianite and thorite are listed in Table 2, pp. 10 to 11.

TABLE 1.--URANIUM MINERALS REPORTED

Black

Name Chemical Comp.	% U_3O_8	Color	Streak	Flourescence	Luster
<u>Pitchblende</u> UO_2 (uranium dioxide)	50-80	Steel to velvety black, grayish, greenish	Brownish black, gray olive-green shiny	None	Pitch-like, earthy, dull, or glassy
<u>Uraninite</u> UO_2 (uranium dioxide)	65-85	Black (grayish, greenish, brownish)	Brownish black, gray-ish, olive-green shiny	None	Submetal-lic, pitch-like, dull or greasy
<u>Rauvite</u> $CaO.2UO_3.5V_2O_5.16\ H_2O$ (?) (Calcium uranium vanadate)	27-31	Brownish red, pur-plish black	Light brown	None	Adaman-tine to waxy
					Yellow
<u>Carnotite</u> $K_2(UO_2)_2(VO_4)_2.3H_2O$ (Potassium uranium vanadate)	50-55	Canary yellow	Yellow	None	Earthy, dull; Crystal pearly

IN SOUTH DAKOTA

Minerals

Hardness	Specific Gravity	Crystal Habit	Occurrence	Remarks	County Reported
5-6	6.5-8.5	Colloform, rounded surfaces, massive	Veins with Co, Ni, Ag, secondary U minerals	Always blackish, slivers, powdered	Lawrence Pennington
5-6	8-10	Massive, crystalline	Pegmatites veins	Same as Pitchblende	Custer Lawrence Pennington
Variable	3	Masses, crusts, filmy coating	Fills cracks, impregnates sandstones	Very fine grained, variable physical properties	Fall River

Minerals

Soft, 2-3	4-5	Earthy masses, crystalline, powdery	Scattered deposits, lenses in sandstone fossils, logs	Color may be masked or dulled by iron or organic stain	Butte Custer Fall River Harding Pennington

TABLE 1.--URANIUM MINERALS REPORTED

Name Chemical Comp.	% U_3O_8	Color	Streak	Flourescence	Yellow Luster
Autunite $Ca(UO_2)_2(PO_4)_2.10H_2O$ (Calcium uranium phosphate)	58-61	Lemon yellow; apple green	Yellow	Bright yellow green	Vitreous, pearly
Uranocircite $Ba(UO_2)_2(PO_4)_2.8H_2O$ (Barium uranium phosphate)	55	Yellow-green	------	None	Pearly
Tyuyamunite $Ca(UO_2)_2(VO_4)_2.nH_2O$ (Calcium uranium vanadate)	48-55	Greenish yellow; Canary yellow	------	None or very weak green	Earthy pearly
Torbernite $Cu(UO_2)_2(PO_4)_2.12H_2O$ (Copper uranium phosphate)	56-61	Emerald to apple green	Pale green	None or faint green	Vitreous, pearly
Uranophane $CaO.2UO_3.2SiO_2.7H_2O$. (Calcium uranium silicate)	65-76	Lemon-yellow, orange yellow	Paler than color	None to faint green	Pearly to greasy
Becquerelite $2UO_3.3H_2O$ (Uranium oxide)	80	Amber to brownish yellow	Yellow, yellowish brown	------	Adamantine, resinous, greasy

Minerals

Hardness	Specific Gravity	Crystal Habit	Occurrence	Remarks	County Reported
2-2.5	3	Micaceous crystals small, thin tabular	Coatings on many types of rocks	Always fluoresces, fairly common with uraninite, silver, iron	Custer Harding Lawrence Pennington
2-2.5	3.5	Mica-like crystals, similar to autunite	With autunite and torbernite	Resembles autunite	Pennington
2-3	3.3-4.3	Earthy, crystalline coatings, scales	Associated with calcite, sometimes carnotite	Similar to carnotite turns green on exposure to sunlight	Custer Fall River Harding Pennington(?)
2-2.5	3.2	Micaceous aggregates, square crystals	Coatings on many types of rocks	Common secondary uranium mineral	Custer Lawrence Pennington
2-3	3.8-3.9	Radiating aggregates, rosettes, fibrous	Veins, pegmatites, limestone	Associated with other uranium minerals	Pennington
2-3	5.2	Tabular, elongated crystals; also massive	Alteration product of pitchblende	Darker yellow color than carnotite and tyuyamunite	Harding(?)

TABLE 1.--URANIUM MINERALS REPORTED

Yellow

Name Chemical Comp.	% U_3O_8	Color	Streak	Flourescence	Luster
Gummite Variable (chiefly hydrated uranium oxide)	40-80	Reddish yellow, orange red	Yellow	None	Vitreous to pearly
Metazeunerite $Cu(UO_2)_2(AsO_4)_2 \cdot 8H_2O$. (Copper uranium arsenate)	56	Grass to emerald green	Yellow-green	----	Vitreous to pearly

TABLE 2.--SOME COMMON

Black

Name	Percent ThO_2 / Percent U_3O_8	Color	Streak	Flourescence	Luster
Thorianite $(Th,U)O_2$ (Thorium, uranium oxide)	50-90 / 0-33	Black (brownish, ~~gray~~ ish)	Same as color	None	Submetallic dull, or greasy
Thorite $ThSiO_4$ (Thorium silicate)	25-65 / 0-22	Largely black, reddish brown, orange	Orange-yellow, Brown	None	Fresh: glassy; altered: dull to greasy

Minerals Hardness	Specific Gravity	Crystal Habit	Occurrence	Remarks	County Reported
2.5-3	3.9-4.2	Rounded or flattened pieces, resembling gum	Alteration product of uraninite or pitchblende	Commonly with pitchblende. Conchoidal fracture	Pennington
2-2.5	3.6	Tabular crystals or square plates	Coats joints and fracture surfaces	Resembles torbernite. Uneven fracture	Pennington

THORIUM MINERALS

Minerals Hardness	Specific Gravity	Fracture	Crystal Habit	Occurrence	Remarks
5-7	6.5-9.8	Uneven to sub-conchoidal	Cubic crystals, may be water worn	Placers and pegmatites	May have bronze tarnish
4.5-5	4-5.4	Conchoidal, brittle	Massive or compact crystals	Placers, small amounts in granites, pegmatites	Varieties rich in uranium are massive

MODE OF OCCURRENCE

According to Mason (1952, p. 41), the average amount of uranium in the earth's crust is 4 grams per ton or 4 parts per million as compared with 0.1 for silver and 0.005 for gold. This comparison in addition to the vast number of uranium-bearing minerals may imply that uranium is prevalent in considerable amounts; however, commercial concentrations are relatively few.

Where to look for uranium is a problem of importance to the prospector. Uranium ore deposits occur principally in igneous and sedimentary rocks, and the chief modes of occurrence of the uranium-bearing minerals in igneous and sedimentary rocks are grouped accordingly as follows:

Igneous Rocks

Igneous rock bodies assume many shapes and sizes; however, pitchblende and uraninite occur primarily in vein deposits and to a lesser extent in pegmatite deposits. The shape, size, areal extent, and structural attitude of a mineralized body are important in ascertaining the mining methods and the overall commercial aspects.

Veins

Veins are sheetlike or tabular-shaped deposits of minerals which fill cracks, fissures, faults, or joints in almost any type of host or enclosing rock. Major occurrences of pitchblende in veins are those in the Katanga region, Belgian Congo; at Great Bear Lake, Canada; and, in the Joachimsthal Mines, Czechoslovakia. Domestic pitchblende-bearing veins are found in Colorado, Idaho, Montana, Arizona, Utah, and Nevada where pitchblende may be associated with lead, zinc, copper, silver, and gold.

Pegmatites

Pegmatites are light-colored coarse-grained igneous rocks with the composition of granite whose chief constituents are feldspar, quartz, and mica. Thus far, uranium-bearing pegmatites are rarely of economic significance. Generally, the uranium minerals occur in small pockets or nests in pegmatites, and uraninite is encountered more frequently than pitchblende. Many pegmatites exist in the Black Hills and scattered uraninite has been found in some of them, but no commercial deposits have been discovered.

Sedimentary Rocks

These rocks consist of minerals or rocks derived from pre-existing rocks as a result of either weathering processes, organisms, or chemical precipitation.

The principal sedimentary rocks which contain uranium-bearing minerals are sandstones and shales, while minor amounts are found in lignitic coals, placer deposits, limestones, and fossils.

Sandstones

Uranium minerals occur in sandstones, clayey sandstones, or conglomeratic sandstones. Some deposits are found in thin lens-like, irregular-shaped masses, while others are relatively thick, widespread, and fairly uniform with mineralization roughly parallel to the bedding planes. The grade of uranium ore may fluctuate considerably in sandstones, depending on irregular thickness, percent of uranium present in the source rocks or uraniferous solutions, movements of descending ground water or ascending hydrothermal solutions which are controlled largely by vertical and horizontal lithologic variations, structure, and porosity and permeability. Many sandstones exhibit fairly consistent colors ranging from buffs, grays, to browns. Generally, sufficient quantities of secondary uranium minerals impart bright colors which are easily distinguished from the relatively drab colors of the sandstones.

The carnotite-bearing sandstones of the Colorado Plateau are the chief domestic source of uranium. Carnotite ores are mined from the Lakota and Dakota sandstones in Fall River County, South Dakota.

Shales

Certain very dark to black carbonaceous shales are uraniferous. Uranium-bearing shales differ from uraniferous sandstones. The shales are usually lower grade, seldom exceeding 0.1 percent U_3O_8. Shales are generally lithologically consistent throughout a stratum and fair-uniform in thickness and grade. The vivid colors of many secondary uranium minerals are seen sporadically along cracks, bedding planes, or outcrops. Therefore, field recognition is difficult and warrants the use of radioactivity detectors. Laboratory analysis may be necessary for mineralogical identification as well as chemical assay.

Common uranium-bearing shales are exposed in eastern and central United States. The Ludlow formation contains commercial amounts of uranium in Harding County. Many shales are exposed in South Dakota; some of them are black and carbonaceous and may be radioactive.

Lignites

Uraniferous lignites are generally low grade, comparable to the uraniferous shales. However, when uraniferous lignites are burned uranium is concentrated in the ash.

Uranium-bearing lignite deposits are found in Harding County, South Dakota, North Dakota, Wyoming, Montana, and Nevada.

Placers

Placer deposits consist of sand and/or gravel and a valuable mineral in which the metal can be mined profitably. Placers are generally river gravels; however, a few are marine beach gravels. Placer minerals have been transported as solid minerals, not as solutions. Placer minerals are concentrated as a result of their high specific gravity and resistance to weathering processes. In addition, they are durable and tough. Most uranium minerals are susceptible to decomposition, and, therefore, are not usually economically significant in placers. However, several thorium minerals such as thorianite and thorite, which may carry up to 33 percent U_3O_8, may be concentrated in commercial quantities. Radiation counters are the best means of detecting radioactivity in placers.

Stream placers are fairly common in Colorado and Idaho, and prospectors have won small amounts of gold from placers in the Black Hills.

Fossils

Some petrified logs and bones have been replaced in part by uranium. Several logs from the Colorado Plateau have yielded amazingly rich concentrations of uranium, radium, and vanadium which have been worth an aggregate total exceeding $500,000.

Logs and bones occur in the Lakota sandstone formation around the periphery of the Black Hills, in the White River group, and the Hell Creek and Tongue River formations in the northwestern part of the State, in the White River group in the Badlands and south-central portion of South Dakota, and in the Pierre formation which is exposed around the Black Hills, Missouri River Valley, and north and west-central parts of the State.

TESTING FOR URANIUM

A prospector can make various kinds of tests to determine whether uranium is present in a mineral or rock. These tests all involve either radioactivity or fluorescence. Several tests for both radioactivity and fluorescence are described briefly.

Radioactivity

This characteristic of uranium-bearing minerals and rocks can be detected only by means of radiation detection instruments. Thorium minerals, which may or may not contain uranium, are also radioactive. The prospector can not distinguish between uranium and thorium radiation in the field. Laboratory tests are required to identify the minerals responsible for radioactivity and the uranium content or percentage of U_3O_8. Problems which may arise during radiometric field surveys are treated under the heading "Prospecting with Geiger and Scintillation Counters" in this report.

Photographic Film Test

Both sunlight and radioactive rays will blacken unexposed photographic film. The test involves wrapping a strip of unexposed film so that light can not penetrate, placing a small metallic object on the wrapped film, and placing the mineral or rock sample on top of the metallic object. If the sample is radioactive, the radiation will produce a "radiograph" or picture of the metallic object.

The sharpness of image and the time required to produce the image will provide a rough measure of the quantity of radioactive material, which may be uranium or thorium, present in the sample. Uraninite, which contains from 65-85 percent U_3O_8, may produce a sharp image in one day, whereas less radioactive minerals may require days or weeks to produce a comparable image.

Scintillation Test

Bright flashes of light, termed "scintillations", result when radioactive rays encounter a screen coated with zinc sulphide powder. Scintillations are observed by using a tube-shaped scintilliscope, an instrument which consists of a magnifying eye piece and a zinc sulphide coated screen.

This instrument will detect fairly strong radioactive materials and should be used in the dark. Comparative observations between radioactive samples of known uranium content and the sample will give a rough idea of the amount of radioactivity present.

Geiger or Scintillometer Comparison Test

Both of these instruments are discussed in detail later. The following procedure will give the prospector a rough estimate of the radioactive content of the sample: record the background count; place a known sample of uranium ore (0.1 percent U_3O_8 is the accepted minimum) and record the number of counts; remove the known sample of uranium ore far enough away so that it does not affect the counter; record the background count again; place the unknown sample, which should be about the same size as the known sample, the same distance away from the counter as the known sample; record the reading; subtract the background count from the known sample count, and subtract the background count from the unknown sample count; and, compare the difference.

Fluorescence

Fluorescent minerals will glow when exposed to ultraviolet light, often referred to as "black light". An ultraviolet instrument should be used in the dark.

Very few uranium minerals fluoresce in their natural state. Autunite fluoresces bright yellow or apple-green. Pitchblende and uraninite never fluoresce in their natural state. Other fluorescing uranium minerals are rare. Many non-uranium minerals fluoresce.

Bead Test

The chemical "bead test" enables many uranium minerals to fluoresce, and this test may be performed in the field.

A bead test requires the following equipment: a piece of iron wire with a $\frac{1}{4}$-inch loop in one end, an alcohol lamp or Bunsen burner to produce a small hot flame, lithium or sodium fluoride powder, and an ultraviolet lamp.

Dip the wire loop into either type fluoride powder, heat over the flame until a bead or molten drop is formed, dip bead into finely-ground sample so that several grains adhere to the bead, apply the bead plus sample grains to the flame until the grains are melted into the bead, cool the bead, and then examine it under ultraviolet light in a dark place. If the bead fluoresces a bright yellow-green, the sample contains uranium. It should be noted, however, that the test is useless if the sample contains large quantities of thorium cerium. Other minerals may fluoresce using this particular test, but they will not glow the diagnostic bright yellow-green of uranium.

PROSPECTING WITH GEIGER AND SCINTILLATION COUNTERS

The well-equipped uranium prospector has a Geiger counter or a scintillometer. These popular instruments are by far the most practical radiation detection instruments, and they are standard field equipment. Scintillometers are commonly used for airborne prospecting because of their greater sensitivity. Counters with long cable-connected probes, are used to detect radioactivity in drill holes. Chemical assays are essential in determining the exact quantity of uranium oxide in a sample.

Uranium (Gamma) Radiation

Geiger and scintillation counters are principally gamma ray detectors. Basically, gamma rays are similar to X-rays as both are short-wave radiations that travel in straight lines at the speed of light, that possess neither mass nor chemical change, that are not affected by magnetism or electricity, that blacken photographic film, that penetrate matter, that ionize or dissociate gases, such as those in Geiger tubes, and that will produce bright flashes or scintillations in sodium or potassium iodide crystals used in scintillometers.

Uranium Measurement

According to Wright (1954, pp. 15-19):

"...The Geiger counter, which is primarily sensitive to gamma rays, cannot detect uranium directly. Instead the counter measures the radiations of the five gamma ray producers, ... only when the gamma ray emitters are present in amounts proportional to the amount of uranium can the counter give an accurate measure of the uranium present... it is a limitation on the accuracy any uranium analysis made by measuring radioactivity... the gamma ray emitters are in normal amounts... if the material tested is in radioactive equilibrium. If uranium is freshly purified and separated from its active daughter elements, (uranium-238, which is largely responsible for the radioactivity of uranium ore, is the parent element of 13 radioactive or daughter elements) it immediately starts to decay and reform its daughter elements. As these progressively decay all the elements normally in the decay series gradually accumulate. Finally, after about 1 million years, each element is present in such amount that it decays at the same rate as it is produced, and thereafter no further change takes place in the quantity of any daughter element. The series is thus in radioactive equilibrium.

When uranium ore is in equilibrium, a certain fixed proportion of each daughter element is present, whether the ore contains 0.1 or 50 percent uranium. Therefore, at equilibrium each gamma emitter is present in its normal amount and the radioactivity measured by a counter is dependent on the amount of uranium present; hence, a counter reading can provide a reliable indication of the uranium contained in the ore."

The lack of equilibrium is a common source of inaccurate counter or radiometric assays, because counters can not measure uranium directly, but rather some of uranium's decay products.

Concerning the calibration of field counters, Wright (1954, p. 14) states,

"The meters on most counters are calibrated in either counts per second or milliroentgens (abbreviation--mR) per hour. A milliroentgen is 1/1000 roentgen (abbreviation--R).. The roentgen (R) is defined as that quantity of X-radiation which will produce one electrostatic unit of ions in one cubic centimeter of air under standard conditions of temperature and pressure. The roentgen is a measure of the quantity or amount of radiation, regardless of whether that quantity is produced quickly by intense radiation or slowly by moderate radiation. Therefore, the rate of gamma ray production--or, in other words, the intensity of radiation--must be expressed as roentgens per unit of time. The roentgen is the standard unit for measuring X-rays and because of the similarity between these and gamma rays the unit has been used in counter calibration."

The amount of gamma ray penetration varies directly with the density of the penetrating material. For instance, gamma rays from uranium are stopped by approximately 1 foot of rock, 2½ feet of water, 3 inches of lead, and several hundred feet of air. Geiger counters and scintillometers generally can not detect gamma radiation from rich uranium ores that are overlain by as little as 1 or 2 feet of rock or soil. Therefore, detection instruments register and measure only the gamma rays from the top 1 or 2 feet of rock or soil. Overburden or soil absorbs the gamma rays from the underlying bedrock.

Miscellaneous Radiations

Abnormal counter readings may be attributed to radon gas or thorium.

Radon Gas

Radon is a gaseous product of uranium decomposition. Radon may be frequently encountered underground; however, it is also known to occur on exposed surfaces, down a slope due to its high specific gravity (7.526 times heavier than air), on detection counters, on clothing, on dust particles, and especially in areas of freshly broken rock and poor ventilation, particularly rock crevices, mine workings, drill holes, and so forth. Radon can render a counter virtually useless for several hours.

Thorium

Thorium is a radioactive element that may occur in sufficient quantities to influence counter measurements. Thorium, like uranium, begins a radioactive series which includes 11 daughter members. Gamma radiation from thorium amounts to about two-fifths as much as that of uranium. Counters will record the same readings for uranium-bearing minerals containing only two-fifths as much radioactivity as thorium-bearing minerals. Generally, appreciable quantities of thorium do not occur with secondary uranium ores found in the United States. However, thorium does occur with uranium in some granitic rocks and pegmatites.

Geiger-Muller Counters

The Geiger-Muller (Geiger for short) counter was the first radiation detector developed. The instrument embodies the Geiger tube (Fig. 1, p. 22). The tube is constructed of glass or metal and is connected by a circuit and batteries (Fig. 2, p. 22). The tube, which is filled with one or more gases such as helium, krypton, or argon, operates on a positive charge of about 1,000 volts that travels the center wire of the tube. The Geiger tube is activated and radiation detection results when gamma rays penetrate the Geiger tube. A few gamma rays penetrate the tube and ionize the gas to produce negatively charged electrons which are attracted toward the positively charged center wire to produce a negative electrical pulse of electric current. These radioactive pulses are visibly recorded by a neon light or a meter and are audibly indicated by a headset. Each time the Geiger tube is discharged by less than one percent of the gamma rays the neon bulb lights, the meter needle flickers, and the earphones click.

Scintillation Counters

This relatively new radioactivity detector is more sensitive to gamma ray radiation than the Geiger counter. With this detector small crystals of either sodium or potassium iodide change radiations into tiny flashes of light (scintillations). A light-sensitive photomultiplier tube (Fig. 3, p. 23) transmits the flashes as electrical pulses which activate a recording meter.

Scintillations are produced by 50 percent of the gamma rays that encounter the crystal. Therefore, scintillometers are more sensitive than Geiger counters.

Counter Care

Scintillometers and Geiger counters are built of fairly rugged construction to withstand a nominal amount of abuse; however, they are precision instruments and should be handled with utmost care. Special precautions that will increase the longevity of counters are as follows:

1. Unless your instrument is moisture-proof, keep the counter dry and away from wet places as a wet counter can "short out".
2. Protect your counter from contamination of radioactive dust or radon gas. Do not carry a counter with radioactive specimens. If a counter is contaminated, it will function improperly until the radioactive materials have completely decayed.
3. Keep counters away from luminous dials (watch, compass, clock, etc.). Radioactive radium in luminous paint will increase the count.
4. To preserve the life of the batteries, turn off the counter immediately after using and keep the counter away from intense heat. It may be wise to carry an extra set of batteries. Follow the manufacturer's instructions when changing batteries or you might get a high-voltage shock.
5. Do not use a Geiger counter in freezing weather.
6. To avoid injury to the counting mechanism, prevent the meter needle from swinging off the dial by either adjusting to a less sensitive counter setting or by moving to a place of less radioactivity.

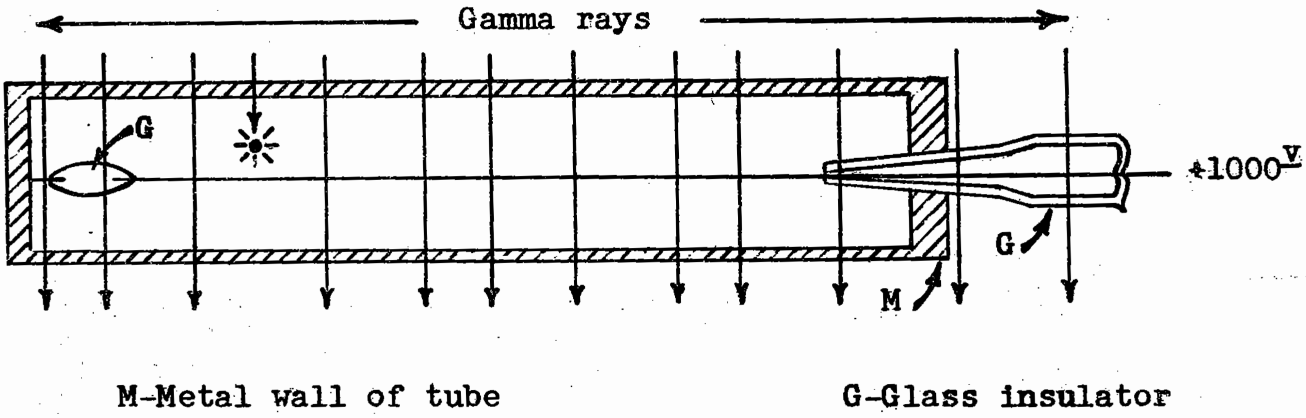


Figure 1.-Cross section of a Geiger tube. In operation, the center wire is charged to about 1,000 volts. Of the many gamma rays which strike the tube, only a few (one is shown) strike a gas molecule within the tube in such a way as to discharge the tube. (After Wright).

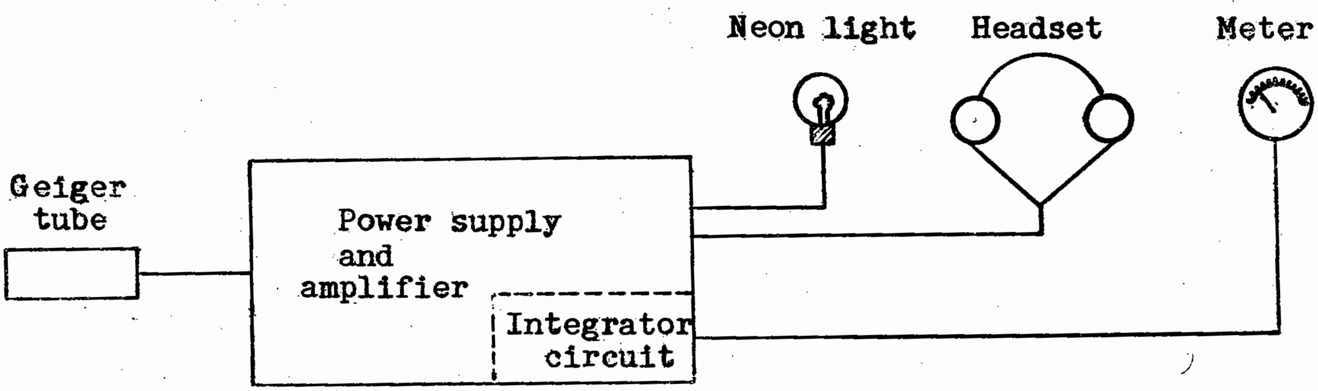


Figure 2.-Block diagram of a Geiger counter. In some models the Geiger tube is contained within the counter case. (After Wright).

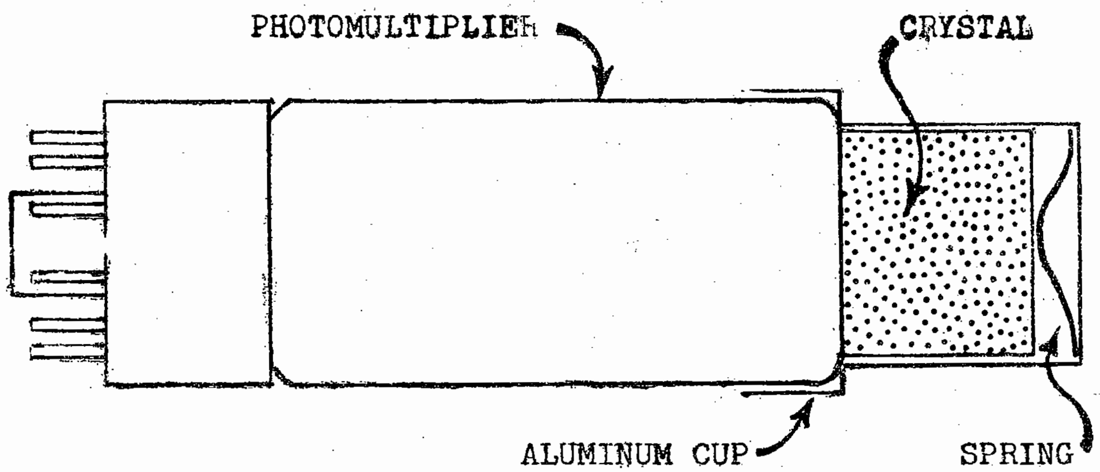


Figure 3.--The crystal photomultiplier assembly of a scintillometer. (After Wilson, et al.)

7. If the counter does not function properly after replacing the batteries, take the counter to a qualified electronics repairman or return it to the dealer or manufacturer.

No license from the Atomic Energy Commission is required to own a radiation detection instrument or to prospect for radioactive ores. However, persons wishing to take such an instrument out of the country must obtain a license from the Licensing Control Branch, Division of Construction and Supply, U. S. Atomic Energy Commission, 1901 Constitution Avenue, Washington 25, D. C.

Background Effect

Radioactivity is prevalent in practically all of the rocks in the earth's crust, largely in infinitesimally small amounts. Radioactivity is produced by cosmic rays which collide with the earth's surface. Counters may have small traces in the materials of construction. The total of these radiations plus the normal radioactivity of the area, which are always recorded by counters, constitute the "background count". It is vitally important to know that the radiation count of radioactive minerals will increase the counter readings above the background count.

The background count may increase or decrease in areas depending on the general types of rocks. For instance, granites (light colored igneous rocks) are usually more radioactive than basalts (dark colored igneous rocks). Going from a limestone to a granite generally increases the background count.

The first step in prospecting an area is to ascertain the average background radioactivity by totaling the number of counts or the average meter reading for periods of one, two, three or more minutes. Fluctuations in cosmic activity, nearness to nuclear bomb test areas, marked temperature changes, or counter sensitivity, due perhaps to weakened batteries or faulty mechanism, cause the background count to change at one time or place. Therefore, it is advisable to take periodic background readings.

Miscellaneous Effects

In addition to background, absorption, and equilibrium, the effects of topography, cover, mass, and underground workings are significant.

Background counts may vary perceptibly between areas of relatively flat or level surfaces and rough topography or terrain. On flat ground, a counter can pick up descending cosmic radiation and ascending radioactivity equally as well. However, in a sharp-walled valley or a depression in the ground a counter may register a larger proportion of ground radiation as some of the cosmic rays are cut out. In a mine tunnel, however, all radioactivity comes from the rocks and/or radon gas as cosmic radiation is eliminated.

The size of the radioactive sample has a direct bearing on the counter reading. Obviously, a large piece of radioactive rock emits more gamma radiation than a small piece even though both contain the same percentage of uranium. Therefore, a hand specimen, which is broken from a large mass of rock, gives a smaller count than the rock mass. This "mass effect" may create a false impression relative to the percentage of uranium in the rock. A prospector can not determine the precise grade or percentage of U_3O_8 in a radioactive rock by comparing a field counter reading of a radioactive sample with the reading from an ore sample of known uranium content. Therefore, do not ship radioactive rock to a mill on the basis of Geiger or scintillation readings! Always resort to chemical assays.

Underground counter readings may present problems not encountered with surface counter readings. Mass effect may increase the background count. Radon gas may influence the counter. Uraniferous solutions of ground water may precipitate uranium in the form of thin coatings on mine surfaces and create the impression that the entire rock area behind the face or exposed surface is a veritable "gold mine".

Radiometric Assaying

One can not overemphasize the value of chemical analysis of radioactive deposits. The minimum acceptable percentage of uranium is 0.1 percent U_3O_8. Chemical analyses determine uranium content directly, whereas field counters are influenced by the variety of things previously mentioned.

A somewhat accurate analysis of the uranium percentage can be made providing the sample is in radioactive equilibrium. Laboratory counters are best for this purpose. These instruments accurately measure the background and sample counts for any desired length of time. Each laboratory counter and field counter may have their individual calibration charts to use for radiometric assays. (See Figs. 4 and 5, p. 27).

Radiometric Surveys

Certain field procedures are important as soon as radioactive rocks have been discovered. Detailed, systematic work is necessary to establish the trend and geographic or areal extent of the deposit. This may be done by constructing a grid or pattern survey by taking counter readings every 25 or 50 feet. These readings, minus the background counts, should be plotted on a map at the reading stations to show the size of the radioactive anomaly area. Then, lines of equal radiation intensity, called "isorads", can be drawn through the stations of equal radioactivity. (See Fig. 6, p. 28). This information will serve as a guide to further exploration which may entail sampling, drill holes, test pits, and stripping operations.

Vehicle-mounted counters may detect radioactivity that extends across highways or fields. The rapidity of such surveys permits large-scale reconnaissance surveys, resulting in a radioactivity profile. When radioactive anomalies are noted, the prospector may resort to a detailed survey as outlined above. Incidentally, this technique may be used on routine business or pleasure trips.

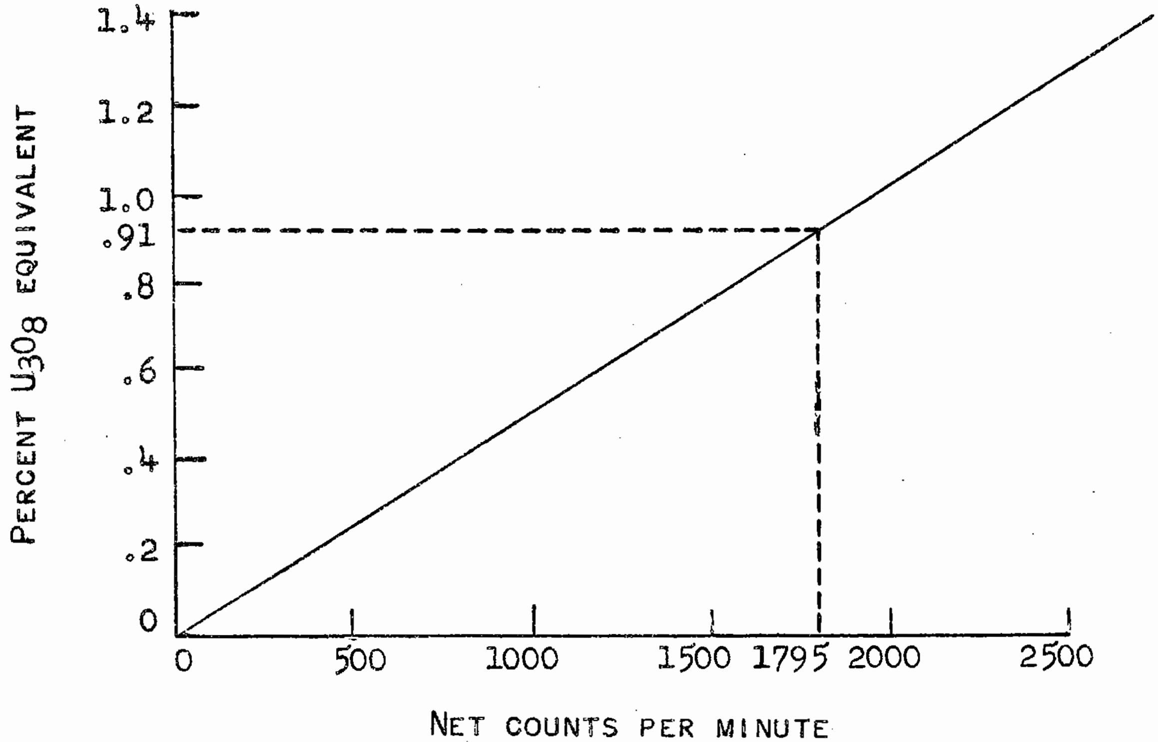


Figure 4.--Calibration chart for a laboratory counter. By use of the graph the radioactivity of a rock sample can be recalculated as percent U_3O_8 equivalent; for example, a sample which yields 1795 net counts per minute assays 0.91 percent U_3O_8 equivalent. A calibration chart can be used only for the counter for which it was prepared. (After Wright).

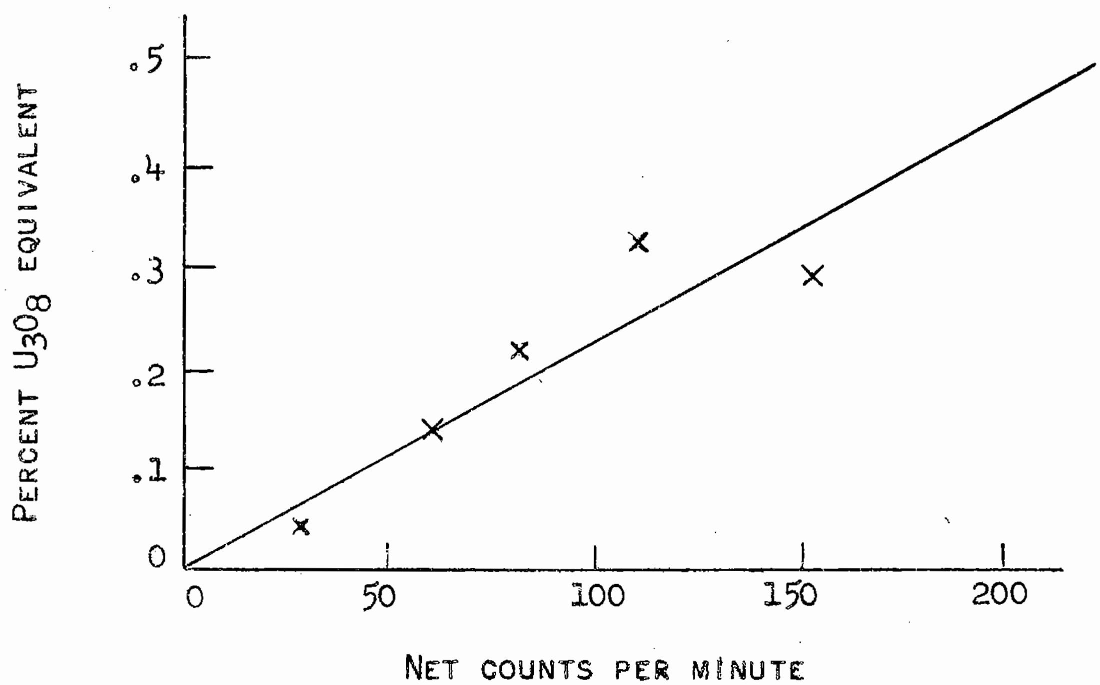


Figure 5.--Calibration chart for field counter. This graph was prepared by plotting the radioactivity of five assayed samples, indicated by x. A field counter is less sensitive than a laboratory counter and hence detects fewer counts for a given amount of uranium, counted for the same time interval. (After Wright).

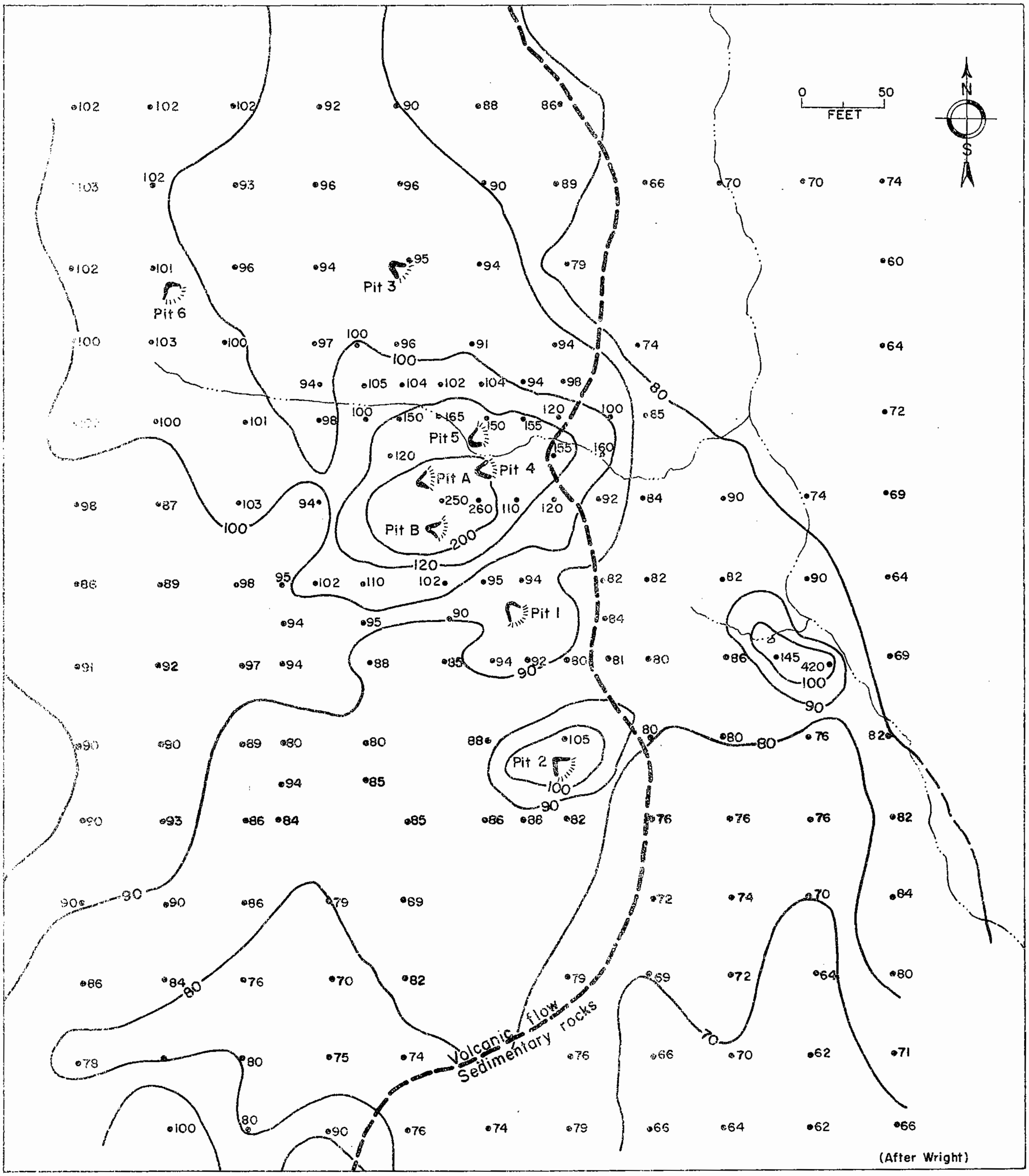


FIGURE 6.– Radiation survey of the Annie Laurie prospect, Arizona.

LABORATORY ASSAYS

When a prospector detects abnormal radioactivity he should take certain steps to evaluate his discovery. He should recheck his instrument's readings to substantiate his initial readings. If the rocks contain favorable radioactivity, the prospector should take samples and have them assayed for uranium by a commercial assayer or by a Government assay agency.

It should be remembered that a chemical or radiometric assay indicates the percentage of uranium contained in that sample only. Therefore, one high-grade sample, which may represent only a small portion of a deposit, does not necessarily infer that the prospector has a uranium ore. Ore is sometimes mistakingly referred to as everything that is mined. However, ore is technically refined as an aggregation of ore minerals and rock or material from which at least one metal can be extracted at a profit. Therefore, the term ore involves both geology and economics.

Radioactive samples should accurately represent the rocks in the entire deposit, thus giving an average grade and evaluation for the deposit. However, if the prospector takes a "grab" or best representative or highest radioactive sample, he should record this information and send it with the sample to the assay laboratory.

According to "Prospecting for Uranium" (1951, pp. 40-42):

"Samples submitted to.... a Federal agency... for assay should weigh at least 1 pound, should be carefully wrapped in a strong package, and should be clearly labeled with the sender's return address... it is desirable to include the following specific information with each sample:

1. The sample number, if more than one sample is submitted in the same package.
2. The exact location from which the sample was obtained, including the State, county, nearest town, claim name (if any), mine name (if any), and the section, township and range (if known).
3. The estimated amount of material represented by the sample; that is, the length, width, and depth of the deposit insofar as they can be determined.
4. Previous tests made on the sample. For example, if a Geiger counter test was made, include the model number and manufacturer of the instrument, the average background count

(in counts per minute) when the sample was tested, and the total count (in counts per minute), including background, registered by the sample when placed a stated distance from the probe. If photographic or analytical tests have been made, include the results.

5. Information on the proportion of the original sample that the submitted sample represents if the submitted sample has been concentrated.

6. Other materials, if any, being mined from rocks from which the sample was obtained.

7. Other relevant information, including a short description of the deposit."

Government assayers report the results of analyses to the prospector and to the Atomic Energy Commission if the sample is radioactive.

The following commercial assayers (this list is not necessarily complete) test for uranium:

H. D. Brown Laboratory
Route 3
Grand Junction, Colorado

Horace J. Hallowell
Analytical & Consulting Chemist
323 Main Street
Danbury, Conn.

Abbot A. Hanks
624 Sacramento Street
San Francisco 11, Calif.

Ledoux & Company, Inc.
359 Alfred Avenue
Teaneck, New Jersey

Charles O. Parker
Denver, Colorado

Lucius Pitkin, Inc.
47 Fulton Street
New York 7, N. Y.

Smith's Laboratory
Moab, Utah

Smith-Emery Company
920 Santee Street
Los Angeles 15, Cal.

The State Geological Survey identifies rock and mineral samples and tests rock and mineral samples for radioactivity without charge. However, the Survey does not make chemical assays.

The Atomic Energy Commission at Hot Springs receives numerous reports of uranium and thorium occurrences, but the Commission can not send a representative to verify each of these reports. However, it is the Commission's policy to send a representative into the field to examine reported deposits whenever strong preliminary evidence is received that radioactive materials in quantities of interest to the Commission do occur as reported. It is not possible to make any general statement in advance about methods of mining, milling, processing, or treating uranium ores. These methods depend on a variety of factors, particularly on the type and amount of ore.

Under the present regulations of the Atomic Energy Commission, prospectors are not required to report the discovery of new deposits of radioactive ores. However, the Atomic Energy Commission does appreciate being informed of new discoveries. The Atomic Energy Commission assists prospectors by making geological surveys and furnishing free testing and assaying service in appropriate cases, and by guaranteeing a price for the uranium ore.

LICENSING REGULATIONS

A license from the Atomic Energy Commission is needed to sell, transfer, or receive certain quantities and grades of uranium and thorium ores which have been removed from the ground, no matter where or when they are mined.

The general provisions of the United States Atomic Energy Commission Licensing Regulations are as follows:

"40.1 Basis and purpose. The regulations in this part, for the control of source material essential to the production of fissionable material, are promulgated by the United States Atomic Energy Commission pursuant to the Atomic Energy Act of 1946 (60 Stat. 755) in order to assure adequate source material for production, research, and development activities and to prevent the use of such material in a manner inconsistent with the national welfare.

40.2 Definitions.

(a) As used in this part, the term "source material" means any material, except fissionable material, which contains by weight one-twentieth of one percent (0.05 percent) or more of (1) uranium, (2) thorium, or (3) any combination thereof.

(b) "Fissionable material" means fissionable material as defined in section 5 of the Atomic Energy Act of 1946 and regulations which may be issued pursuant to that act by the Commission.

(c) "Raw source material" means (1) source material which has not been chemically processed in any manner and (2) source material in the form of residues or tailings.

(d) "Refined source material" means source material other than raw source material.

(e) "Person" means any individual, corporation, partnership firm, association, trust, estate, public or private institution, group, the United States or any agency thereof, any government other than the United States, any political subdivision of any such government, and any legal successor, representative, agent, or agency of the foregoing, or other entity, but shall not include the Commission or officers or employees of the Commission in the exercise of duly authorized functions.

(f) "The United States," when used in a geographical sense, includes all territories and possessions of the United States and the Canal Zone.

(g) "Commission" means the Atomic Energy Commission created by the Atomic Energy Act of 1946, or its duly authorized representative.

40.10 Restriction on transfers. Unless authorized by a license issued by the Commission, no person may transfer or deliver, receive possession of or title to or export from the United States, any source material after removal from its place of deposit in nature. This includes the disposition of raw source material (including residues or tailings) by dumping into streams or sewers, or disposition in such other manner that recovery cannot be made. The restriction of this section does not apply to any transfer, delivery, or receipt of possession or title exempted by 40.11.

40.11 Exempted transfers. Except where export is intended or where export occurs, the restriction of 40.10 does not apply to any transfer, delivery, or receipt of possession or title, of the following:

(a) During any single calendar month a quantity of raw source material after removal from its place of deposit in nature which contains less than 10 pounds of uranium or thorium or any combination thereof, or

(b) Products listed in Schedule I (40.60).

40.20 Application for licenses. Applications for licenses to transfer or deliver, receive possession of or title to, or export source material shall be filed with the United States Atomic Energy Commission, P. O. Box 30, Ansonia Station, New York 23, New York. Applications should be filed on Form AEC--2, copies of which are available at the above address. When it is impracticable to use this form, applications may be made by letter or telegram, giving the information required by Form AEC--2.

40.21 Issuance of licenses. Upon a determination that an application meets the requirements of the Atomic Energy Act of 1946 and of the regulations of the Commission, the Commission will issue a license in such form and upon such conditions as it deems appropriate and in accordance with law.

40.22 Standards for issuance of licenses. In making the determination mentioned in 40.21, the Commission will be guided by the following standards:

(a) Assurance of the common defense and security;

(b) Assurance of adequate source materials for production, research, and development;

(c) Prevention of the use of source materials in a manner inconsistent with the national welfare;

(d) Preservation of health and safety.

So far as consistent with these standards, licenses will be granted upon conditions that will not interfere with the conduct of normal business activities. No license will be issued to any person if to do so would, in the opinion of the

Commission, be inimical to the common defense and security.

40.23 Types of licenses. Licenses are of two basic types, general and specific. General licenses are issued to an identified class of persons who are not designated by name, such as common or contract carriers, retail druggists or physicians, and others, to permit transfers of source material under specified conditions without the filing of an application with the Commission. General licenses now in effect are set out in Schedule III (40.62). Specific licenses are issued to named persons in response to applications filed with the Commission. Specific licenses may authorize a continuing activity or, as in the case of exports, may be limited to an individual transaction. So far as consistent with the purposes of the Atomic Energy Act of 1946, licenses will be tailored to fit the normal business requirements of the license.

40.24 Conditions of licenses. Each license will require the licensee to comply with certain conditions, including the filing of reports with the Commission and restrictions upon the use of source material. Willful failure of a licensee to file any such report which truthfully sets forth all information required, or willful failure to comply with any other condition of the license, shall constitute a violation of the regulations in this part.

40.25 Revocation, suspension, modification of licenses. Any license may be modified, withdrawn, suspended, revoked, or annulled at any time in the discretion of the Commission upon a determination by the Commission that the public health, interest or safety requires such action or that the licensee has willfully failed to comply with any condition of the license. In the absence of such a determination, no modification, withdrawal, suspension, revocation, or annulment of any license will be made except upon application therefor by the licensee or unless, prior thereto, facts or conduct warranting such action have been called to the attention of the licensee in writing and the licensee has been accorded opportunity to demonstrate or achieve compliance with all lawful requirements. Nothing in this part shall limit the authority of the Commission to issue or amend its regulations in accordance with law.

40.26 Renewal of licenses. In any case in which a licensee has filed an application in proper form for a renewal or a new license not less than 30 days prior to expiration of his existing license, such existing license, to the extent that it has reference to any activity of a continuing nature, shall not expire until the application for a renewal or a new license has been finally determined by the Commission.

40.27 Transfer of licenses. Licenses shall be nontransferable.

40.28 Licenses to transfer uranium for certain uses. Unless justified by exceptional circumstances licenses will not be issued for transfers of source material which contains by weight uranium in excess of one-twentieth of one percent (0.05%) for use in the manufacture of or for incorporation in any of the products listed in Schedule II (40.61).

40.29 Control or possession of source material by persons who do not hold specific or general licenses.

(a) Any person who has, or who hereafter obtains, possession of or title to (1) a quantity of raw source material after removal from its place of deposit in nature which contains 10 pounds or more of uranium, thorium, or any combination thereof, or (2) a quantity of refined source material which contains 1 pound or more of uranium, thorium, or any combination thereof (except refined source material incorporated in products listed in Schedule I 40.60) shall, not later than 30 days after the effective date of the regulations or title, whichever is later, file with the Commission a reasonably detailed statement of:

(i) The nature of the material,
(ii) Its quantity,
(iii) Its uranium and thorium content,
(iv) Its location, and
(v) Its ownership.

(b) The requirement in paragraph (a) of this section does not apply to any person who holds a specific or general license from the Commission.

Reports

40.30 Reports. Reports, in addition to those called for in licenses, may be required by the Commission from time to time, subject to approval by the Bureau of the Budget in certain cases, with respect to the ownership, possession, extraction, refining, shipment, or other handling of source material after removal from its place of deposit in nature, as the Commission may deem necessary.

Violations

40.40 Penalties for violations. A violation of the regulations in this part shall be deemed to be a violation of the Atomic Energy Act of 1946 and shall subject the violator to the penalties therein prescribed. In addition, the Commission may take such action with respect to source material involved in any violation as it deems appropriate and in accordance with law.

Interpretations, Petitions, and Communications

40.50 Valid interpretations. Except as specifically authorized by the Commission, no interpretation or explanation of the meaning of the regulations in this part issued by any officer or employee of the Commission other than one issued by the General Counsel in writing will be recognized to be valid and binding upon the Commission.

40.51 Petitions. Petitions for relief from any restriction imposed under the regulations in this part may be made by filing a letter, in duplicate, with the United States Atomic Energy Commission, Post Office Box 30, Ansonia Station, New York 23, New York, stating the reasons why the petition should be granted.

40.52 Communications. All communications concerning the regulations of this part or any license issued under them should be addressed to the United States Atomic Energy Commission, P.O. Box 30, Ansonia Station, New York 23, New York.

40.53 Right to Require Deliveries Reserved. No license granted under the regulations in this part shall be deemed to constitute a waiver of the Commission's right to require delivery of source material to it under the conditions stated in Section 5 (b) (7) of the Atomic Energy Act of 1946 (60 Stat. 755).

Schedules

40.60 Schedule I: Exempted products (see 40.10 and 40.29).

(a) Incandescent mantles.

(b) Ceramic products.

(c) Refractories.

(d) Glass products.

(e) Photographic film, negatives and prints.

(f) Rare earth metals and compounds, mixtures and products containing not more than 0.25 percent by weight thorium, uranium, or any combination of these.

(g) Vacuum tubes.

(h) Thoriated tungsten containing not more than 3 per cent by weight thorium.

40.61 Schedule II: Prohibited uses of uranium (see 40.28).

(a) Ceramic products.

(b) Glass products.

(c) Photographic films, negatives, and prints.

40.62 Schedule III: General licenses (see 40.23). Transfers, deliveries and receipts of possession of or title to source material, except where export is intended or where export occurs, which are within any one or more of the following categories, are hereby generally licensed:

(a) Transfers, deliveries and receipts of possession of (but not of title to) source material by contractors and agents of the Commission in the authorized course of their business for the Commission.

(b) Transfers, deliveries and receipts of possession of (but not of title to) source material by common or contract carriers for transportation purposes only in the regular course of business;

(c) Transfers, deliveries and receipts of possession of and title to a quantity of refined source material which contains less than one pound of uranium, thorium, or any combination thereof, from or to any one person during any single calendar month, to the extent that the transaction consists of either:

(1) Transfer to or receipt of possession or title by a licensed dispensing pharmacist solely for the compounding of medicinals for delivery to consumers, or

(2) Transfer to or receipt of possession or title by a physician or consumer for medicinal purposes only, and not for resale, or

(3) Transfer to or receipt of possession or title by an educational institution or hospital for educational or medicinal purposes only, and not for resale.

40.70 Effective date. The regulations in this part shall become effective at midnight, March 31, 1947. This effective date, which is less than thirty days subsequent to publication, is found necessary and appropriate by the Commission in view of the fact that controls on transfers of source material exercised by the Civilian Production Administration under the Second War Powers Act will lapse at midnight, March 31, 1947.

Dated at Washington, D. C., this 17th day of March, 1947.

By order of the Commission.

David E. Lilienthal,
Chairman."

SELLING PROCEDURE AND PRICE SCHEDULES

When uranium exists in commercial quantities, it may be mined and sold either to the U. S. Atomic Energy Commission or to any company or person within the United States, providing both the buyer and seller are licensed by the Atomic Energy Commission.

Uranium ore-buying stations and qualified uranium mills are as follows:

Ore-buying stations

Bluewater (Grants), New Mexico: Anaconda Copper Mining Company
Shiprock, New Mexico: American Smelting and Refining Company
Marysvale, Utah: American Smelting and Refining Company
Monticello, Utah: American Smelting and Refining Company
Edgemont, South Dakota: American Smelting and Refining Company
Riverton, Wyoming: American Smelting and Refining Company

Qualified uranium mills

Durango, Colorado: Vanadium Corporation of America
Grand Junction, Colorado: Climax Uranium Company
Naturita, Colorado: Vanadium Corporation of America
Rifle, Colorado: United States Vanadium Company
Uravan, Colorado: United States Vanadium Company
Monticello, Utah: The Galigher Company (for A. E. C.)
Salt Lake City, Utah: Vitro Chemical Company, 600 West 33rd St., South

As noted above, the American Smelting and Refining Company at Edgemont has been an ore-buying station for some time. A new industry in the form of a uranium processing mill, perhaps capable of processing 200 tons per day, is scheduled to be built in or near Edgemont by the Mines Development Corporation, Golden, Colorado.

The following Atomic Energy Commission Domestic Price Schedules are as follows:

"Title 10--ATOMIC ENERGY--Chapter 1--Atomic Energy Commission (Domestic Uranium Program Circular 6) Part 60--Domestic Uranium Program

Bonus for Initial Production of Uranium Ores from Domestic Mines

60.6 Bonus for initial production of uranium ores from new domestic mines

(a) What this section does. This section provides for bonus payments for initial and certain other production of uranium-bearing ores. It is intended to encourage and assist the development of new sources of domestic uranium production in the interest of the common defense and security.

(b) Production bonus established. The U. S. Atomic Energy Commission will pay a bonus under the conditions set forth in this section for delivery to a Commission ore-buying station or a qualified uranium mill (hereafter called station or mill) of uranium ores from an eligible mining property up to the maximum quantities specified in this section.

(c) Term of this section. This section will apply to deliveries made under its terms between March 1, 1951, and February 28, 1957, inclusive.

(d) Payment of the bonus. Bonus payments will be computed on the following basis:

Ores assaying less than 0.10 percent U_3O_8: no payment.
Ores assaying 0.10 percent U_3O_8 and more, as follows:

U_3O_8 assay:	Payment per pound of U_3O_8
0.10 percent	$1.50
0.11 percent	1.70
0.12 percent	1.90
0.13 percent	2.10
0.14 percent	2.30
0.15 percent	2.50
0.16 percent	2.70
0.17 percent	2.90
0.18 percent	3.10
0.19 percent	3.30
0.20 percent and more	3.50

Fractional parts of a pound will be paid for on a pro rata basis to the nearest cent. Assays will be adjusted to the nearest 0.01 percent for purposes of payment. Weights are avoirdupois dry weights. Bonus payments made under this section will be in addition to any other payments for delivery of the ore. They will be paid directly by the Commission and not by the station or mill. [Table 3, pp. 41 to 42, is a schedule of minimum prices paid for uranium ore.]

(e) Maximum quantity of uranium ores for which bonus payments will be made. Subject to the conditions of this section, bonus payments will be made on deliveries of uranium ore from an eligible mining property to a station or mill until bonus payments have been made on 10,000 pounds of

TABLE 3.--SCHEDULE OF
(As Specified In
Atomic

Grade Of Ore, Percent U_3O_8	Pounds Of U_3O_8 Per Ton Of Ore	BASE PRICE		GRADE PREMIUM $.75 A Lb. Over 4 Lb.
		Pound U_3O_8	Ton of Ore	
0.10	2.00	$1.50	$ 3.00	$ --
0.11	2.20	1.70	3.74	--
0.12	2.40	1.90	4.56	--
0.13	2.60	2.10	5.46	--
0.14	2.80	2.30	6.44	--
0.15	3.00	2.50	7.50	--
0.16	3.20	2.70	8.64	--
0.17	3.40	2.90	9.86	--
0.18	3.60	3.10	11.16	--
0.19	3.80	3.30	12.54	--
0.20	4.00	3.50	14.00	--
0.21	4.20	Do	14.70	0.15
0.22	4.40	Do	15.40	0.30
0.23	4.60	Do	16.10	0.45
0.24	4.80	Do	16.80	0.60
0.25	5.00	3.50	17.50	0.75
0.26	5.20	Do	18.20	0.90
0.27	5.40	Do	18.90	1.05
0.28	5.60	Do	19.60	1.20
0.29	5.80	Do	20.30	1.35
0.30	6.00	3.50	21.00	1.50
0.31	6.20	Do	21.70	1.65
0.32	6.40	Do	22.40	1.80
0.33	6.60	Do	23.10	1.95
0.34	6.80	Do	23.80	2.10
0.35	7.00	3.50	24.50	2.25
0.36	7.20	Do	25.20	2.40
0.37	7.40	Do	25.90	2.55
0.38	7.60	Do	26.60	2.70
0.39	7.80	Do	27.30	2.85

PRICES FOR URANIUM ORE
Circ. 5 Revised, and Circ. 6)
Energy Commission

GRADE PREMIUM $.25 A Lb. Over 10 Lb.	Mine Develop. Allowance .50/Lb.	PRICE PER TON OF ORE Price Before Initial Prod. Bonus & Haulage Allowance	Initial Prod. Bonus On 10,000 Lbs.	Price Before Haulage Allowance
$ --	$ 1.00	$ 4.00	$ 3.00	$ 7.00
--	1.10	4.84	3.74	8.58
--	1.20	5.76	4.56	10.32
--	1.30	6.76	5.46	12.22
--	1.40	7.84	6.44	14.28
--	1.50	9.00	7.50	16.50
--	1.60	10.24	8.64	18.88
--	1.70	11.56	9.86	21.42
--	1.80	12.96	11.16	24.12
--	1.90	14.44	12.54	26.98
--	2.00	16.00	14.00	30.00
--	2.10	16.95	14.70	31.65
--	2.20	17.90	15.40	33.30
--	2.30	18.85	16.10	34.95
--	2.40	19.80	16.80	36.60
--	2.50	20.75	17.50	38.25
--	2.60	21.70	18.20	39.90
--	2.70	22.65	18.90	41.55
--	2.80	23.60	19.60	43.20
--	2.90	24.55	20.30	44.85
--	3.00	25.50	21.00	46.50
--	3.10	26.45	21.70	48.15
--	3.20	27.40	22.40	49.80
--	3.30	28.35	23.10	51.45
--	3.40	29.30	23.80	53.10
--	3.50	30.25	24.50	54.75
--	3.60	31.20	25.20	56.40
--	3.70	32.15	25.90	58.05
--	3.80	33.10	26.60	59.70
--	3.90	34.05	27.30	61.35

TABLE 3.--SCHEDULE OF
(As Specified In
Atomic

Grade Of Ore, Percent U_3O_8	Pounds Of U_3O_8 Per Ton Of Ore	BASE PRICE Pound U_3O_8	BASE PRICE Ton of Ore	GRADE PREMIUM $.75 A Lb. Over 4 Lb.
0.40	8.00	$3.50	$ 28.00	$ 3.00
0.41	8.20	Do	28.70	3.15
0.42	8.40	Do	29.40	3.30
0.43	8.60	Do	30.10	3.45
0.44	8.80	Do	30.80	3.60
0.45	9.00	3.50	31.50	3.75
0.46	9.20	Do	32.20	3.90
0.47	9.40	Do	32.90	4.05
0.48	9.60	Do	33.60	4.20
0.49	9.80	Do	34.30	4.35
0.50	10.00	3.50	35.00	4.50
0.60	12.00	Do	42.00	6.00
0.70	14.00	Do	49.00	7.50
0.80	16.00	Do	56.00	9.00
0.90	18.00	Do	63.00	10.50
1.00	20.00	3.50	70.00	12.00
2.00	40.00	Do	140.00	27.00
3.00	60.00	Do	210.00	42.00
4.00	80.00	Do	280.00	57.00
5.00	100.00	Do	350.00	72.00
6.00	120.00	Do	420.00	87.00
7.00	140.00	Do	490.00	102.00
8.00	160.00	Do	560.00	117.00
9.00	180.00	Do	630.00	132.00
10.00	200.00	Do	700.00	147.00

PRICES FOR URANIUM ORE--Continued
Circ. 5 Revised, and Circ. 6)
Energy Commission

GRADE PREMIUM $.25 A Lb. Over 10 Lb.	Mine Develop. Allowance .50/Lb.	PRICE PER TON OF ORE: Price Before Initial Prod. Bonus & Haulage Allowance	Initial Prod. Bonus On 10,000 Lbs.	Price Before Haulage Allowance
$ --	$ 4.00	$ 35.00	$ 28.00	$ 63.00
--	4.10	35.95	28.70	64.65
--	4.20	36.90	29.40	66.30
--	4.30	37.85	30.10	67.95
--	4.40	38.80	30.80	69.60
--	4.50	39.75	31.50	71.25
--	4.60	40.70	32.20	72.90
--	4.70	41.65	32.90	74.55
--	4.80	42.60	33.60	76.20
--	4.90	43.55	34.30	77.85
--	5.00	44.50	35.00	79.50
0.50	6.00	54.50	42.00	96.50
1.00	7.00	64.50	49.00	113.50
1.50	8.00	74.50	56.00	130.50
2.00	9.00	84.50	63.00	147.50
2.50	10.00	94.50	70.00	164.50
7.50	20.00	194.50	140.00	334.50
12.50	30.00	294.50	210.00	504.50
17.50	40.00	394.50	280.00	674.50
22.50	50.00	494.50	350.00	844.50
27.50	60.00	594.50	420.00	1,014.50
32.50	70.00	694.50	490.00	1,184.50
37.50	80.00	794.50	560.00	1,354.50
42.50	90.00	894.50	630.00	1,524.50
47.50	100.00	994.50	700.00	1,694.50

A value of $0.31 per pound for vanadium (V_2O_5) up to, but not exceeding, ten pounds of V_2O_5 for each pound of U_3O_8 contained in ores.

A haulage allowance of 6¢ per ton mile up to a maximum of 100 miles is determined by the Commission. Tonnages for purposes of this allowance shall be calculated on the basis of natural weights rather than dry weights.

contained uranium oxide less the number of pounds, if any, accepted by stations or mills (or any other uranium ore processing plants) from that mining property between April 9, 1948 and February 28, 1951, inclusive.

(f) Ores for which bonus payments will be made. Ores for which bonus payments will be made must have been delivered to and paid for by either a station or mill. However, in special cases, bonus payments may be made for ores which have been accepted by the station or mill but for which payment is still pending. Bonus payments will not be made for ores which a station or mill refuses to accept. The weights and final assays made to ascertain the amount of payment due from the station or mill shall be sued to determine the amount of bonus payments under this section.

(g) Which mining properties are eligible. In order for a mining property to be eligible for bonus payments under this section,

(1) As required by paragraph (e) of this section, the total quantity of uranium oxide as contained in ore accepted by stations or mills (or any other uranium ore processing plants) from that property between April 9, 1948 and February 28, 1951, inclusive, must have been less than 10,000 pounds; and

(2) The property must be within the United States, its territories, possessions or the Canal Zone; and

(3) The property must be certified by the Commission as eligible using the following criteria as guides:

(i) Purpose of the bonus. The purpose of the bonus is to encourage and assist the development of new sources of domestic uranium production.

(ii) Character of mining property. The mining property may consist of a placer or lode location, or if not covered by location, a tract which the Commission finds to be comparable or otherwise appropriate. However, an entire holding consisting of contiguous locations or tracts will be regarded as only a single eligible unit of mining property if the locations or tracts are held in common in the manner set forth in the following paragraph.

(iii) Title or interest of the holder of the property. The title or interest in the mining property should be one of ownership or lawful possession of mining rights. This type of holding will generally be that of an owner or leaser (lessee). It is recognized that there are various arrangements such as split check leases, price rate contracts and the like whereby persons either as employees or independent contractors conduct mining operations on designated areas of property held by another who also supplies certain of the mining services or equipment or both and who receives in return a percentage of the proceeds of the ore produced. In the case of such arrangements, the person who grants the right to conduct these mining operations will be considered as the holder of the mining property although others perform mining operations on it.

(iv) Minimum size of mining property. The mining property, if it is made up of a location or locations, should contain at least 15 acres. The minimum size of lands on Indian reservations will be established by the Commission after consultation with the Bureau of Indian Affairs of the Department of Interior. The minimum size of other mining properties will be established by the Commission in individual cases in the light of the purpose of the bonus.

(v) Subdivision or consolidation of property. Since the division of existing mining properties into smaller units might have the effect of increasing bonus payments without advancing the purpose of the bonus program, division of a single unit of mining property on or after March 1, 1951, will not be recognized in determining its eligibility for bonus payments under this section. In addition, consolidation or merger of contiguous mining properties on or after March 1, 1951, will not affect the eligibility of the separate properties for bonus payments.

(vi) Special cases. Since the above criteria are merely guides to assist the Commission in its decisions, areas which fail to meet all of the criteria may be certified by the Commission as eligible in special cases where it is determined that the deviations are not substantial or that their disqualification would cause serious inequities. In determining whether or not serious inequities would result, the physical characteristics and location of the deposit may be a factor. Under appropriate circumstances, a segment of a certified property may itself be certified as eligible. On the other hand, technical compliance with all the above criteria will not necessarily make a property eligible. Properties leased to private operators by the Commission will not be eligible for bonus payments except under special circumstances and as provided for in the lease.

(h) Determination by the Commission. The Commission expressly reserves the right to decide the amount of any bonus payments to be made, whether the property should be certified as an eligible mining property, the person to whom the bonus should be paid and whether for any reason a bonus is not payable. These decisions shall rest in the sole discretion of the Commission and shall be final and conclusive. The Commission further reserves the right to establish procedures to carry out the bonus program. Any bonus payments made hereunder with respect to particular ores shall be the only such bonus payments made for those ores. The Commission will not consider any other application for bonus payments on those ores.

(i) Application for certification. Applications for certification of a property as eligible should be made to:

U. S. Atomic Energy Commission
Grand Junction Operations Office
P. O. Box 270
Grand Junction, Colorado

The application should include a description of the mining property indicating its size, location, ownership, interest of the applicant and public recording. There should also be included a statement by the applicant that to the best of his knowledge the total quantity of uranium oxide contained in ore accepted by stations or mills (or any other uranium ore processing plants) from that property between April 9, 1948 and February 28, 1951, inclusive, was less than 10,000 pounds. A form prescribed by the Commission and obtainable at a station or mill should be used for supplying the above information. Certification by the Commission will be a prerequisite to payment of the bonus, but after certification, payments will be made for ores which are delivered before certification and which meet the requirements of this section. Normally certification will not be made before uranium deposits have been discovered on the property, but the Commission may issue certifications prior to discovery in special cases. The Commission reserves the right to revoke a certification if it determines that its issuance was based on fraud, misrepresentation or mistake or if the requirements of this section are not complied with. The Commission may require such information and right to make such inspections of the mining property as it finds necessary for the purpose of determining its eligibility for bonus payments and the amounts to be paid.

Note: Misrepresentation or falsification of facts in an application for certification or for bonus payments may subject the offender to criminal penalties under pertinent provisions of the United States Code including section 1001 of Title 18. Any such offenses also will disqualify the offender from receiving bonus payments.

(j) Application for bonus payment. Application for a bonus payment should be made on a prescribed form (obtainable at a station or mill) at intervals not more frequent than once a month during a period when ore deliveries from the property are believed to meet the requirements of this section. Applications may be addressed as follows:

U. S. Atomic Energy Commission
Grand Junction Operations Office
P. O. Box 270
Grand Junction, Colorado

In addition to the application, the Commission may require such other information as it finds necessary.

(k) Who may apply for bonus payments. The person (other than a royalty payee or the like) who has lawfully received payment for a station or mill for the delivery of ore from a certified mining property may apply for bonus payments under this section. However, in special cases, the applications of persons whose ores have been accepted by the station or mill but for which payment is still pending will be considered.

(l) Mill processing ores from its own mines. In the event that an operator of a mill processes in the mill ores which it obtains from mining properties operated by it, the Commission will pay the bonus, under the conditions set forth in this section to the same extent as if the mining properties were operated by another person who delivered ore to the mill and received payment for it from the mill. In such cases, however, the weights and assays used to fix the amount of payment due as a bonus under this section shall be determined in accordance with practices satisfactory to the Commission...

Dated at Washington, D. C., this 27th day of June 1951

By order of the Commission.

M. W. Boyer
General Manager."

LAWS AND REGULATIONS

Persons wishing to prospect for radioactive ores, or to mine them, must comply with Federal, State, and local mining regulations that apply to ores generally. Persons wishing to prospect on private land must ascertain that the owner has no objection. If uranium is discovered on private land, the prospector must, of course, reach an agreement with the owner of the property.

United States Government

According to Circular No. 1278, U. S. Department of the Interior General Land Office:

"INFORMATION IN REGARD TO MINING CLAIMS ON THE PUBLIC DOMAIN

The purpose of this circular is to furnish brief information pertinent to the location and purchase of mining claims under the United States mining laws.

1. Initiation of rights to mineral land. Rights to mineral lands, owned by the United States, are initiated by prospecting for minerals thereon, and, upon discovery of mineral, by locating the lands upon which such discovery has been made. A location is made by staking the corners of the claim, posting notice of location thereon (see 10), and complying with the State laws, regarding the recording of the location in the county recorder's office, discovery work, etc.

2. State mining laws. As supplemental to the United States mining laws there are State statutes relative to location, manner of recording of mining claims, etc., in the State, which should also be observed in the location of mining claims. Information as to State laws can be obtained locally or from State officials.

3. Lands subject to location and purchase. Vacant public surveyed or unsurveyed lands are open to prospecting, and upon discovery of mineral, to location and purchase, as are also lands in national forests in the public-land States (forest regulations must be observed), lands entered or patented under the stock raising homestead law (title to minerals only can be acquired), lands entered under other agricultural laws but not perfected, where prospecting can be done peaceably, and lands within the railroad grants for which patents have not issued.

4. Status of lands. Information as to whether any particular tract of land is shown by the records to be vacant and open to prospecting may be obtained from the register of the land districts in which the tract is situated. Since location notices of mining claims are filed in the office of the county recorder, ordinarily no information regarding unpatented mining claims is obtainable from the district land office or the General Land Office unless application for patent has been filed.

5. Minerals subject to location. Whatever is recognized as a mineral by the standard authorities, whether metallic or other substance, when found in public lands in quantity and quality sufficient to render the lands valuable on account thereof, is treated as coming within the purview of the mining laws. Deposits of coal, oil, gas, oil shale, phosphate, potash, and in Louisiana and New Mexico sulphur, belonging to the United States, can be acquired under the mineral leasing laws, and are not subject to location and purchase under the United States mining laws.

6. Mining locations--Areas. Lode locations for minerals discovered in lode or vein formation may not exceed in length 1,500 feet along the vein and in width 300 feet on each side of the middle of the vein, and end lines of the location to be parallel to each other. Placer locations, which include all minerals not occurring in vein or lode formation, may be for areas of not more than 20 acres for each locator, no claim to exceed 160 acres made by not less than eight locators. Placer locations must conform to the public surveys wherever practicable.

7. Who may make locations. Citizens of the United States, or those who have declared their intention to become such, including minors who have reached the age of discretion and corporations organized under the laws of any State. Agents may make locations for qualified locators.

8. Number of locations. There is no limit to the number of lode or placer locations which an individual or association may locate, except that in Alaska a person is restricted to the location of two placer claims in any calendar month.

9. Valid locations--Discovery after conveyance. A location is not valid until an actual discovery of mineral is made within the limits thereof. A placer location of more than 20 acres, made by two or more locators and conveyed to a less number before discovery is made, is valid to the extent of 20 acres only for each owner at date of discovery.

10. Locations to be marked on ground--Notice. Except placer claims described by legal subdivision, all mining claims must be distinctly marked on the ground so that their boundaries may be readily traced, and all notices must contain the name or names of the locators, the date of location and

such a description of the claim by reference to some natural object or permanent monument as will serve to identify the claim.

11. Location on streams and bodies of water. Beds of navigable waters are subject to the laws of the State in which they are situated and are not locatable under the United States mining laws. Title to the beds of meandered nonnavigable streams is the reparian owner. The beds of unmeandered, nonnavigable streams are subject to location under the United States mining laws if they are unoccupied as are also the beds of meandered nonnavigable streams when the abutting upland is unappropriated.

12. Maintenance--Annual assessment work--Adverse claim--Jurisdiction. The right of possession to a valid mining claim is maintained by the expenditure annually of at least $100 in labor or improvements of a mining nature on the claim, the first annual assessment period commencing at 12 o'clock noon on the 1st day of July succeeding the date of location. Failure to perform the assessment work for any year will subject the claim to relocation, unless work for the benefit of the claim is resumed before a relocation is made. The determination of the question of the right of possession between rival or adverse claimants to the same mineral land is committed exclusively to the court. (See 18)...

13. Expenditures on claim for patent purposes--Lode--Placer--Mill site. Five hundred dollars in labor or improvements of a mining nature, must be expended upon or for the benefit of each lode or placer claim, and compliance with the United States mining laws made otherwise, to entitle the claimant to prosecute patent proceedings therefore. Such expenditures must be completed prior to the expiration of the period during which notice of the patent proceedings is published. Patent expenditures on a mill site are not required, but it must be shown that the mill site is used or occupied for mining or milling purposes at the time an application for patent is filed.

14. Patent not necessary. One may develop, mine, and dispose of mineral in a valid mining location without obtaining a patent, but possessory right must be maintained by the performance of annual assessment work on the claim in order to prevent its relocation by another.

15. Procedure to obtain patent to mining claims. The owner or owners of a valid mining location, or group of locations, on which not less than $500 has been expended on or for the benefit of each claim, may institute patent proceedings therefore in the district land office. Information as to patent procedure can be obtained from the register of the local land office or from the General Land Office. In general, a survey must be applied for unless

the claim is a placer claim located by legal subdivisions, the application for survey to be made to the public survey office in the State wherein the claim is situated. Applications for patent are filed in the district land office. A notice of the application is required to be posted on the land prior to filing the application and to be published by the register after the application if filed.

16. Blank forms. No set form of location notices nor of the papers filed in patent proceedings for mining claims is required and no blank forms are furnished by the General Land Office, or by the district land offices, for use in mineral cases. Forms containing essentials are printed by local private parties or concerns. The registers of the local land offices can usually advise you where such forms may be obtained.

17. Common improvements. An improvement, made upon one of a group of contiguous claims (cornering is not contiguity) owned in common, may be applied to such claims of the group, in existence at the time the improvement is made, shown to be benefited thereby.

18. Adverse claims. An adverse claim may be filed during the period of publication of notice of an application for patent by one claiming a possessory right under another mining location to all or some portion of the land applied for, and must show fully the nature, boundaries, and extent of the area in conflict, to be followed within 30 days after filing, but suit in a court of competent jurisdiction. If suit is filed, all proceedings on the application, except the filing of the affidavit of the notice, are stayed to await the outcome of the court proceedings.

19. Coowners. A coowner not named in the application for patent can not assert his rights by filing an adverse claim, a protest being proper to cause his alleged rights to be considered when the case is adjudicated. If a coowner fails to do his proper proportion of annual assessment work on a claim, or fails to contribute his proportion of the cost thereof, the coowners who have caused the work to be done during any assessment period may, at the expiration of the assessment year, give such delinquent coowner personal notice in writing, or notice by publication in a newspaper published nearest the claim for at least once a week for 90 days, and if at the expiration of 90 days after such notice in writing, or 180 days after the first newspaper publication, such delinquent should fail to contribute his proportion of the expense required, his interest in the claim becomes the property of his coowners who have made the expenditure.

20. Lode in placer. If a placer mining applicant fails to state that there is a known lode within the bound-

aries of the claim, it is taken as a conclusive declaration that he has no right of possession thereto. If no such vein or lode be known the placer patent will convey all valuable mineral and other deposits within the boundaries of the claim. A known lode not included in an application for patent to the claim may be applied for even after issuance of patent to the placer mining claim. Where a placer mining claimant makes application for a placer containing within its boundaries a lode claim owned by him the lode must be surveyed, the lode being paid for on the basis of $5 per acre and the remaining portions of the placer at the rate of $2.50 per acre.

21. The United States mining laws are applicable to the following States: Alaska (subject to certain modifications), Arizona, Arkansas, California, Colorado, Florida, Idaho, Louisiana, Montana, Nebraska, Nevada, New Mexico, North Dakota, Oregon, South Dakota, Utah, Washington, and Wyoming.

22. National parks and monuments. Mining locations may not be made on lands in national parks and monuments after their establishments.

23. Withdrawals. Withdrawals usually bar location under the mining law, but those made under the act of June 25, 1910 (36 Stat. 847), as amended by the act of August 24, 1912 (37 Stat. 497), permit locations of the withdrawn lands containing metalliferous minerals, subject however to section 24 of the Federal water power act when controlled by that act.

24. Minerals on Indian lands. In general, the mineral deposits in Indian reservations are subject to leasing and are under the administration of the Bureau of Indian Affairs.

25. Mineral land in agricultural entries--Protest--Contest. Where lands known to be valuable for minerals are embraced in an agricultural filing, other than a stock raising homestead filing, a mineral claimant may initiate a contest thereagainst by filing a protest sworn to and in duplicate, in the local land office, alleging sufficient facts, which, if proven, will establish the mineral character of the land, and warrant cancellation of the agricultural filing. The protest must be corroborated by one or more witnesses having knowledge of the facts alleged. In the case of stock raising homestead entries, a mineral claimant, whose location antedates the homestead filing, must protest such filing in order to protect his title to the surface of his mining claim.

26. Cost of patent proceedings for mining claims. With the exception of the fixed charges, such as the fee for filing an application for patent, which is $10, the purchase price of lands in lode claims and millsites at $5 per acre,

and $5 for each fractional part of an acre, and $2.50 per acre or fraction of an acre for placer lands, unless otherwise provided by law as to certain lands, no estimate can be furnished as to what it will cost to procure a patent. The cost of publication, survey, and abstract of title depend upon the services rendered and vary in each case.

C. C. Moore, Commissioner"

Concerning the rights to mine uranium-bearing lignites, The Grand Junction Operations Office of the Atomic Energy Commission announced March 30, 1955:

"...the Commission has asked the Department of the Interior to rule on the question of how persons may obtain rights to mine uraniferous lignites found in the public domain...Ordinarily, metalliferous minerals, including uranium minerals, when discovered on the public domain may be located under the provision of the mining laws. On the other hand, coal, phosphate and certain other non-metallic minerals found on the public domain are subject to disposition only under the mineral leasing laws...The Department is expected to render an opinion on this question as soon as a study now under way can be completed."

State of South Dakota

Uranium claims are staked in the same manner as lode claims.

The following mining claim laws are quoted from the South Dakota Code Revision Report (1939, pp. 2025 to 2028):

"...42.0102 Dimensions of lode claim. The length of any lode claim hereafter located within this state may equal but shall not exceed fifteen hundred feet along the vein or lode.

The width of a lode claim shall be three hundred feet on each side of the center of the vein or lode, provided that any county may, at any general election, determine upon a width less than three hundred feet but not less than twenty-five feet on each side of the vein or lode.

42.0103 Certificate of location and record thereof. The discoverer of a lode shall within sixty days from the date of discovery record his claim in the office of the register of deeds of the county in which such lode is situated by a location certificate which shall contain:

(1) The name of the lode;
(2) The name of the locator or locators;
(3) The date of location;
(4) The number of feet in length claimed on each side of the discovery shaft;
(5) The number of feet in width claimed on each side of the vein or lode;
(6) The general course of the lode as near as may be;
(7) Such description of the claim as shall identify it with reasonable certainty.

42.0104 Location certificate void, when. Any location certificate of a lode claim which shall not contain the matters specified in Section 42.0103 shall be void.

42.0105 Recording fee. The register of deeds shall be entitled to receive the sum of one dollar for each location certificate recorded and certified by him and shall furnish the locator or locators with a certified copy of such certificate when demanded, for which he shall be entitled to receive fifty cents.

42.0106 Certificate limited to single location. No location certificate shall claim more than one location whether the location be made by one or several locators. If it purports to claim more than one location, it shall be absolutely void except as to the first location therein described, and if they are described together or so that it cannot be told which location is first described, the certificate shall be void as to all.

42.0107 Manner of locating claim. Before filing such location certificate the discoverer shall locate his claim:

(1) By sinking a discovery shaft thereon sufficient to show a well defined mineral vein or lode and not less than ten feet in depth on the lower side;

(2) By posting at the point of discovery on the surface a plain sign or notice containing the name of the lode, the name of the locator or locators, and the date of discovery, the number of feet claimed in length on either side of the discovery, and the number of feet in width claimed on each side of the lode; and

(3) By marking the surface boundaries of the claim.

42.0108 Marking surface boundaries. Such surface boundaries shall be marked by eight substantial posts, hewed or blazed on the side or sides facing the claim and plainly marked with the name of the lode and the corner, end, or side of the claim that they respectively represent and sunk in the ground; one at each corner and one at the center of each side line and one at each end of the lode. When it is impracticable on account of rock or precipitous ground to sink such posts, they may be placed in a monument of stone.

42.0109 Dimensions of cut or adit. Any open cut, at least ten foot face, cross-cut, or tunnel at a depth sufficient to disclose the mineral vein or lode or an adit of at least ten feet in along the lode from the point where the lode may be in any manner discovered, shall be equivalent to a discovery shaft.

42.0110 Time allowed for sinking shaft. The discoverer shall have sixty days from the time of uncovering or disclosing a lode to sink a discovery shaft thereon.

42.0111 Location includes what. The location or location certificate of any lode claim shall be construed to include all surface ground within the surface lines thereof and all lodes and ledges throughout their entire depth, the top or apex of which lie inside of such lines extended vertically with such parts of the lodes or ledges as continue by dip beyond the side lines of the claim but shall not include any portion of such lodes or ledges beyond the end lines of the claim or the end lines continued, whether by dip or otherwise, or beyond the side lines in any other manner than by the dip of the lode.

42.0112 Limits of claim. If the top or apex of the lode in its longitudinal course extends beyond the exterior lines of the claim at any point on the surface or as extended vertically downward, such lode may not be followed in its longitudinal course beyond the point where it is intersected by the exterior.

42.0113 Security to owner of land. When the right to mine is in any case separate from the ownership or right of occupancy to the surface, the owner or rightful occupant of the surface may demand satisfactory security from the miner, and if it is refused, may enjoin such miner from working until such security is given.

42.0114 Amended certificate. If at any time the locator of any mining claim heretofore or hereafter located or his assigns shall apprehend that his original certificate was defective, erroneous, or that the requirements of the law had not been complied with before filing or shall be desirous of changing his surface boundaries or of taking in any part of an overlapping claim which has been abandoned and he shall be desirous of securing the benefit of this chapter, such locator or his assigns may file an additional certificate subject to the provisions of this chapter. Such relocation does not interfere with the existing rights of others at the time of such relocation and no such relocation or the record thereof shall preclude the claimant from proving any such title as he may have held under any previous location.

42.0115 Annual work required. The amount of work to be done or improvements made during each year to hold possession of a mining claim shall be that prescribed by the laws of the United States, to-wit: one hundred dollars annually. The period within which such work shall be required to be done annually on all unpatented claims so located shall commence on the first day of January succeeding the date of location of such claim.

42.0116 Abandoned claim: relocation. The relocation of an abandoned lode claim shall be by sinking a new discovery shaft and fixing new boundaries in the same manner as if it were the location of a new claim or the relocator may sink the original shaft, cut, or adit to a sufficient depth to comply with the requirements of an original location, and erect new or adopt the old boundaries, renewing the posts if removed or destroyed. In either case a new location stake shall be erected. In any case whether the whole or part of an abandoned claim is taken, the location certificate must state that the whole or any part of the new location is located as abandoned property.

42.0117 Disputed property: survey. In all actions in any Circuit Court of this state wherein the title or right of possession to any mining claim shall be in dispute the Court or Judge thereof may, upon application of any of the parties to such suit, enter an order for the underground as well as surface survey of such part of the property in dispute as may be necessary to a just determination of the question involved. Such order shall designate some competent surveyor not related to any of the parties to such suit or in anywise interested in the result of the same; and upon the application of the party adverse to such application, the Court may also appoint some competent surveyor to be selected by such adverse applicant whose duty it shall be to attend upon such survey and observe the method of making the same at the cost of the party asking therefore. It shall also be lawful in such order to specify the names of witnesses named by either party, not exceeding three on each side, to examine such property, who shall be allowed to enter into such property and examine the same. Such Court or Judge thereof may also cause the removal of any rock, debris, or other obstacle in any of the drifts or shafts of such property when such removal is shown to be necessary to a just determination of the question involved. No such order shall be made for survey and inspection except in open Court or in chambers upon notice of at least six days, and not then except by agreement of parties or upon the affidavit of two or more persons that such survey and inspection is necessary to the just determination of the suit, which affidavits shall state the facts in such case and wherein the necessity for survey exists; nor shall such order be made unless it appears that the party asking therefor has been refused the privilege of survey and inspection by the adverse party.

42.0118 Affirmative relief by injunction. The Circuit Court or any Judge thereof shall have power to issue writs of injunction for affirmative relief having the force and effect of a writ of restitution restoring any person to the possession of any mining property from which he may have been ousted by force and violence or by fraud, or from possession of which he is kept by threats, or whenever such possession was taken from him by entry of the adverse party on a Sunday or legal holiday or while the party in possession was temporarily absent therefrom; the granting of such writ to extend only to the right of possession under the facts of the case in respect to the manner in which the possession was obtained, leaving the parties to their legal rights on all other questions as though no such writ had issued."

II. URANIUM DEPOSITS IN SOUTH DAKOTA

INTRODUCTION

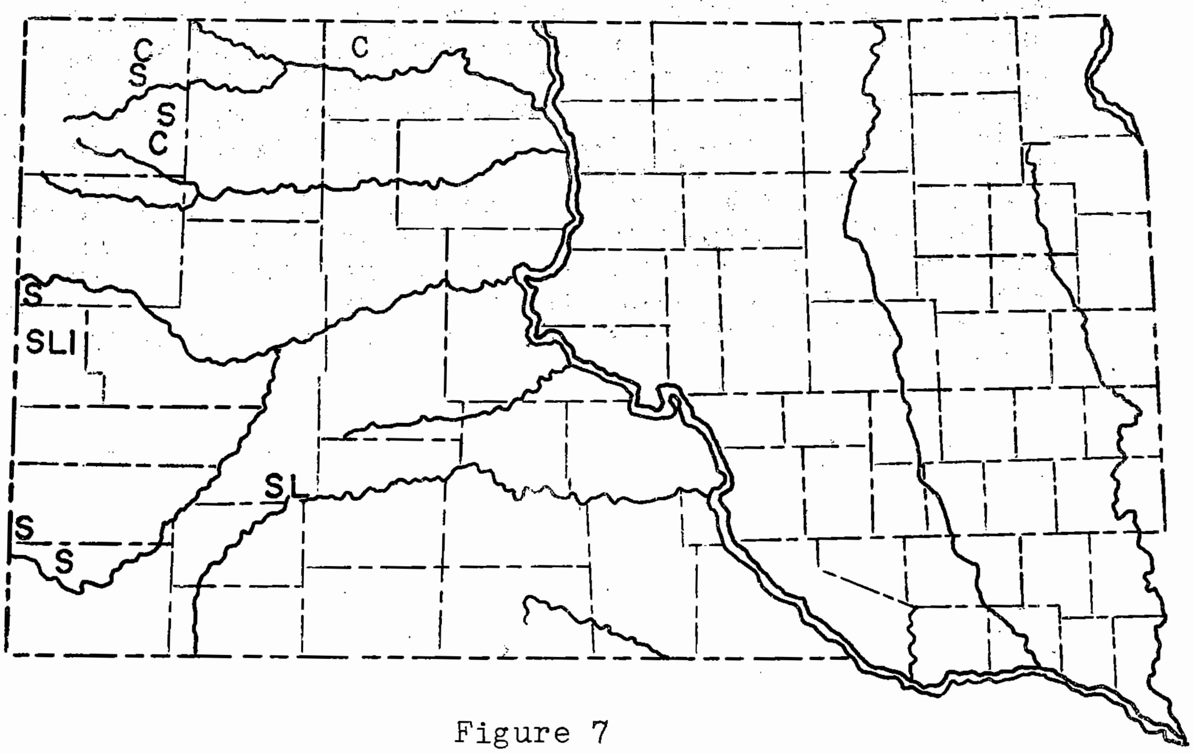


Figure 7

Index map showing uranium deposits in South Dakota

Uranium was first reported in the Black Hills (Stillwell, 1885, p. 82); however, the first commercial uranium deposit was discovered in Fall River County in 1951.

As a result of uranium discoveries, development, and production in the Edgemont district, Fall River County; near Dewey, Custer County; near Belle Fourche, Butte County; and, the recent discovery and development in the North and South Cave Hills, Harding County, South Dakota has become a recognized uranium-producing State with a decidedly bright future.

Uranium has been produced from more than 100 claims. An ore-buying station was established at Edgemont in December, 1952, and enthusiasm has flared up over the new ore-processing mill which is being constructed at Edgemont. Therefore, uranium has brought a new industrial boom to South Dakota through the media of intense exploration, rapid development, and production largely by private industry. The current epidemic, uranium fever, is encouraging and may result in new uranium discoveries of economic significance.

FALL RIVER AND CUSTER COUNTIES

In 1951, the first commercial deposit of uranium in South Dakota was discovered in the Craven Canyon area which is located about eight miles north of Edgemont, Fall River County. Fall River is the major uranium producing county in the State. About 1,700 mining claims have been staked in Fall River County, and approximately 1,000 claims have been staked in Custer County. Exploration and mining activities are moderately intense.

The principal mining areas in the Edgemont district (see Figure 8) trend northwest from about six and one-half miles east of Edgemont near Chilson Canyon to Red Canyon, seven miles north-northeast of Edgemont, to Craven Canyon, eight miles north of Edgemont, to Coal Canyon, seven miles north-northwest of Edgemont, and to Driftwood Canyon, about 10 miles northwest of Edgemont. The producing areas in Custer County are located near Bennett Canyon, about 12½ miles northwest of Edgemont and five and one-half miles southeast of Dewey.

Craven Canyon and Surrounding Areas

Nation and State-wide attention has been focused on this locality since June, 1951, when carnotite was discovered. This locale is the uranium "hub" of South Dakota's miniature "Colorado Plateau".

Uranium data, pertinent to the uranium minerals, lithology, stratigraphic position of ore bodies, structural controls of uraniferous solutions and ore deposits, and the origin of the ores, have largely been determined from the Craven Canyon area. These data have been indispensable guides to geologists, prospectors, and miners who have discovered similar uranium ores in other sectors of Fall River, Custer, and Butte Counties. These data indicate that other areas of similar geology may contain uranium in commercial quantities.

History

Uranium was discovered in South Dakota in Craven Canyon in June, 1951, by Jerry G. Brennan of Rapid City who was studying Indian pictographs. Brennan found the uranium mineral carnotite which was identified at the South Dakota School of Mines, Rapid City. Brennan staked the first uranium claim, the Pictograph, on September 4, 1951.

The Gould ore body, which is the largest producer in South Dakota, was discovered in May, 1954, as a result of a private operator wildcat drilling in search of uranium ore in another horizon.

Location

The carnotite deposits of Craven Canyon are situated eight and nine miles north of Edgemont. The original prospects were located in Secs. 24, 25, T. 7 S., R. 2 E. and Secs. 19, 30, T. 7 S., R. 3 E. At present, the largest producing mines in Craven Canyon are the Clarabelle and Greenslipper groups and the Professor group in the N½ Sec. 19, T. 7 S., R. 3 E. (See Fig. 8). The Gould Mine is near Chilson Canyon in Secs. 11, 12. T. 8 S., R. 3 E.

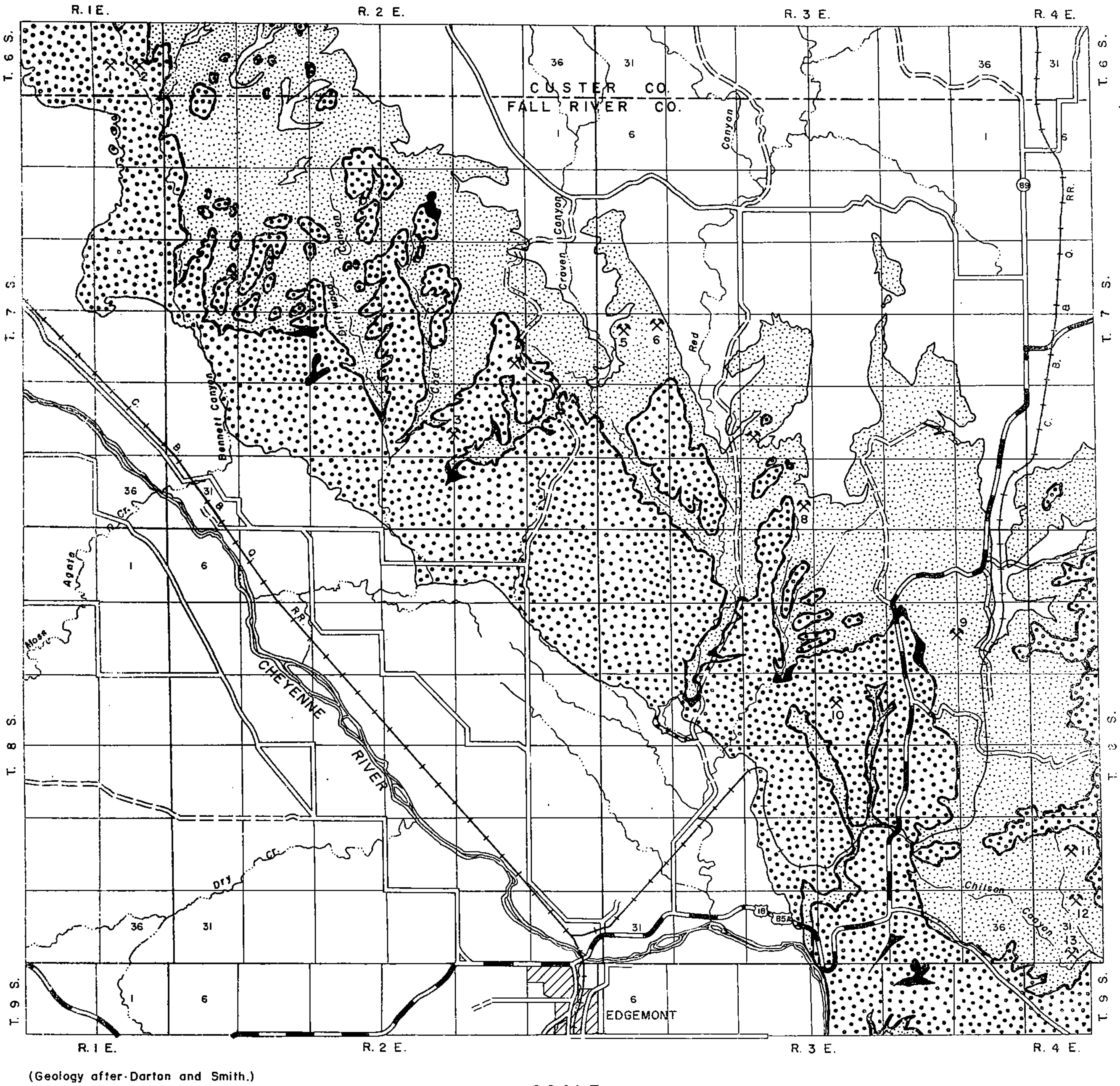
General Geology

Carnotite ores in Craven Canyon are restricted to the Lakota sandstone. The Lakota is the basal formation of the Inyan Kara group (Lower Cretaceous age) which is composed of, in ascending order, the Lakota, the Fuson, and the Dakota (Fall River) formations. Table 4, p. 61 shows the exposed formations and other data in the Inyan Kara group. Figure 8 is an areal geology map of the Inyan Kara group in part of Fall River and Custer Counties.

The Inyan Kara group constitutes the outer hogback around the Black Hills. (See Fig. 9).

The Lakota formation, which is sometimes mistakingly called a sandstone, is composed generally of interbedded sands and sandstone, silts and siltstones, clays and claystone, and variable amounts of carbonaceous material, some coal, and petrified wood. Massive hogback and cliff-forming sandstones make the formation conspicuous. The formation may average about 200 feet in thickness. In some instances, the contact between the Lakota and the overlying Fuson formation is chosen arbitrarily on the basis of color and texture. Together, the Lakota and Fuson formations are 381 feet thick in Craven Canyon (Baker, *et al*, 1952). However, the Lakota is 151 feet thick in Coal Canyon which is two miles west of Craven Canyon in Sec. 22, T. 7 S., R. 2 E.

The Lakota formation in Craven Canyon is described by Page and Redden (1952, p. 4) as follows:



LEGEND

FORMATIONS

Dakota

Fuson

Lakota

MINES

1. Freezeout Group
2. Lucky Strike Group
3. Virginia City Group
4. Traill Faction Group
5. Professor Group
6. Clorabelle-Greenslipper Group
7. Hot Point Area
8. Holdup No. 15.
9. Gould.
10. Lion.
11. Accidental.
12. Washboard.
13. Damsite.

FIGURE 8.- Areal geology map of a portion of Fall River and Custer Counties showing the largest producing uranium mines in that area.

P.R.

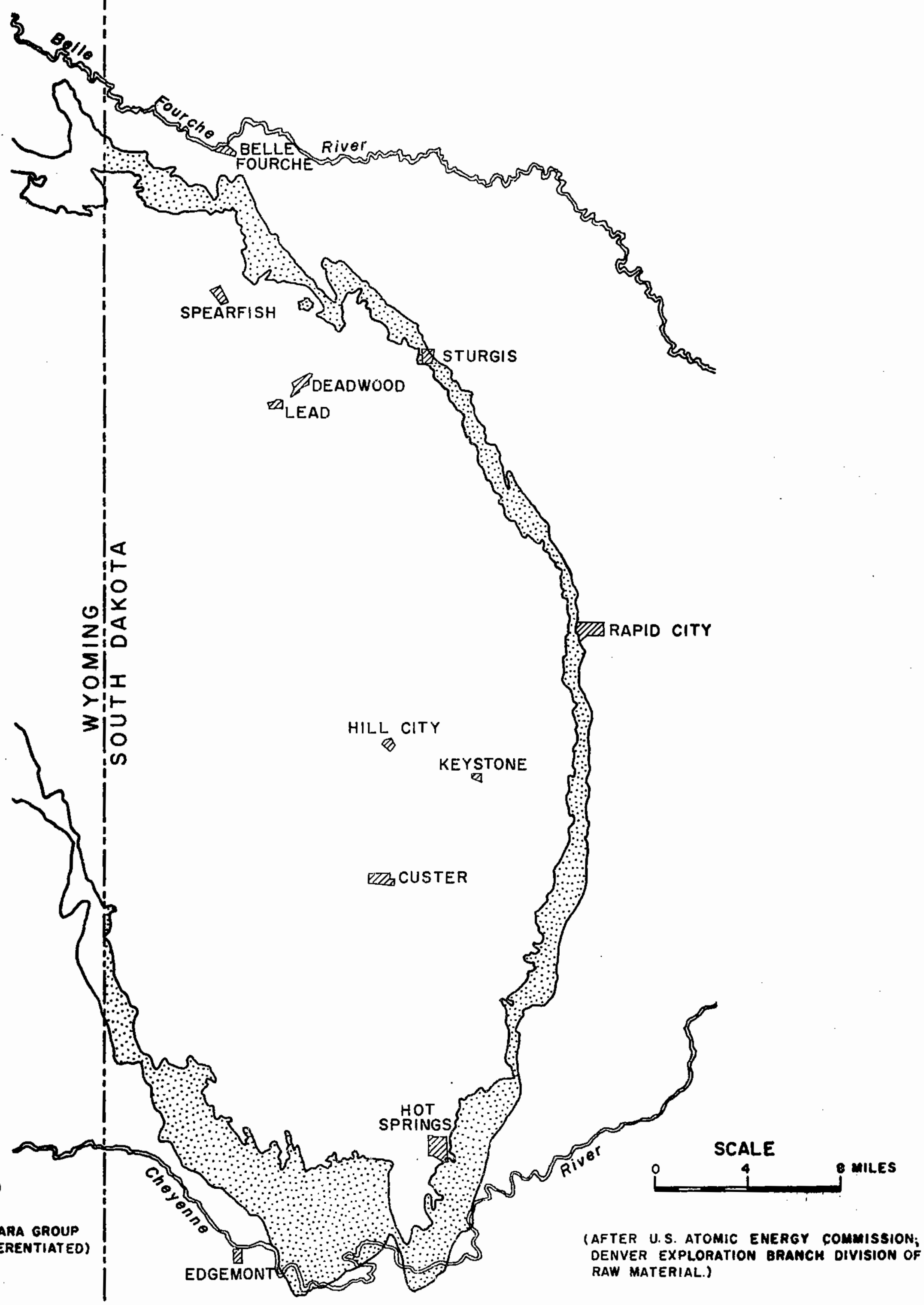


FIGURE 9.- Outcrop map of the Inyan Kara group around the **Black Hills,** South Dakota.

"...a white to buff, massive to thin-bedded sandstone containing many 1-to 6-inch beds of white to reddish-purple shale. Throughout the area studied, a 1-to 3-foot bed of dense, black carbonaceous shale is exposed about 110 feet above the base of the sandstone. This bed makes an excellent horizon marker because it weathers characteristically to gray, papery plates...

The beds of the Lakota sandstone consist of uniformly fine grains of quartz and appreciable amounts of interstitial white clay. Locally, clay-pellet zones occur as thin beds or channel fillings as much as 3 feet thick. Concretionary structures occur throughout most of the formation. Quartz-rich concretions...are as much as 4 feet in diameter. The lower 4 feet of the sandstone exposed on the Pictograph claim is ripple marked, but ripple marks are not common in other parts of the sandstone. Cross-bedding is common in many of the beds, but in the upper part of the sandstone it is a relatively inconspicuous feature. More commonly, thin-bedded and massive sandstone beds alternate and interfinger...

Carnotite and limonite stains are abundant on the sandstone throughout the area. Manganese oxides coat fracture surfaces and occur as spots in carnotite-bearing sandstone..."

TABLE 4.--EXPOSED FORMATIONS OF THE INYAN KARA GROUP

Age	Formation	Thickness in Feet	Lithology
Lower Cretaceous	Dakota (Fall River)	30-165	Thin-bedded, brown-red, iron-stained, fine-grained sandstone, interbedded shale, siltstone claystone, coal
	Fuson	100-125	Varicolored shales, clays, and sandstones
	Lakota	150-250	Massive, light gray medium to coarse grained sandstone, carbonaceous material, petrified logs

Certain pink-purplish sandstones form encircling haloes around carnotite ore bodies in the Lakota sandstone. It was thought formerly that the haloes were diagnostic for the occurrence of ore bodies, but the Atomic Energy Commission (Hall, personal communication) analyzed this possibility and found it invalid. Carbonaceous materials were believed to be universally associated with carnotite; however, some carnotite deposits are devoid of carbonaceous material.

The Fuson formation, which separates the Lakota and Dakota (Fall River) formations, is barren of uranium in the State. The Coal Canyon detailed stratigraphic section shows the lithology of the formation.

The Dakota formation is not a homogeneous sandstone. However, while the principal lithology is a persistently buff to brown sandstone, subordinate amounts of clays and silts are present, sometimes in the indurated forms of claystones, siltstones, and boulder conglomerates. This rock unit varies in thickness from 30 to 165 feet in many wells drilled in Fall River County. The Coal Canyon section shows the character of the Dakota formation.

The Gould Mine is located in the Dakota formation, about 75 feet above the Fuson-Dakota contact. The ore body attains a thickness of 14 feet, and it is overlain by a silty sandy boulder conglomerate.

Uranium deposits are generally confined to permeable sandstones, and the carnotite-tyuyamunite minerals are deposited as grain coatings and interstitial fillings. Therefore, lithology is basically important to the occurrence of ore deposits, both from the standpoint of permeability, the critical factor that allows freedom of movement for ore-bearing solutions, and chemical environment in which ore-bearing solutions can be precipitated as mineral and ore deposits.

The following detailed section of the Inyan Kara group of formations was compiled by the author from an Atomic Energy Commission drill-core log:

Detailed Section of Inyan Kara Group from Coal Canyon, NW¼ NW¼ NE¼, Sec. 22, T. 7 S., R. 2 E.

Inyan Kara Group	Feet
Dakota (Fall River) Formation	
Not logged..................................	10
Sand, light brown, fine-grained, dark gray clay and silt partings, limonite and hematite stain, carbonaceous specks....	6¼
Sandy silt, light brown to light gray, limonite-filled wood impressions, carbonaceous specks..................	3 3/4

	Feet
Sandstone, silt, claystone, interbedded, dark gray, carbonaceous material......	$3\frac{1}{4}$
Sandstone, light tan, fine-grained, cross-bedded, limonite and hematite stain, carbonaceous specks..................	$11\frac{1}{2}$
Silty clay, light to dark gray, interbedded, laminated, cross-bedded, progressively darker and finer textured toward base.........................	$20\frac{1}{4}$
Clayey siltstone, dark gray, massive- to fine-grained, hematite stain...........	11
Total Dakota (Fall River) measured	66

<u>Fuson Formation</u>

Silty clay, red-brown, weathered, hematite and carbonate grain coatings......	$1\frac{1}{2}$
Clayey siltstone, light to medium gray, interbedded clay and silt, cross-bedded, hematite, limonite, and carbonate grain coatings.........................	$4\frac{1}{2}$
Sandstone, red-brown at top, light brown at base, massive- and slightly cross-bedded, hematite and limonite grain coatings............................	23
Clay, red-gray............................	3
Silty claystone, blue-gray, massive, subconchoidal fracture..................	7
Silty claystone, red-gray, massive, conchoidal fracture......................	5
Clay, green-gray, massive.................	4
Clayey siltstone, red, very fine-grained, massive, hematite stain................	12
Silty claystone, blue-gray, medium- to coarse-grained, massive................	3
Sandy silt and sandstone, light gray, friable sandstone, massive............	$4\frac{1}{2}$
Clayey siltstone, blue-gray, medium-grained, massive......................	3
Sandy clayey silt, blue, fine-grained, massive............................	$1\frac{1}{2}$
Silt, brown, fine-grained, massive, hematite stain.......................	2
Sandy clayey silt, blue-gray, medium-grained, massive......................	2
Sandy silt and sandstone, light gray, very fine-grained, massive............	14
Sandstone, light brown, friable, fine- to medium-grained, massive, limonite stain.................................	16
Siltstone, green to brown, fine- to medium-grained, massive................	$7\frac{1}{2}$
Total Fuson measured................	$113\frac{1}{2}$

Lakota Formation	Feet
Sandstone, brown, fine- to medium-grained, massive, hematite and limonite stain, clay galls................	$20\frac{1}{2}$
Sandstone, light brown, thin- and cross-bedded, sandy clay galls..............	6
Sandstone, light gray, very fine-grained, thin-bedded.........................	6
Conglomeratic sandstone, light brown, coarse- to very coarse-grained, thin-bedded..............................	3
Sandstone, light gray, fine- to very fine-grained, cross-bedded, feldspar pebbles............................	5
Sandstone, purplish red, carbonaceous material............................	5
Clay, black, siltstone lenses...........	3
Sandstone, dark gray to red, fine-grained, thin-bedded, hematite and limonite stain, carbonaceous material..........	4
Sandstone, purplish red to light brown, cross-bedded, hematite and limonite stain..............................	2
Sandstone, light brown, hematite stain..	13
Sandstone, gray to brown, very fine-grained, massive.....................	26
Clay, silty clay, gray, vertical fractures..........................	3
Sandstone, gray, very fine-grained, cross-bedded.........................	4
Clayey siltstone, medium to dark gray, carbonaceous material.................	9
Sandstone, purplish red to light brown, very fine-grained, massive...........	$35\frac{1}{2}$
Clay, black-gray, calcareous, massive...	3
Clay, medium gray, calcareous, thick-bedded...............................	$3\frac{1}{2}$
Total Lakota measured.............	$151\frac{1}{2}$

Structural conditions in the Edgemont area apparently play a major role in the localization of the uranium deposits. Structure is perhaps directly responsible for the conveyance of a considerable volume of uraniferous solutions.

The regional dip is to the southwest. Two southwest plunging, asymmetric anticlines, namely the Cascade and Chilson, constitute the chief tectonic features in this immediate area. Both folds have steeply dipping west flanks with less steeply dipping east limbs. According to Hall (personal communication), large deposits of carnotite-tyuyamunite are located in areas of gentle dip immediately adjacent to areas where dips change radically either up or down. Most production is from the structural terrace, called the Red Canyon monocline, which is located on the west flank of the Chilson anticline. The most likely ore loci are found on structural terraces or small anticlinal noses, monoclines, or locally flattened areas of the regional dip. It appears that the majority of the uranium deposits are found in locations with dips of less than five degrees.

Mineralogy

Two closely-related uranium minerals, carnotite, $K_2(UO_2)_2(VO_4)_2 \cdot 3H_2O$ (potassium uranium vanadate), and tyuyamunite, $Ca(UO_2)_2(VO_4)_2 \cdot nH_2O$, (calcium uranium vanadate), constitute the bulk of the uranium ores. Both minerals are yellow in color, but tyuyamunite turns green on exposure to sunlight. However, chemical analysis is generally necessary to differentiate between them. Carnotite occurs in Craven Canyon, according to Page and Redden (1952, p. 6),

"...in irregular patches as coatings on or interstitial to sand grains; as layers as much as 2 inches thick parallel to bedding; as irregular, thin layers within sandstone beds; as veins, as much as half an inch thick along joints; and as a thin film, in places mixed with carbonate (?) and an unidentified green mineral, coating surface exposures. The carnotite is commonly associated with iron oxides and, in places, with small grains and specks of manganese oxides. On the Pictograph claim some of the richest ore is associated with casts of plant fossils containing carbonaceous material."

Localization of Ores

Concerning the localization of carnotite in Craven Canyon,

Page and Redden (1952, p. 7) state:

"The carnotite occurrences in the Craven Canyon area appear to be restricted to the lower 100 to 150 feet of the Lakota sandstone; most are within 50 feet of a distinctive papery-weathering, nonradioactive, carbonaceous black shale that is 100 to 125 feet above the base of the formation. The richer deposits are, for the most part, in sandstone in which the individual beds are less than 2 feet thick, and commonly no more than 1 inch thick. The lower-grade deposits appear to be mainly in the more massive and thicker beds where the carnotite, for the most part, is present as a stain on weathered surfaces.

The deposits generally are parallel to bedding, but in detail they are cross cutting. In most of the deposits carnotite-rich layers coat cross-cutting veinlets and occur in thin zones that appear to have been more permeable than adjacent parts of the sandstone. In places the carnotite appears to be localized by plant fossils but elsewhere fossil-bearing beds lack any noticeable uranium minerals.

Three general, favorable zones have been recognized in the area and are, from top to bottom, (1) a zone 20 to 30 feet above the carbonaceous shale, (2) a zone 20 to 30 feet below the carbonaceous shale, and (3) a zone about 25 feet below (2). A fourth zone about 20 feet below (3) has been recognized in one place and may be found on further prospecting to be widespread."

The most salient characteristics of the Gould ore body are summarized by Bright (1955, pp. 6-7):

"The ore body underlies an irregular contact between an impermeable silt-boulder conglomerate and a medium- to coarse-grained sandstone. The conglomerate seals the top of the ore body. A relationship appears to exist between the tenor of the ore and a low or swale in the overlying conglomerate contact. Jointing and erratic cementation control the ore locally.

Carnotite-type minerals characterize the massive, flat-lying sedimentary ore deposit. In many places, red-brown iron-oxide staining, associated with the ore as parallel banding and as massive cementation, masks the yellow color of the uranium minerals. Carbonaceous material in the ore body is not discernible megascopically."

Grade

Exploitable ore bodies vary from small size and low in grade to relatively large size and locally high in grade.

It is reported (King, 1954b, p. 2) that the general minable grades in this area range upward from 0.1 percent to perhaps 0.5 percent uranium oxide, but that most operators attempt to hold their grade at about 0.2 percent uranium oxide. This, of course, implies that the mining methods are selective; that is, much sub-ore rock, which includes many rocks with uranium stain, is rejected.

Table 5 was compiled from Page and Redden (1952, pp.9-17).

TABLE 5.--ANALYSES OF URANIUM SAMPLES FROM CRAVEN CANYON, FALL RIVER COUNTY

Claim Name	Type of Sample	Length of Sample (Ft.)	Equiv. U %	% Uranium	% Vanadium
Pictograph	Channel	2.0	0.17	0.22[1]	0.12
Sec. 30,	"	1.2	0.26	0.30	0.13
Twp. 7S.,	"	4.5	0.045	0.049	0.04
Rge. 3E.	"	5.0	0.053	0.055	0.02
	"	4.0	0.047	0.052	0.02
	"	4.5	0.052	0.040	0.02
	"	2.0	0.14	0.23	0.08
	Grab	---	0.070	0.078	n.d.[2]
	"	---	1.1	2.0	"
Ophelia	Channel	2.0	0.077	0.095	0.06
Sec. 30,	Grab	4.0	0.14	0.20	0.10
Twp. 7S.,					
Rge. 3E.					
Imogene	-----	2.0	0.23	0.33	----
Sec. 19,	Grab	5.5	0.058	0.054	----
Twp. 7S.,					
Rge. 3E.					
Helen	Channel	8.0	0.044	0.049	0.04
Sec. 19,					
Twp. 7S.,					
Rge. 3E.					
Gertrude	Channel	1.0	0.13	0.16	----
Sec. 19,	"	2.0	0.16	0.16	0.08
Twp. 7S.,	Grab	same 2.0	0.19	0.23	----
Rge. 3E.	Channel	6.0	0.019	0.019	0.04
Lucy	"	5.0	0.030	0.032	0.02
Sec. 24, 25,					
Twp. 7S.,					
Rge. 2E.					
Eunice	Channel	3.4	0.024	0.015	----
Sec. 19,					
Twp. 7S.,					
Rge. 3E.					
Dagmar	Channel	3.0	0.062	0.039	----
Sec. 19,					
Twp. 7S.,					
Rge. 3E.					

1. The higher percentage of uranium in this and several other samples compared with percentage of equivalent uranium suggests that much of the carnotite may have been precipitated recently.
2. Not determined.

Mining

Mining in this area is generally of the surface or open pit type. According to King (1954 b, p. 3):

"Only half a dozen mines have gone underground seriously. Most operators have stripped surface exposures or anomalies by bulldozer and loaded their ore by front end loader into the trucks which haul it to the buying station. The underground operations are not mechanized. It is characteristic of these mines that the tonnage is insufficient in a given orebody to warrant the purchase of diesel or electric mules. There are exceptions but in many cases the operators prefer to strip the overburden and mine the largest deposits from the surface. It is expected that large deposits will be found in depth where mechanical equipment will be required but at present no mining is being done more than 75 feet from the surface. This situation points up the fact that at this stage of uranium mining in the Black Hills, only the surface is being scratched. Ore should theoretically exist in bodies at least as large and as rich at 200 to 500 feet in depth as it does near the surface. AEC drilling has indicated that this is so as far as grade is concerned. The large ore bodies have not yet been found at depth but it is believed that refinement of ore-finding techniques will result in their discovery in the not too distant future."

Origin

It is possible that the uranium-bearing solutions were originally hydrothermal in origin and were primarily associated with the intrusive igneous bodies of the Black Hills.

The Chilson anticline and small, superimposed folds in addition to complex joint and fault patterns apparently constitute the structural control that provided solution channelways for ore deposition in the Lakota and Dakota formations.

Lithology is vitally important, both to permeability and deposition. The access and movement of uraniferous solutions are prohibited by impermeable rocks or marked changes in lithology which halt the movement of circulating uranium-charged ground water. Clays and shales in the Inyan Kara group are impermeable and, consequently, barren of uranium. This applies to the Fuson formation and certain beds in the Lakota and Dakota formations. Changes in lithology and permeability cannot be predicted from surface exposures as these features can change radically underground and may be highly local in nature.

Ore deposition in this area, comparable to the Colorado Plateau, favor the transition beds between predominantly sandy and predominantly clayey sections, and the larger ore bodies vary in thickness between three and 20 feet.

Favorable structural criteria should prove invaluable in predicting areas of potential uranium ore. Gross lithologies of formations serve as useful geologic guides in the examination of exposed rocks and drill-hole samples.

Future Prospecting

The recognition and application of structural and lithologic features in this and other areas will enhance the possibility of discovering significant ore bodies.

Extensive drilling in areas of known ore bodies will outline the areal extent of the deposits. The Gould ore body was discovered by drilling.

Most of the exploration, which is based largely on exposed uranium deposits and anomalies, have been confined to shallow depths. However, the Atomic Energy Commission (King, 1954 a, p. 4) has indicated that ore is not confined to the surface horizons as one drill hole in the Edgemont district indicates uranium ore near the base of the Lakota formation at a depth of about 470 feet. This ore did not contain carnotite but exists in hydrocarbons.

The exploration techniques of airborne radiometric surveys have proved indispensable as a rapid method of detecting potential ore deposits. Several of the largest mines in this area, the Virginia City and Holdup 15, were discovered as a result of aerial surveys. The best anomalies do not necessarily point to the richest mines, but all anomalies warrant investigation. Of course, anomalies represent merely exposed rock or only the top foot or two of rock or soil.

The Edgemont district has not been thoroughly explored and tested, so it remains classified as an area with economic potential.

BUTTE COUNTY

Two producing deposits with sporadic production and some deposits with intermittent radioactivity are found along the South Dakota-Wyoming border near Belle Fourche. Like the Edgemont area, the Inyan Kara group comprises the outer hogback around the Black Hills (see Fig. 9).

Airborne anomalies were noted in August, 1953, and subsequent investigation resulted in the discovery of carnotite in the Dakota (Fall River) formation.

In the Dakota formation, the base of a coal bed is weakly radioactive and noncommercial, but an underlying six-foot thick sandstone has assayed up to 0.15 percent uranium oxide.

The Aladdin anticline trends across the South Dakota-Wyoming border. The Atomic Energy Commission, recognizing the possibilities of structural control for ore deposition, carried on limited exploratory drilling early in 1953 on the nose of the plunging anticline (King, 1954, p. 3). Ore is indicated in the Belle Fourche area at depths of nearly 200 feet in the Lakota formation.

This area has not been thoroughly explored. Extensive surface prospecting and drilling may encounter ore bodies. It is of potential economic significance that the Lakota and Dakota formations are exposed around the periphery of the Black Hills from the Belle Fourche area to the Edgemont district.

HARDING COUNTY

The second commercial uranium deposit in South Dakota was found in the North and South Cave Hills in Harding County. Noncommercial uraniferous lignites occur in the Slim Buttes, but ore-grade sandstones are found near Reva Gap and Cedar Canyon in the Slim Buttes. It may be of economic importance to note that radioactivity has been reported in the Short Pine Hills in the southwestern part of the county. (See Fig. 10).

Cave Hills Area

History

In 1954, the Atomic Energy Commission became interested in uraniferous sandstones in the Slim Buttes and decided to fly airborne surveys over the Slim Buttes. Messrs. Ellis and Fiegen, pilots from Spearfish, were scheduled to fly over the buttes, but a high wind precluded their operations. Instead, they flew over the Cave Hills and recorded high anomalies. As a result, they staked the first claims on August 15, 1954. Since that time, activity in this area has been intense. It is reported that most of the area has been staked. Several companies and individuals have undertaken extensive mining and exploration programs in the North and South Cave Hills.

Location

Uraniferous lignites are located in the North Cave Hills in T. 20, 21 N., R. 5, 6 E. Uraniferous lignites, carbonaceous siltstone, and clinker are found in the South Cave Hills in T. 20, 21 N., R. 4, 5 E.

General Geology

The geology of Harding County is generally simple. The bedrock consists of relatively flat-lying sediments, that are intermittently folded and faulted in several areas (see Figure 10).

These have been dissected by water and wind erosion into conspicuous regions of rough terrain. The canyon country of the Little Missouri River divide and the picturesque buttes and mesas that are sprinkled over the area form significant physiographic features. The flat-topped, steep-sided North and South Cave Hills, along with the Slim Buttes and Short Pine Hills, tower to heights of several hundred feet over the gently undulating uplands.

The exposed sediments in the Cave Hills range in age from Upper Cretaceous to Oligocene; however, Eocene rocks are apparently absent. (See Table 6).

TABLE 6.--EXPOSED FORMATIONS IN HARDING COUNTY

Age	Group	Formation	Thickness in Feet	Lithology
Miocene		Ogallala or Arikaree	75-260	Light gray, fine-grained tuffaceous sandstone, local basal conglomerate, nodular.
Oligocene	White River	Brule Chadron	160-236	Pink, massive, hard, silty clay, alternating sandstone and bentonitic clay. "Dazzling" white sandstone.
Eocene				Absent.
Paleocene	Fort Union	Tongue River	300	Yellow to brown, fine-grained, soft, cavernous sandstone, silt, clay, ortho-quartzite, coal.
		Ludlow-Cannonball	370	Ludlow: Buff to yellow sand, sandstone, silt, clay, coal. Cannonball: Light to dark gray marine clay, silt, and sand, molluscan concretions.
Upper Cretaceous		Hell Creek	425	"Somber beds" of drab, gray gumbo sand, silt, clay, coal, dinosaur bones.

TABLE 6.--EXPOSED FORMATIONS IN HARDING COUNTY--Continued

Age	Group	Formation	Thickness in Feet	Lithology
Upper Cretaceous		Fox Hills	20-75	Light gray to yellow, fine-grained quartzose sand.
		Pierre	50	Dark blue-gray bentonitic gumbo-like clay, concretions.

The Ludlow and Tongue River Formations are economically significant.

The Ludlow formation is somewhat restricted in occurrence to the tops of higher divides and to the middle and lower reaches of mesas, buttes, and outliers.

The contact between the underlying Hell Creek formation and the Ludlow formation is generally placed at the base of the Shadehill coal facies which occurs at the base of the Ludlow. The Shadehill may consist of one or more beds of coal, carbonaceous clay called "blackjack", or peat-clay. A massive, thick-bedded basal sandstone of the Tongue River formation marks the contact between the Ludlow and Tongue River formations. The Ludlow is about 370 feet thick in the Reva Gap area of the Slim Buttes.

The gross lithological features of the Ludlow consist of lenticular, heterogeneous, gray to buff colored, fine- to medium-grained sands, sandstones, clayey sands, sandy clays, occasionally cross-bedded, ripple-marked sandstones, and gray to brown silt and clay. At least eight lignitic coals are found in the Ludlow. These coals may contain or grade laterally into "blackjack" or peat-clay, and the coals may lens out entirely.

In the Ludlow, carbonaceous siltstone, clinker, peat-clay, and lignite are radioactive. Two generalized stratigraphic sections, include the principal uranium occurrences in the Ludlow and exhibit the associated lithology.

Section at the Bobcat Mine, South Cave Hills,
SE¼NE¼ Sec. 5, T. 20 N., R. 5 E.

<u>White River Group</u> — <u>Feet</u>

<u>Chadron Formation</u>
Bentonitic clays and sands................50-70

Feet

Fort Union Group

Tongue River Formation

Sandstone, buff-yellow, massive, cavernous, jointed................	30-60

Ludlow Formation

Covered interval.....................	75+
Shale and pseudoscoria, maroon (occasionally radioactive)........	½-1
Clinker, black to gray, porous, uranium mineral autunite occurs as void coatings and incrustations...........	½
Ash, buff..........................	½
Sandstone, salmon colored, massive..	3

Section at the Lonesome Pete No. 2 Mine, South Cave Hills, N½ Sec. 26, T. 21 N., R. 4 E.

Fort Union Group

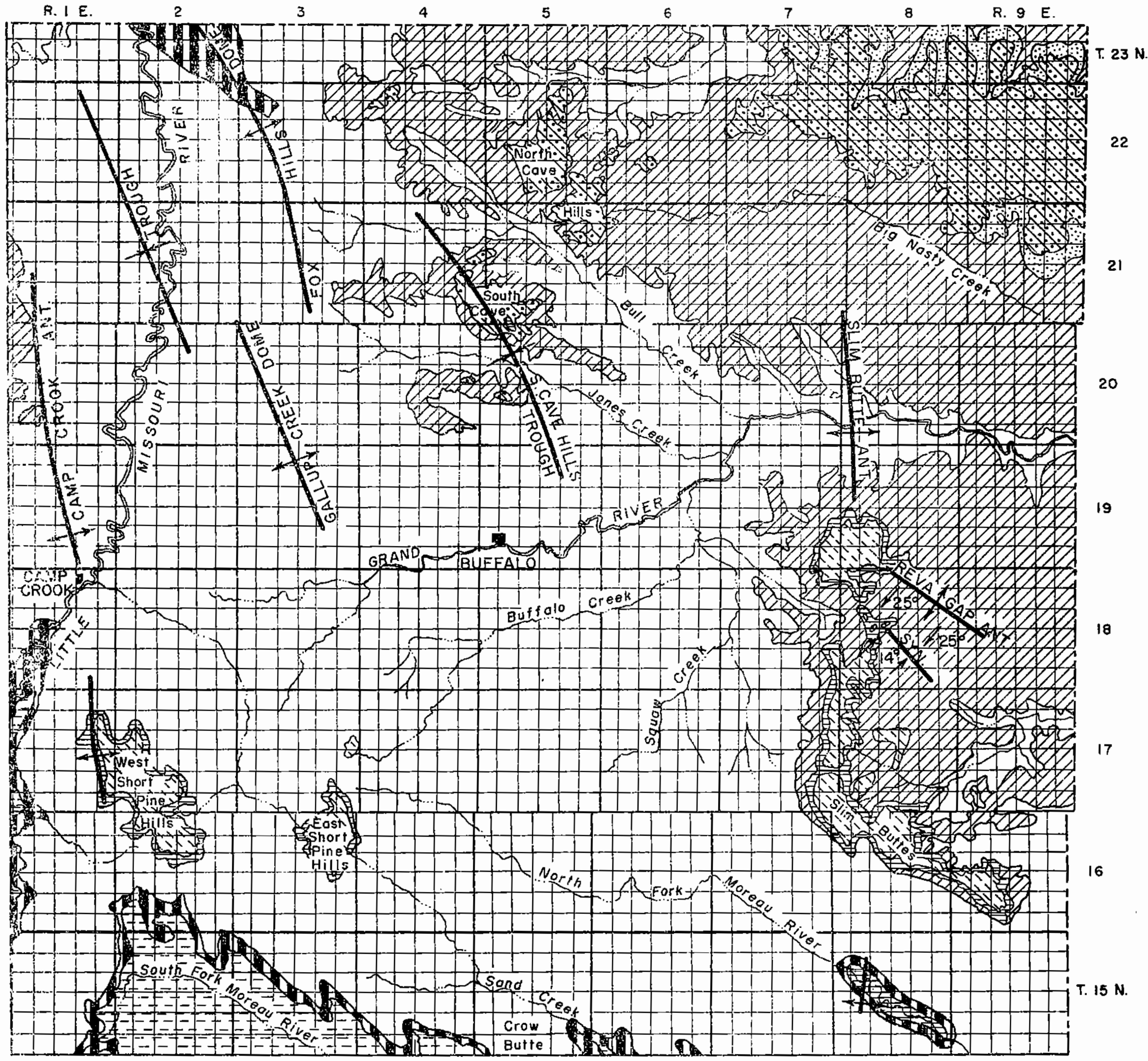
Tongue River Formation

Sandstone, buff brown, massive, jointed	30-40

Ludlow Formation

Colluvium or slope wash and talus material composed of intercalated sands, mudstones, clays with limonitic concretions...............	25-30
Coal (called the "D" bed) appears to be slumped. It is slightly radioactive...........................	?
Sands, mudstone, limonitic concretions...........................	40-50
Coal (called the "C-rider" bed). It is not radioactive.................	1 3/4-2
Sands, silts, and carbonaceous seams interbedded.......................	4
Coal (called the "C" bed). It is not radioactive.......................	2-3
Silts, sands, with friable sandstone, limonitic concretions and jarosite.	60-70
Carbonaceous siltstone (ore horizon), drab gray with unidentified "organo-uranium complex" mineral.....	2½
Clay and mudstone, gray...............	1/6-1/3
Coal (called the "B" bed), black, soft, earthy. A grab sample showed slight radioactivity..............	12+

GEOLOGIC MAP
OF
HARDING COUNTY, SOUTH DAKOTA



LEGEND

- Ogallala or Arikaree Formation
- White River Group
- Tongue River Formation
- Ludlow-Cannonball Formation
- Hell Creek Formation
- Fox Hills Formation
- Pierre Formation
- 25° Dip in degrees

SCALE IN MILES

6 3 0 6 12

NOTE

GEOLOGY MODIFIED FROM U.S.G.S. BULL. 627

FIGURE 10.

The "organo-uranium complex" mineral appears to have an affinity for carbonaceous matter. The overlying lithology is permeable and the underlying clay is relatively impermeable. Therefore, the uranium could be arrested by both carbon and the underlying impermeable rock.

Other lithologic units contain autunite. For instance, a brown peat-clay assays up to 0.25 percent uranium oxide, and a weathered, thin-bedded, flaky, shiny, impure coal assays up to eight percent uranium oxide.

The South Cave Hills are topped with the basal Tongue River sandstone, while the North Cave Hills contain two distinct Tongue River sandstones, both erosion remnants that hold up the hills. The basal sandstone is somewhat resistant to erosion, and it forms sheer, vertical walls. Pine trees grow in loose, incoherent sand, and they outline the areal extent of the sandstone. The sandstone is characterized by massiveness, well-defined joint systems, and caves that have formed as a result of wind and water erosion of differentially-compacted sandstone. The North Cave Hills possess a lower sandstone that is 30-100 feet thick, yellow-brown, fine- to medium-grained, massive, slightly cemented with lime, and cross-bedded. A thin bed of impure lignite, which is an ore horizon, overlies the basal sandstone. The coal is overlain by an upper sandstone that is up to 135 feet thick, reddish-brown, somewhat massive, noncalcareous, soft, cross-bedded sandstone, composed largely of quartz sand.

The following stratigraphic section contains the uraniferous earthy lignite:

Section at the Pickpocket No. 1 Mine, North Cave Hills, Secs. 35, 36, T. 22 N., R. 5 E.

<u>Fort Union Group</u>	<u>Feet</u>
<u>Tongue River Formation</u>	
Silty sand, buff to drab gray, limonitic concretions................	3
Peat-clay, chocolate brown..........	1/3-½
Coal (called the "E" bed), black, soft, earthy, sooty. (ore horizon).......	5/6-1 1/6
Sandstone, massive, right-angle joint pattern. (Few samples from basal portion of this sandstone assay ore grade)...........................	30-40
<u>Ludlow Formation</u>..................	not measured.

The orogenic forces which folded the Black Hills are reflected in the rocks of Harding County in the form of low anticlines and synclines. (See Fig. 10). The regional dip is generally toward the northeast and east at a rate of about 30 to 40 feet per mile.

It is a matter of conjecture whether deep-seated structural controls are in any way responsible for conveying primary ore-bearing solutions to the Harding County rocks or exert any marked influence on the intensity of mineralization or localization of ores. Primary uranium minerals have not been identified thus far.

A well-defined right-angle joint pattern, which trends north-south, east-west is conspicuous in the basal Tongue River massive indurated sandstone, particularly in the North Cave Hills. Therefore, joint control may provide excellent permeability channelways for the downward movement of uranium-charged solutions into the Tongue River and Ludlow formations from the overlying White River sediments.

Slump blocks have been dislodged from the parent Tongue River basal sandstone. Some of these blocks may be sizable enough to impose problems to prospectors and miners. Recognition of these slump blocks and the determination of the magnitude of vertical displacement are important. If uranium ore is present in a slump block of considerable displacement, exploratory drilling behind the slump block may be necessary to ascertain the proper place of the ore horizon. In addition, samples should be taken for assay in order to outline the dimensions of the ore body.

Mineralogy

Two uranium minerals, autunite, $Ca(UO_2)_2(PO_4)_2 \cdot 10H_2O$ (Calcium uranium phosphate), and the "organo-uranium complex", occur in the Cave Hills.

Autunite, which is the only uranium mineral that fluoresces in its natural state, is found in a six-inch thick clinker in the Ludlow formation at the Bobcat Mine. The autunite occurs as faint green coatings and incrustations in the clinker. The writer collected a sample of ore-grade uraniferous lignite from the Tongue River coal at the Pickpocket No. 1 Mine. The autunite is not visible; however, ultraviolet light clearly shows that the autunite is disseminated throughout the coal. Where autunite is visible, the uranium grade is increased several percent as evidenced by a brown peat-clay that assays up to 2.5 percent uranium oxide. A moderately weathered, thin-bedded, impure coal with tiny white analcite (nonradioactive) specks and visible autunite assays up to 8 percent uranium oxide. According to King (personal communication), the poorest ore-grade coaly material is black, dull, and powdery and assays up to 0.4 percent uranium oxide. The ash content appears higher in uraniferous lignites than in barren coals.

The "organo-uranium complex", which contains an unidentified uranium mineral, occurs in a carbonaceous siltstone in the Ludlow formation in the Lonesome Pete No. 2 Mine. The rock has a dull gray color with no diagnostic uranium coloration. In contrast, carnotite, which is bright canary yellow in color, forms a sharp, vivid contrast with the Lakota and Dakota sandstones in the Edgemont district. Only a Geiger counter or scintillometer can detect the presence of uranium in the carbonaceous siltstone.

Localization of Ores

Uranium ores are not restricted to any particular lithology. However, the lignite beds, carbonaceous siltstone, and peat-clay (sometimes referred to as lignite shale) contain carbonaceous matter. Certain portions of the basal Tongue River sandstone are radioactive.

The ore-bearing lignite beds are generally thin, about a foot or two thick, and uranium is concentrated in them to attain ore grade. In some cases, uranium is disseminated throughout thicker coals which usually does not reach ore grade. Uranium-bearing solutions may be arrested by impermeable beds overlying coal beds or other types of lithology and, consequently, preclude a favorable lower lithology from commercial mineralization.

At the Lonesome Pete No. 2 Mine, the top coal, the "D" bed, and the lowest coal, the "B" bed, are radioactive. The "B" bed shows ore-grade assays. The intermediate "C" and "C-rider" coal beds are barren.

At the Pickpocket No. 1 Mine, the Tongue River "E" bed contains the mineral autunite which is sporadically concentrated in small clusters or aggregates and as disseminated crystals throughout the permeable portions of the soft carbonaceous material.

Grade

Several ore-grade assays, some of which are fairly high grade, are found in the Ludlow and Tongue River rocks. However, average grade has not been determined from any of the deposits because of the paucity of exploratory drilling and assay work. The following uraniferous rocks and assays indicate that, if the deposits contain sizable tonnages, this area may attain State and national prominence: thin-bedded, impure coal with visible autunite, 8 percent uranium oxide; brown peat-clay, 2.5 percent; carbonaceous siltstone with "organo-uranium complex" mineral, 0.85 percent; top of "B" coal bed, 0.26 percent; black, dull, powdery coaly material, 0.4 percent; coal clinker, 0.1 percent; and, sandstone, 0.1 percent.

Mining

The overall areal extent of the mineralized beds of the Ludlow and Tongue River formations is limited by the actual dimensions of the Cave Hills. Little exploratory work has been accomplished, and tonnage data are unavailable.

The largest mining operation exists at the Haivila and Josephson Lonesome Pete No. 2 Mine where more than 100,000 cubic yards of rock has been removed in quest of the carbonaceous siltstone. Their mining operations consist of attacking the carbonaceous siltstone bed, which is located about 150 feet below the butte-capping sandstone, with heavy earth-moving equipment. This exploratory work has yielded ore-grade assays; however, they have not resorted to drilling behind the outcrop.

In the North Cave Hills, the uraniferous Tongue River "E" coal bed is covered by a thin, three-foot thick blanket of overburden at the Evans and Munkres Pickpocket No. 1 Mine. The average ore grade can easily be obtained by simple stripping operations.

At present, the Atomic Energy Commission is not purchasing ore from Harding County because the metallurgy for uranium-bearing lignite coal is not perfected economically, and the question arises as to whether land is available under the Federal Coal Leasing Act or subject to mineral claim.

Origin

The theory has been postulated that the uranium was derived from the overlying White River group of sediments by weathering processes. Apparently, leached uranium entered acid (?) ground water solutions, percolated downward and laterally through channelways and permeable Tongue River and Ludlow strata, and was finally deposited in carbonaceous or coaly material which appear to contain favorable physical and chemical environments of deposition, arrested by impermeable strata and deposited, or deposited as a result of an alkaline (?) environment which may have neutralized the acidic (?) ground water. Permeability in the zone of ground water circulation apparently is a critical factor in determining the migration distance of uraniferous solutions from the source materials.

Future Prospecting

In the North Cave Hills, the Tongue River "E" coal bed, which lies directly on the basal massive sandstone, may extend laterally beneath a thick massive sandstone. Exploratory drilling would be necessary to find this coal and possible ore bodies.

With the discovery of the carbonaceous siltstone in the South Cave Hills and ore-grade sandstone in the Slim Buttes, prospectors should not restrict their exploratory activities solely to coal. The sandstone-type deposits exhibit distinctive yellow coloration, but not quite as vivid and as "eye-catching" as the colors found in the Edgemont district.

Limonite, jarosite, and melanterite are iron minerals that are colored various shades of yellow, ranging from ocher yellow to brownish yellow. These minerals occur in many beds in the Hell Creek, Ludlow, and Tongue River formations. Despite the ubiquitous occurrence of these iron minerals and their characteristic stains, it is advisable to investigate every rock with yellow coloration. Incidentally, one or more of these minerals occur in every county in South Dakota.

Slim Buttes Area

History

Knowledge of uraniferous lignites in this area dates back to 1951. Sandstone-type uranium ores were discovered in 1953-54. It is reported that most of the favorable areas in the Slim Buttes have been staked.

Location

Uraniferous lignites are found in the higher reaches of the Slim Buttes. The buttes cover a considerable portion of the southeast one-fourth of Harding County. (See Fig. 10)

Sandstone-type ore-grade deposits exist near Reva Gap in Secs. 9, 10, T. 18 N., R. 8 E. and in Cedar Canyon in NE¼ Sec. 8, T. 16 N., R. 8 E.

General Geology

Stratigraphically, the exposed formations that constitute the Slim Buttes range in age from Upper Cretaceous to Miocene. Eocene rocks are absent. The formations, from the oldest to the youngest, are the Hell Creek, Ludlow, Chadron and Brule of the White River group, and Ogallala or Arikaree. The Tongue River formation is absent in the Slim Buttes.

The Hell Creek formation is thus far barren of radioactivity. It forms the bedrock over much of the county and erodes easily into badlands. The formation is exposed on the west flank of the buttes near Reva Gap. The formation attains a thickness of about 425 feet, and it consists primarily of "somber beds" of drab, dark gray to brown bentonitic clays, silts, and sands and admixtures of these textures, some thin coals, peat-clays, ironstone concretions, and dinosaur bones. The surface weathers to a "popcorn", similar to the bentonitic clays in the Pierre formation along the Missouri River Valley.

The Ludlow formation contains both the uraniferous lignites and the sandstone-type uranium deposits, numerous coal beds, "blackjack", peat-clays, pseudoscoria, clinker beds, buff to yellow siltstones and sandstones, and light to medium gray clays. The formation is 369 feet thick several miles north of the Slim Buttes (Petsch, 1955, p. 5). The formation was eroded to a peneplain or relatively flat surface prior to White River deposition.

The Chadron and Brule formations comprise the White River group of sediments. These formations underlie the Ogallala or Arikaree rimrock and overlie the Ludlow formation. The White River sediments are almost identical with those found in the Badlands National Monument. Petsch (personal communication) measured 164 feet of Chadron and 73 feet of Brule at Reva Gap, SW$\frac{1}{4}$ Sec. 8, T. 18 N., R. 8 E.

The Chadron is composed essentially of light brown to gray silts and clays, a "dazzling" white sand, and light green bentonitic clay, and a thin layer of white slabby, cherty limestone in the upper part.

The Brule formation consists mainly of light green fine-grained sandstone and alternating beds of gray bentonitic clays and pink silty clays.

Slumping is characteristic of both formations. In fact, some of the White River sediments have literally flowed down the steep banks and deeply dissected valleys of the buttes.

The following detailed stratigraphic section of the White River formations was made by Petsch (personal communication):

Detailed Section of Chadron and Brule Formation Near Reva Gap NW$\frac{1}{4}$ Sec. 17, T. 18 N., R. 8 E.

<u>White River Group</u>	<u>Feet</u>
<u>Brule Formation</u>	
Sandstone, siltstone, clay, alternating series	10 5/6
Sandstone, calcareous, very fine-grained, massive	7
Clay, pale gray, hard	6 3/4
Sandstone, bentonitic, fine-grained, calcareous, few 1-3 inch clay partings	8
Clay, pale green to white, hard sandstone layers 1-inch to 1-foot thick	12
Siltstone, pale green, cross-bedded, ledgemaker	3 1/3
Clay, bentonitic, hard	$2\frac{1}{2}$
Sandstone, bentonitic, white to pale green, calcareous, ledgemaker, contains 2-6 inch clay beds	$8\frac{1}{2}$
Silt, bentonitic, pale to bright green	$\frac{1}{2}$
Sandstone, bentonitic, pale green, calcareous, hard, fine-grained	$1\frac{1}{2}$
Sandstone and clay, alternating in 1-inch and 4-inch layers	1 3/4
Sandstone, pale green, fine-grained, ledgemaker	$1\frac{1}{2}$
Clay, bentonitic, pale brown-gray, calcareous	$\frac{1}{2}$
Clayey silt, bentonitic, white, hard, slightly calcareous	1
Clay, pale brown and gray	$\frac{1}{4}$
Sandstone, pale green, fine-grained, hard, calcareous and bentonitic	$1\frac{1}{2}$
Clay, pale brownish gray	3
Sandstone, silty and bentonitic, white, fine-grained calcareous, cross-bedded, ledgemaker	2 3/4
Total Brule measured	73
<u>Chadron Formation</u>	
Clay, bentonitic, hard	16
Clay, bentonitic, pale brown, hard, siliceous beds, 4-inch layer of green and brown clay nodules at top	32

	Feet
Limestone, slightly bentonitic, white, vuggy, ledgemaker....................	2
Clay, bentonitic, pale brown and pale green, mottled, weathers to "popcorn" surface..............................	70
Sandstone, "dazzling" white...............	10
Conglomerate, lens-like, white, gravel size, bentonitic cement.................	3/4
Sandstone, bentonitic matrix, coarse-grained, porous........................	5
Conglomerate, gravel, clay balls, quartz and feldspar pebbles..................	1
Sand and clay, light gray and rusty......	3/4
Bentonite, white and rusty, laminated....	1/6
Silty clay, very fine-grained, hard, occasional thin 1/8-inch clay ironstone streaks.........................	9½
Clay, alternating gray and tan...........	7
Concretions, iron, rusty, hard, 3 layers.	4
Sandy clay, tan and gray, mottled, hard..	5
Total Chadron measured..............	163 1/6

Base of exposure.

The Ogallala or Arikaree formation lies on the flat erosion surface of the Brule formation. However, toward the southern end of the buttes, the formation lies on the Ludlow formation and at the extreme southern portion, the formation rests on the Hell Creek formation. The formation is about 260 feet thick near Reva Gap (Petsch, personal communication). The formation is composed of basal sandstone and conglomerate, greenish white tuffaceous sandstone, hard green, blocky, massive sandstone, and white, fine-grained, indurated volcanic ash at the top. The formation forms the conspicuous caprock of the buttes.

Mineralogy

Apparently an "organo-uranium complex" mineral exists in the uraniferous lignites. Large deposits of low-grade uranium-bearing lignites show no visible uranium minerals. The uranium may occur as disseminated material absorbed by carbon, the chief constituent of the coal. Other minerals associated with the coal include gypsum, analcite, jarosite, limonite, and quartz.

The author examined a sample of carnotite, $K_2(UO_2)2(VO_4)_2.3H_2O$, (potassium uranium vanadate), or tyuyamunite, $Ca(UO_2)_2(VO_4)_2.nH_2O$, (calcium uranium vanadate), from Sec. 9, T. 18 N., R. 8 E. The mineral occurs in a Ludlow sandstone. The sandstone is a light gray-buff, fine- to medium-grained, moderately indurated with bentonitic clay, permeable, slightly arkosic quartzose sandstone. The uranium mineral is greenish yellow, soft, powdery, and occurs as thin fillings along the bedding planes, as segregated masses, and as interstitial filling. Accessory non-uranium minerals include orthoclase, muscovite, biotite, limonite, and glauconite. No carbonaceous material was noted.

Localization of Deposits

Concerning the localization of uranium in the lignites, Gill (1954, p. 113) states:

"...each of the Lignites [Mendenhall coal bed and rider and the Olesrud beds in Secs. 1, 36, T. 17, 18 N., R. 7 E.] is radioactive only where it is the stratigraphically highest bed,...The beds of uraniferous lignite are 3 to 11 feet thick...

The lignite has an average ash content of about 18 per cent..."

Carnotite-type minerals occur in a channel sandstone at the top of the White River group in Cedar Canyon, NE¼ Sec. 8, T. 16 N., R. 8 E. The thickness of the uranium-bearing sandstone ranges from two to more than six feet in thickness. The mineral is concentrated near tree roots and stems and along fracture planes.

Grade

Several chemical analyses have been made on the radioactive lignites and lignite ash in the Mendenhall area. The average uranium content of the lignites approximates 0.008 percent uranium oxide, and when the lignite is burned uranium is concentrated in the ash up to 0.065 percent uranium oxide (Gill, 1954, p. 114). Table 7, (Gill, 1954, p. 114) gives the analyses and tonnages of uraniferous lignites in the Mendenhall area. (See page 84).

Tyuyamunite, which occurs in the Ludlow sandstone found in Tyboe prospect pit near Reva Gap, SW¼ Sec. 10, T. 18 N., R. 8 E., assays up to 0.19 percent uranium oxide.

Two samples from Cedar Canyon contained 0.08 and 0.23 percent uranium oxide (Gill, 1953, p. 125).

A carnotite or tyuyamunite sample from Sec. 9, T. 18 N., R. 8 E. was examined by the writer and found to be quite radioactive. No chemical assays have been made from this area.

TABLE 7.--ANALYSES OF URANIFEROUS LIGNITES IN THE MENDENHALL AREA, HARDING COUNTY

Bed	Ave. Thickness, Feet	Area Acres	% U in Lignite	% Ash	Lignite Short Tons[1]	Uranium Short Tons[2]
Minimum grade of 0.005 percent uranium in lignite						
Mendenhall "rider"	4.9	585	0.012	---	5,046,000	525
Mendenhall bed	6.1	1,150	0.007	---	12,202,000	870
Olesrud bed (Upper bench)	5.2	1,405	0.007	---	12,823,000	940
		3,140			30,071,000	2,335
Minimum grade of 0.010 percent uranium in lignite						
Mendenhall "rider"	5.6	115	0.018		1,141,000	165
Mendenhall bed	4.5	530	0.010		4,211,000	425
Olesrud bed (Upper bench)	3.3	795	0.010		4,591,000	460
		1,440			9,943,000	1,050
Minimum grade of 0.03 percent uranium in lignite ash						
Mendenhall "rider"	6.1	340	0.042	25.1	3,621,000	325
Mendenhall bed	6.1	1,110	0.041	16.6	11,634,000	805
Olesrud bed (Upper bench)	5.0	1,330	0.046	18.0	11,588,000	935
		2,780			26,843,000	2,065
Minimum grade of 0.05 percent uranium in lignite ash						
Mendenhall "rider"	4.0	190	0.065	25.5	1,335,000	195
Mendenhall bed	5.0	775	0.052	15.3	6,804,000	555
Olesrud bed (Upper bench)	4.3	890	0.058	15.9	6,660,000	605
		1,855			14,799,000	1,355

1. Calculations based on 1,750 tons per acre-foot. Net result rounded to nearest 1,000 tons.
2. Figures rounded to nearest 5 tons.

Mining

Mining operations have been largely restricted to prospect pits, evaluation, and stockpiling. Because of the lack of mining, reserves are thus far unformulated for the sandstone-type deposits.

A 10,000-foot diamond core drilling program for uranium-bearing lignites was undertaken by the U. S. Geological Survey on behalf of the Atomic Energy Commission from October, 1952, until July, 1953, in the Mendenhall area. According to Gill (1954, p. 113),

"...the Mendenhall area indicates reserves of approximately 127 million tons of lignite in four beds 3 to 12 feet thick which underlie about 4,000 acres...Of the total reserves of lignite...about 30,000,000 tons are radioactive, in the Mendenhall rider, the Mendenhall and the Olesrud beds...A total of about 3,100 acres is underlain by radioactive lignite...the overburden is less than 60 feet over about 680 acres, and from 60 to 120 feet over 650 acres. Thus a considerable tonnage could be mined by stripping."

Origin

The origin of the uranium in the lignites in this area is hypothesized to be the same as that found in the Cave Hills area. According to Denson, et al. (1952, pp. 8-10):

"...the uranium probably occurs as a disseminated adsorbed constituent of carbon...studies of lignite from North Dakota demonstrated that the uranium, although not present as a distinct mineral, was closely associated with the organic carbonaceous materials...analysis of the ash from radioactive lignite cores in South Dakota show that although most chemical elements are uniformly distributed through a vertical section of lignite, uranium and molybdenum were among those few elements which show a marked decrease downward from the top of the bed suggesting that they were probably introduced from above by meteoric waters ...the uranium is younger than the lignite...in which it occurs and that it was extracted by the lignite, subsequent to coalification, from the percolating ground waters descending from overlying volcanic rocks or rocks of volcanic derivation [White River and Ogallala or Arikaree sediments..]"

Chemical analyses of the White River sediments in the Slim Buttes show that the tuffaceous sandstones contain 0.001 percent uranium oxide and chemical analyses of water from springs now emanating from the White River sediments show uranium ranging from 30 to 45 parts per billion

(Denson, et al., 1952, pp. 10-11).

Concerning the uraniferous sandstones of the Ludlow formation, ground waters charged with uranium were apparently transported away from the coal beds and directly into the sandstones from the Ogallala or Arikaree and/or White River source sediments. More uranium may be found in these and similar sandstones some distance away from the Slim Buttes. Permeable strata dipping away from the buttes may control and direct uranium-bearing solutions into favorable host rocks which may be buried at various depths below the surface. The Reva Gap anticline may be directly responsible for the structural control of uraniferous solutions.

Future Prospecting

Prospectors should be familiar with the types of uranium minerals, occurrences, and host rocks. Carnotite and tyuyamunite cannot always be expected to display brilliant yellow colors, and the uranium minerals found in the coals as a rule cannot be seen. Therefore, a radiation detection instrument is essential. Drilling is necessary to obtain samples for assays and to outline radioactive deposits.

Prospectors may entertain the possibility of encountering uranium deposits around the buttes as well as in the rocks of the buttes.

The Atomic Energy Commission and the U. S. Bureau of Mines are testing the possibility of processing the lignite and carbonaceous materials. Problems, which are inherent to coals of this rank, arise regarding stockpiling. Fresh lignite is generally blocky, but weathered lignite slakes or crumbles upon exposure as the result of the loss of moisture. The fine slaked coal is susceptible to wind deflation and spontaneous combustion.

The Slim Buttes constitute a part of the Custer National Forest. The Department of the Interior and Atomic Energy Commission have not decided whether Federal land is available under the Coal Leasing Act or subject to mineral claim. In addition, the metallurgy for uarnium-bearing lignites has not been perfected economically. Therefore, the Atomic Energy Commission is not purchasing uraniferous lignites.

Tongue River lignites also crop out over an area of about 100 square miles in the northeastern part of the county. Lignites in the Ludlow formation are exposed in many localities (see Fig. 10). These coals occur as far as eight miles west and five miles south of the North and South Cave Hills and extend eastward to within one mile of the Perkins County line both from the Cave Hills and the northern half of the Slim Buttes.

Some Hell Creek coals, thus far reported as nonradioactive, are found in the northwestern part of the county and below the Cave Hills and the Slim Buttes.

PENNINGTON COUNTY

Economic possibilities point favorably to the Chadron and Brule formations of the White River group in the area around the Badlands National Monument and a large portion in the south-central portion of the State.

History

The White River sediments correlate almost identically with those in Harding County. Therefore, on July 23, 1953, Federal geologists, using the Harding County rocks as geologic guides, discovered uranium-bearing sandstone of ore grade in the Chadron formation on the south scarp of Hart Table in southeastern Pennington County. Also, metatyuyamunite (?) and carnotite were found in the Chadron and Brule formations, respectively.

Location

Hart Table is located in NE$\frac{1}{4}$ Sec. 31, T. 3 S., R. 13 E., less than one-fourth mile south of the Badlands National Monument boundary. This area is situated three miles southwest of Scenic and about 40 miles southeast of Rapid City (See Fig. 11).

General Geology

The White River badlands is the type locality for badlands topography and exhibits a picturesque assemblage of geomorphic land forms, characterized by earth pillars, earth pyramids, pinnacles, buttresses, and recesses. Buttes, mesas, and deep, sharply carved valleys are typical in this region.

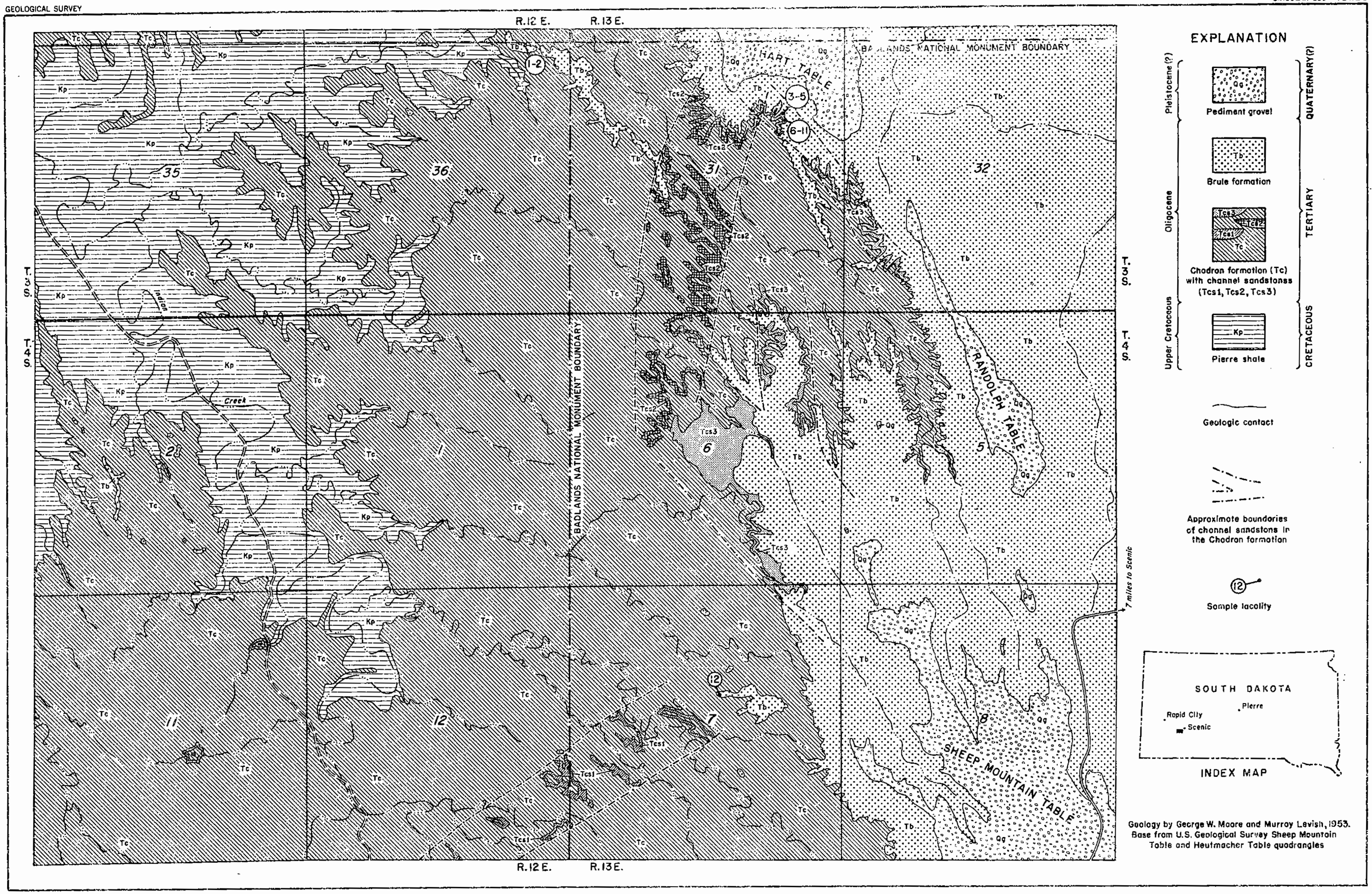
Stratigraphically, the exposed strata include the Upper Cretaceous Pierre formation, the Oligocene Chadron and Brule formations, and the Pleistocene (?) pediment gravels (See Table 8, p.88).

TABLE 8.--EXPOSED FORMATIONS IN THE WHITE RIVER BADLANDS, PENNINGTON COUNTY

Age	Group	Formation	Thickness in Feet	Lithology
Oligocene	White River	Brule	500 ≠	Cross-bedded sandstones, conglomerates, bentonitic claystones, carnotite-bearing blue chalcedony veins
		Chadron	70-140	Yellow-gray bentonitic clay, uranocircite-bearing channel sandstones, metatyuyamunite (?) - bearing limestone
Upper Cretaceous		Pierre	70	Weathered beds of light brown to reddish purple clays (50 feet thick). Fresh Pierre is composed of olive-gray to dark gray bentonitic clay

The Pierre formation, which underlies the Chadron formation, is characterized by an impermeable light olive-gray to dark gray bentonitic clay, thin silt layers, and ironstone concretions. About 70 feet of the Pierre crop out in this area. This formation was peneplained prior to Chadron deposition. Overlying the unweathered Pierre is a 50 foot thick light brown to reddish purple fossil subsoil that indicates deep weathering and oxidation. This stratum forms the contact between the Pierre and Chadron formations.

The Chadron formation, which ranges in thickness between 70 and 140 feet, underlies the Brule formation. The basal Chadron is marked by bluish green clays and coarse gravel. The gravel layers average about one foot in thickness. Massive *Titanotherium* channel sandstones and thin limestones exist in the clays. The middle part of the Chadron consists of from 40 to 70 feet of gray clays, silts, sandstones, and arkosic conglomerates. The upper Chadron is composed of from 20 to 40 feet of clays and a few scattered sandstones. A series of thin limestone beds make



GEOLOGY OF PART OF THE WHITE RIVER BADLANDS, PENNINGTON COUNTY, SOUTH DAKOTA

0 ½ 1 Mile

FIGURE 11

the contact with the overlying Brule formation. The Chadron weathers to typical "haystacks" or smooth, rounded humps. Uranium occurs in a lower sandstone and in limestone beds.

The Brule formation, which attains a thickness of about 500 feet, is divided into the lower or Orella member and the upper or Whitney member. The Orella member, which contains the Oreodon beds, ranges in thickness from about 120 to 210 feet. Lithologically, it consists of uniform, horizontally-banded red, green, and brown sandy clays, siltstones, fine-grained lenticular sandstones, conglomerates, calcareous nodules, and concretionary layers. The middle and upper portions of the Orella contain abundant thin veins of bluish gray chalcedony, some of which contain carnotite. The Whitney member, which incorporates the Protoceras and Leptauchenia beds, varies in thickness between 95 and 260 feet. It is composed of three distinct lithologic units: a lower 40 to 60 foot thick gray and red clay unit, a middle 30 to 100 foot thick nodular unit with volcanic ash concretions and pink clays, and an upper 130 foot thick massive gray to white volcanic ash section.

The uplands are veneered with a five to 15 foot thick pediment gravel.

Structurally, the White River sediments dip southeasterly at the rate of about 30 feet per mile in this area. However, the regional dip is about one or two degrees southeast. No faults have been recognized in this area. Concerning abundant fractures that are filled with chalcedony and sandstone, Moore and Levish (1955, p. 4) comment:

"Chalcedony veins as much as 2 inches thick are common in the mapped area. Some sandstone dikes were also found. The chalcedony veins and sandstone dikes fill nearly vertical fractures, some of which are more than 100 feet long. The fractures are present in the Brule formation and rarely extend into the underlying bentonitic claystone of the Chadron formation...the filling material of the sandstone dikes was clearly derived from a bed of volcanic ash higher in the formation...the chalcedony is generally believed to have been derived by leaching of silica from the volcanic ash in the Brule formation...the origin of the fractures may be due to differential compaction along the sides of underlying channels."

Mineralogy

Uranocircite, $Ba(UO_2)_2(PO_4)_2 \cdot 8H_2O$ (barium uranium phosphate), which occurs in a channel sandstone in the Chadron formation, is yellowish green in color and is associated with apatite and barite.

Metatyuyamunite (?), $Ca(UO_2)_2(VO_4)_2 \cdot 5\text{-}7H_2O$ (calcium uranium vanadate), is found in a freshwater limestone in the Chadron formation, and the mineral is greenish yellow in color.

Carnotite, $K_2(UO_2)_2(VO_4)_2 \cdot 3H_2O$ (potassium uranium vanadate), which is found in chalcedony veins in the Brule formation, is bright canary yellow in color and occurs as a thin coating on the veins.

<u>Localization of Deposits</u>

Uranocircite is found on the south slope of Hart Table in NE¼ Sec. 31, T. 3 S., R. 13 E. in a channel sandstone. The sandstone, according to Moore and Levish (1955, p. 4) is about one mile long, 500 feet wide, and seven feet thick. The mineral is disseminated in the lower two feet of the sandstone, and mineralization is greatest in the basal few inches where samples attained ore grade.

Metatyuyamunite (?) was discovered in a two foot thick limestone in NE¼ Sec. 36, T. 3 S., R. 12 E. The mineral is concentrated in the top inch of the limestone.

Carnotite was found in chalcedony veins in NE¼ NE¼ Sec. 36, T. 3 S., R. 12 E., in SE¼ NE¼ Sec. 31, T. 4 S., R. 13 E., and in SW¼ NE¼ Sec. 7, T. 4 S., R. 13 E. Carnotite is localized on the outer surfaces of the veins.

<u>Grade</u>

Uranocircite samples assay up to 0.25 percent uranium oxide. Metatyuyamunite (?) and carnotite samples assay less than ore grade. Table 9, p. 91, (Moore and Levish, 1955, p. 4) shows analyses of uranium samples from this area.

TABLE 9.--ANALYSES OF URANIUM SAMPLES FROM THE WHITE RIVER BADLANDS, PENNINGTON COUNTY

Map Locality	Type of Material	Type of Sample	Equivalent Uranium %	Uranium %
1	Limestone	Grab	0.017	0.023
2	Chalcedony	"	.007	.008
3	Sandstone	"	.12	.22
4	"	28 in.channel	.006	.005
5	"	36 in.channel	.008	.007
6	"	Grab	.13	.24
7	"	26 in.channel	.014	.013
8	"	12 in.channel	.20	.25
9	"	29 in.channel	.020	.022
10	"	21 in.channel	.013	.012
11	Chalcedony	Grab	.010	.013
12	"	"	.015	.013

Mining

No mining operations are known to exist in this area.

Origin

The origin of uranium in this area is postulated to be the same as that in Harding County. Source uranium material was originally present in volcanic ash deposits in the White River rocks. Descending ground waters leached the uranium and transported it downward and laterally in the zone of circulation. Uranium was precipitated in those rocks which had favorable physical and chemical environments. The fractures probably served as access channelways for the uraniferous solutions.

Future Prospecting

The White River formations constitute the surface rock over portions of Bennett, Jackson, Mellette, Pennington, Shannon, Todd, Tripp, and Washabaugh Counties. The Ogallala or Arikaree formation is exposed in Bennett, Gregory, Shannon, Todd, Tripp, and Washabaugh Counties. Economic uranium deposits may be discovered in these rocks and in underlying rocks in the above-cited counties. This region warrants both aerial and ground radiometric surveys. Prospecting in this region might be compensating. The mineral deposits in Indian reservations (Todd, Shannon and Washabaugh Counties are reservation lands) are subject to leasing and are under the administration of the Office of Indian Affairs.

LAWRENCE COUNTY

Minable quantities of ore-grade uranium have not been found in Lawrence County. However, one sample from this area contained 0.1 percent uranium oxide. Both autunite and torbernite have been identified in the Bald Mountain gold-mining area.

Bald Mountain Area

History

Uranium minerals were first reported in the literature by Stillwell (1885, p. 82). He mentioned the occurrence of pitchblende and uranium mica. Vickers (1954, p. 1) discovered six radioactive occurrences in July, 1953. Thorium also occurs in this area.

Location

This area of investigation is situated about three to six miles west of Lead. Bald Mountain is located in NE$\frac{1}{4}$ Sec. 1, T. 4 N., R. 2 E. The Annie Creek autunite occurs in the NE$\frac{1}{4}$ Sec. 3, T. 4 N., R. 2 E.

General Geology

The major geologic feature in this area is the Black Hills uplift. The Black Hills uplift, which is a "vest-pocket edition" of the Rocky Mountains, has the shape of an elliptical dome that trends generally northwest-southeast. The central core is composed of pre-Cambrian granite and metamorphic rocks such as slates, schists, and quartzites. Paleozoic and Mesozoic rocks encircle the igneous and metamorphic core. Tertiary dikes, sills, and laccoliths intruded the igneous, metamorphic, and sedimentary rocks.

Three ore-bearing sedimentary rock formations crop out in this area. (See Table 10, p. 93).

The Deadwood formation, Upper Cambrian in age and the oldest sedimentary formation, has a maximum thickness of about 500 feet. It consists primarily of a basal brownish quartzitic sandstone and several beds of limestone and sandstone conglomerate. The middle portion contains a thick sequence of alternating green shales, limestones, and glauconitic sandstones. The upper part features brownish sandstones, quartzitic sandstones, and shale. Gold ore, resulting from Tertiary mineralization, is found in this formation.

TABLE 10.--EXPOSED ORE-BEARING FORMATIONS IN THE NORTHERN BLACK HILLS, LAWRENCE COUNTY

Age	Formation	Thickness in Feet	Lithology
Tertiary		Variable	Rhyolite, phonolite, trachyte, lamprophyre intrusives
Lower Mississippian	Madison (Pahasapa)	200-600	Gray, massive-bedded dolomitic limestone. Some gold, silver, lead
Ordovician	Whitewood	80	Dolomite, phosphate nodules, shale, siltstone. Autunite
Upper Cambrian	Deadwood	500	Glauconitic sandstone, limestone, shale. Gold, torbernite

The Whitewood limestone of Ordovician age overlies the Deadwood formation. The Whitewood is composed chiefly of dolomite, green phosphatic nodules, shale, and siltstone. The siltstone contains autunite. The formation attains a maximum thickness of 80 feet in this area.

The Madison (Pahasapa) formation of Lower Mississippian age overlies the Whitewood formation. The Madison consists of a gray, massive-bedded dolomitic limestone that contains small quantities of gold, silver, and lead. The formation ranges in thickness from about 200 to 600 feet.

Igneous rocks of pre-Cambrian age exist in the northern Black Hills, but they are not responsible for uranium mineralization in this immediate area.

Igneous rocks of Tertiary age are directly responsible for the radioactive minerals as they supplied uranium and thorium-bearing hydrothermal solutions.

Structurally, the Black Hills uplift up-arched the sedimentary rocks, and the Tertiary intrusives alerted and deformed the igneous and sedimentary rocks. The sedimentary rocks dip outward from the igneous core generally at less than 20 degrees. Locally, the rocks approach horizontally with gentle dips. Faults and fractures are present, and they probably served as access channels for ore-bearing solutions.

Mineralogy

A large number of ore-minerals are found in this gold-mining area; however, only the uranium-bearing minerals will be discussed.

Autunite, $Ca(UO_2)_2(PO_4)_2 \cdot 10H_2O$ (calcium uranium phosphate), occurs as fracture coatings and disseminations in siltstone in the Whitewood formation (Vickers, 1954, p. 4). Autunite is apple green in color, fluoresces a brilliant yellowish green, and is found in crystalline plates and masses. The gangue minerals are purple fluorite and limonite (Vickers, 1953, p. 2).

Torbernite, $Cu(UO_2)_2(PO_4)_2 \cdot 12H_2O$ (copper uranium phosphate), according to Ziegler (1914, pp. 205-206) has a bright green color and occurs in one-eighth to one-fourth inch crystals that display a fine pearly luster. Torbernite also occurs in small micaceous crystalline aggregates and radiating fibers.

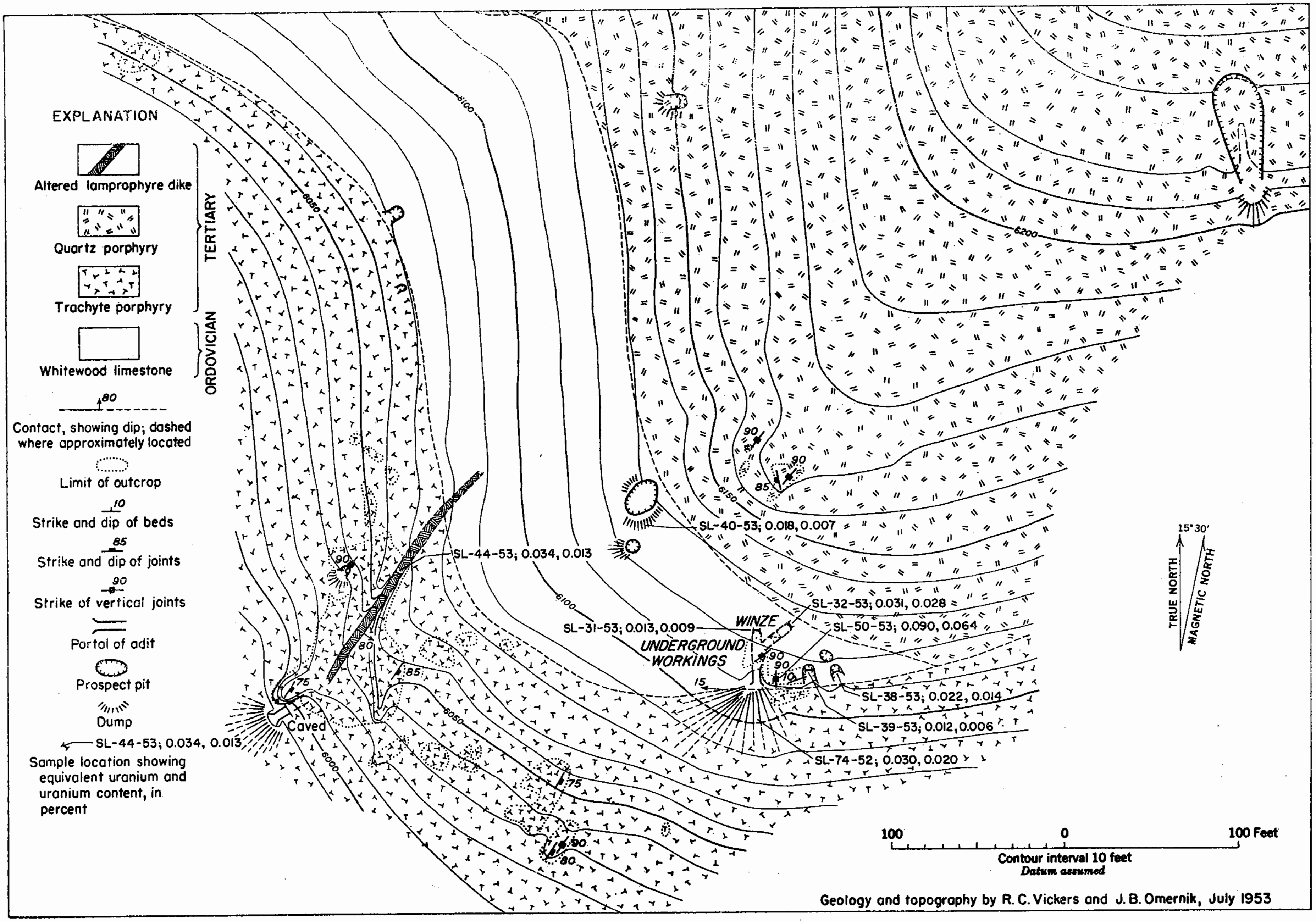
Radioactive thorium is found in many of the rocks in this area.

Localization of Deposits

Autunite is found near Annie Creek, (see Fig. 12), in NE$\frac{1}{4}$, Sec. 3, T. 4 N., R. 2 E. The mineral is concentrated mainly in the lower two feet of a basal Whitewood siltstone at the contact with an intrusive rhyolite porphyry. The highest radioactivity was observed where fractures were closely spaced in the siltstone. Good exposures are lacking in this area. Therefore, the areal extent of uranium occurrences are unknown. The present known extent measured across the strike of the fracture system is about 220 feet. High radioactivity was noted in the Dakota Mine, NW$\frac{1}{4}$, Sec. 2, T. 4 N., R. 2 E.; Dark Horse claim, NE$\frac{1}{4}$, Sec. 1, T. 4 N., R. 2 E.; Decorah Mine, SE$\frac{1}{4}$, Sec. 35, T. 5 N., R. 2 E.; Marie and Mary claim, NW$\frac{1}{4}$, Sec. 2, T. 4 N., R. 2 E.; and, the Mikado claim, NE$\frac{1}{4}$, Sec. 1, T. 4 N., R. 2 E. (Vickers, 1954).

Torbernite occurs in the Ross-Hannibal Mine, about one and one-half miles southeast of Terry. Ziegler (1914, p. 205) states that torbernite is localized in vugs and small cavities in the blue siliceous gold ore of Lower Cambrian age.

Vickers (1954, p. 7) observed that all of the radioactive occurrences are confined to the zone of weathering and are found only in the underground workings or on old mine dumps.



Geologic map of the Annie Creek autunite occurrence, Lawrence County, South Dakota.

From U. S. Geological Circular 351

Figure 12

Grade

One sample of autunite from the Dakota Mine, NW¼ Sec. 2, T. 6 N., R. 2 E., assayed 0.1 percent uranium oxide. However, this area has no uranium deposits sufficiently large to constitute ore. Table 11 (Vickers, 1953, p.2; 1954, p. 7) shows the analyses of several radioactive samples.

TABLE 11.--ANALYSES OF SAMPLES FROM THE BALD MOUNTAIN AREA, LAWRENCE COUNTY

Location and Type of Sample	Percent Equiv. Uranium	Uranium	Thorium[1]
Annie Creek:			
Autunite-bearing siltstone	0.060	0.057	no
" "	.018	.007	yes
Composite dump sample	.030	.020	no
18 inch channel sample	.059	.048	no
Rhyolite porphyry, grab	.012	.004	no
Siltstone, grab sample	.037	.016	no
" "	.008	.004	no
Marie and Mary claim:			
Silicified siltstone	.041	.007	yes
Dakota Mine:			
Altered siltstone	.19	.10	yes
Decorah Mine:			
Altered porphyry	.025	.008	yes
Bald Mountain:			
Altered diatreme[2]	.032	.007	yes
" "	.045	.006	yes
Dark Horse claim:			
Manganese veinlets	.026	.017	no

1. Determined spectrographically.
2. Graphitic schist and quartzite breccia cemented with rhyolite porphyry.

Mining

Mining has been restricted to the exploitation of gold and silver ores. Much of the radioactivity was recorded from mine dumps. No uranium is mined in this locality.

Origin

Concerning the origin of autunite, Vickers (1953, p. 5) states:

"...because of the spacial relations of the uranium minerals to the porphyry sill,...the uranium was introduced into the siltstone by hydrothermal solutions that moved along the contact between the siltstone and the underlying porphyry. The fractured siltstone near the contact with the lower porphyry, which may be the result of movement along the contact produced after or during the emplacement of the porphyry, found a permeable zone through which the ore-bearing solutions could migrate. These solutions probably were related to a late stage of hydrothermal activity that accompanied the intrusion of the porphyries."

Vickers (1954, p. 7) mentions:

"In the Bald Mountain gold-mining area most of the ore that has been mined and most of the mine workings have been in oxidized rock. Because the uranium is more readily transported during weathering in a pyrite gangue, minable quantities of uranium would probably occur only in relatively unoxidized ore."

Both autunite and torbernite are secondary uranium minerals that are derived from primary uranium minerals. Stillwell (1885, p. 82) states that pitchblende occurs on Bald Mountain. Pitchblende might be the primary uranium source of the autunite and torbernite.

Future Prospecting

Additional prospecting in this general area and in the Black Hills might be rewarding. It should be emphasized that the samples which contained the highest radioactivity were collected from mine workings and dumps. However, the Tertiary intrusive rocks and the emplaced, mineralized sedimentary rocks suggest that similar rocks found elsewhere merit careful investigation.

It should be noted when prospecting in this area that the granitic and certain Tertiary intrusive rocks contain higher than average background radioactivity. Also, radioactive thorium is present.

OTHER REPORTED OCCURRENCES

Perkins County

Potentially important uranium-bearing lignite deposits occur in Perkins County. Chemical analyses made by the U.S. Geological Survey (Denson, et al., 1952, p. 12) show that the lignite ash from the Tongue River formation assays up to 0.176 percent uranium oxide.

The uraniferous lignites are located near the town of Lodgepole in Secs. 9, 10, T. 21 N., R. 11 E. and Sec. 19, T. 21 N., R. 12 E. The Coal crops out over an area of about 15 square miles. The uraniferous lignites are found in an area of 120 acres (Denson, et al., 1952, p. 18). It is reported that at least some of the uranium-bearing lignites are located on privately-owned land.

Analyses of samples from six core holes drilled by the U. S. Geological Survey (Denson, et al., 1952, p. 18) show that the upper 18 inches of a seven-foot nine-inch thick coal bed assayed between 0.021 and 0.036 percent uranium oxide (noncommercial). However, the uranium was concentrated in the ash from the 18-inch thick coal, and the assays ran between 0.128 and 0.176 percent uranium oxide (commercial quality).

The State Geological Survey will intensively investigate the surface and subsurface coals in this area this summer. This is one important phase of the overall coal appraisal and areal mapping program.

Corson, Dewey, Perkins, and Ziebach Counties

Certain rocks in these counties are believed by the inhabitants to contain uranium minerals. Many yellow-stained coals and sands have been tested for radioactivity by the Survey, but the rocks have yielded no economic "kicks".

A vast area in these counties contains the Isabel-Firesteel coal member of the Hell Creek formation and several coals in the Ludlow formation. The yellow-stained minerals jarosite and/or melanterite occur along the joints in the coal and as disseminations and nodules in sands and beds associated with the coal. In 1951, the author tested samples of coal, coal ashes, and pseudoscoria collected near Isabel and Firesteel. All samples were barren of radioactivity. These results, however, do not rule out the possibility of these rocks containing uranium.

Missouri River Valley

Several "radioactive" occurrences have been reported from rocks found along the Missouri River Valley. The Survey has tested several samples from formations that are exposed along the Missouri River. Certain beds in the Sharon Springs member of the Pierre formation are radioactive; however, none of the samples tested proved to be commercially significant. The Sharon Springs member is a black marine oil shale and crops out along the Missouri River and its tributaries from the Yankton vicinity to Fort Thompson, a distance of 190 river miles. Many oil shales are radioactive in the United States.

The Niobrara and Pierre formations are exposed in the Missouri River Valley from Yankton to the North Dakota border. The Pierre formation contains jarosite and/or melanterite and bentonite. Jarosite and/or melanterite are ubiquitous and occur in bentonite layers, ironstone concretions, nodules, crusts, and isolated masses or blobs. Bentonite, a hydrous aluminum silicate, is a clay-like rock that is formed by the alteration of volcanic ash and it occurs in relatively pure beds and as disseminations throughout much of the Pierre. Unaltered volcanic ash exists in thin beds at several intervals in the Pierre. Both bentonite and volcanic ash may be source rocks for uranium.

Eastern South Dakota

Much of the area east of the Missouri River is mantled with glacial drift. The drift is composed largely of till which is boulder-clay. Many igneous and metamorphic boulders are sprinkled liberally over this part of the State. The author has tested many boulders for radioactivity, and the results show that granite boulders contain a higher background radioactivity than dark basalt boulders. However, all of the samples tested were below ore grade.

Cretaceous rocks peak through the glacial drift principally along the Missouri, James, and Big Sioux River and their tributaries. These rocks, in addition to the Milbank granite, which is exposed in and around Milbank, may contain uranium.

CONCLUSIONS

This investigation has revealed some enlightening facts concerning the uranium deposits in South Dakota. Certain areas appear favorable for prospecting. Prospectors, using radiation detection instruments, drilling equipment, and geologic guides, should discover additional uranium ore deposits in the State.

Several noteworthy points are as follows:

1. South Dakota has become an important uranium-producing State. A new industry, in the form of a \$2,500,000 ore-processing plant being constructed at Edgemont, promises to be a boon to South Dakota. The State is making an indispensable contribution to the nation's supply of atomic raw materials.

2. The Edgemont district is the largest ore producing area.

3. Ore deposits of carbonaceous siltstone and lignite have been discovered in the North and South Cave Hills, and sandstone-type uranium deposits exist in the Slim Buttes area.

4. Ore-grade uraniferous lignite ash occurs in Perkins County, and huge tonnages of uraniferous lignite underlie the Slim Buttes. The uraniferous lignites in the Cave Hills and possibly some of the uranium-bearing lignites in the Slim Buttes and near Lodgepole in Perkins County remain dormant at least until the metallurgy for uraniferous lignites is perfected economically and until the Federal government resolves the question of whether land is available under the Coal Leasing Act or subject to mineral claim.

5. Many relatively unexplored areas may contain economic deposits of uranium:

a. The Inyan Kara group, which contains the uranium-producing Lakota and Dakota formations in Fall River and Custer Counties, encircles the Black Hills.

b. The Black Hills core of igneous and metamorphic rocks and many sedimentary rocks which girdle the Black Hills carries pitchblende and other uraniferous minerals. Autunite and torbernite occur in the Bald Mountain area. Ore-grade deposits of these and/or other uranium-bearing minerals may be found.

c. The large area in the south-central part of the State which is blanketed with White River and Ogallala or

Arikaree sediments. These sediments contain uranocircite, which assays up to 0.25 percent uranium oxide, metatyuyamunite (?), and carnotite near Scenic.

d. Cretaceous rocks, which crop out along the Missouri River, form the surface over about one-half of western South Dakota.

6. The following suggestions may prove valuable to the uranium prospector:

a. Prospectors should make a careful survey of the available literature treating the areas chosen for exploration. Also, studies of the geology, mineralogy, and uranium occurrences in or near the exploration area will prove helpful.

b. Where soil is more than one or two feet thick, Geiger and scintillation counters measure only the soil and not the underlying bedrock. Airborne and ground surveys may record no significant radioactivity from surface rocks that blanket rich ore deposits. The fabulous Gould ore body was found by drilling.

7. The State Geological Survey will test mineral and rock samples for radioactivity without charge but does not make chemical assays. It also has uranium minerals on display but does not have uranium samples for public distribution.

8. Chemical assays are made by the following commercial assayers (this list is not necessarily complete):

H. D. Brown Laboratory
Route 3
Grand Junction, Colorado

Horace J. Hallowell
Analytical & Consulting Chemist
323 Main Street
Danbury, Connecticut

Abbot A. Hanks
624 Sacramento Street
San Francisco 11, California

Ledoux & Company, Inc.
359 Alfred Avenue
Teaneck, New Jersey

Charles O. Parker
Denver, Colorado

Lucius Pitkin, Inc.
47 Fulton Street
New York 7, New York

Smith's Laboratory
Moab, Utah

Smith-Emery Company
920 Santee Street
Los Angeles 15, Calif.

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