Carnotite-Bearing Sandstone in Cedar Canyon, Slim Buttes, Harding County, South Dakota

By J. R. Gill and G. W. Moore

Trace Elements Investigations Report 411

UNITED STATES DEPARTMENT OF THE INTERIOR
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James R. Gill and George W. Moore

February 1954

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*This report concerns work done on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission.

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TEPCO, RPS, Washington (Including master)	3
	64

CONTENTS

ILLUSTRATIONS

TABLES

CARNOTITE-BEARING SANDSTONE IN CEDAR CANYON, SLIM BUTTES, HARDING COUNTY, SOUTH DAKOTA

By James R. Gill and George W. Moore

ABSTRACT

Carnotite-bearing sandstone and clay have been found in the Chadron formation of the White River group of Oligocene age in the southern part of the Slim Buttes area, Harding County, S. Dak. Locally the mineralized sandstone contains as much as 0.23 percent uranium. The uranium and vanadium ions are believed to have been derived from the overlying mildly radioactive tuffaceous rocks of the Arikaree formation of Miocene age. Analyses of water from 26 springs issuing from the Chadron and Arikaree formations along the margins of Slim Buttes show uranium contents of as much as 200 parts per billion. Meteoric water percolating through tuffaceous rocks is thought to have brought uranium and other ions into environments in the Chadron formation that were physically and chemically favorable for the deposition of carnotite.

INTRODUCTION

Carnotite was found March 15, 1953, in Cedar Canyon in the southern part of the Slim Buttes area (NE1/4 NE1/4 sec. 8, T. 16 N., R. 8 E.), Harding County, S. Dak., where it occurs as an efflorescent yellow coating on lenticular silicified sandstone in the Chadron formation of Oligocene age. Carnotite has since been found in the Chadron formation at two other places in the Slim Buttes area, and the known area of the Cedar Canyon occurrence has been extended.

A geologic and topographic map (fig. 1) covering an area 1,550 by 1,870 feet with a 20-foot contour interval and a horizontal scale of 1 inch equals 200 feet, was made with plane table and alidade to show the stratigraphic and topographic relationships of the mineralized sandstone to the underlying and overlying rocks. A second geologic map (fig. 2) has been prepared at a scale of 1 to 31,680 to show the relationship of the geologic features of the Cedar Canyon area to similar features in adjacent areas. The other carnotite localities are indicated on this map, which may also serve as a guide for further investigations in the southern part of the Slim Buttes area.

Location and accessibility

The Slim Buttes area is located within the Custer National Forest in the southeast part of Harding County, S. Dak., about 30 miles southeast of the town of Buffalo and about 60 miles north of the town of Newell, the nearest rail shipping point. The mapped area covers parts of Tps. 16 and 17 N., Rs. 7, 8, and 9 E.

The area is traversed by a well-graded county road that connects South Dakota Highway 8, about 11 miles north of the area, with U. S. Highway 212 at Newell. The part of the area not accessible by this county road may be reached by numerous dirt ranch roads and Forest Service trails.

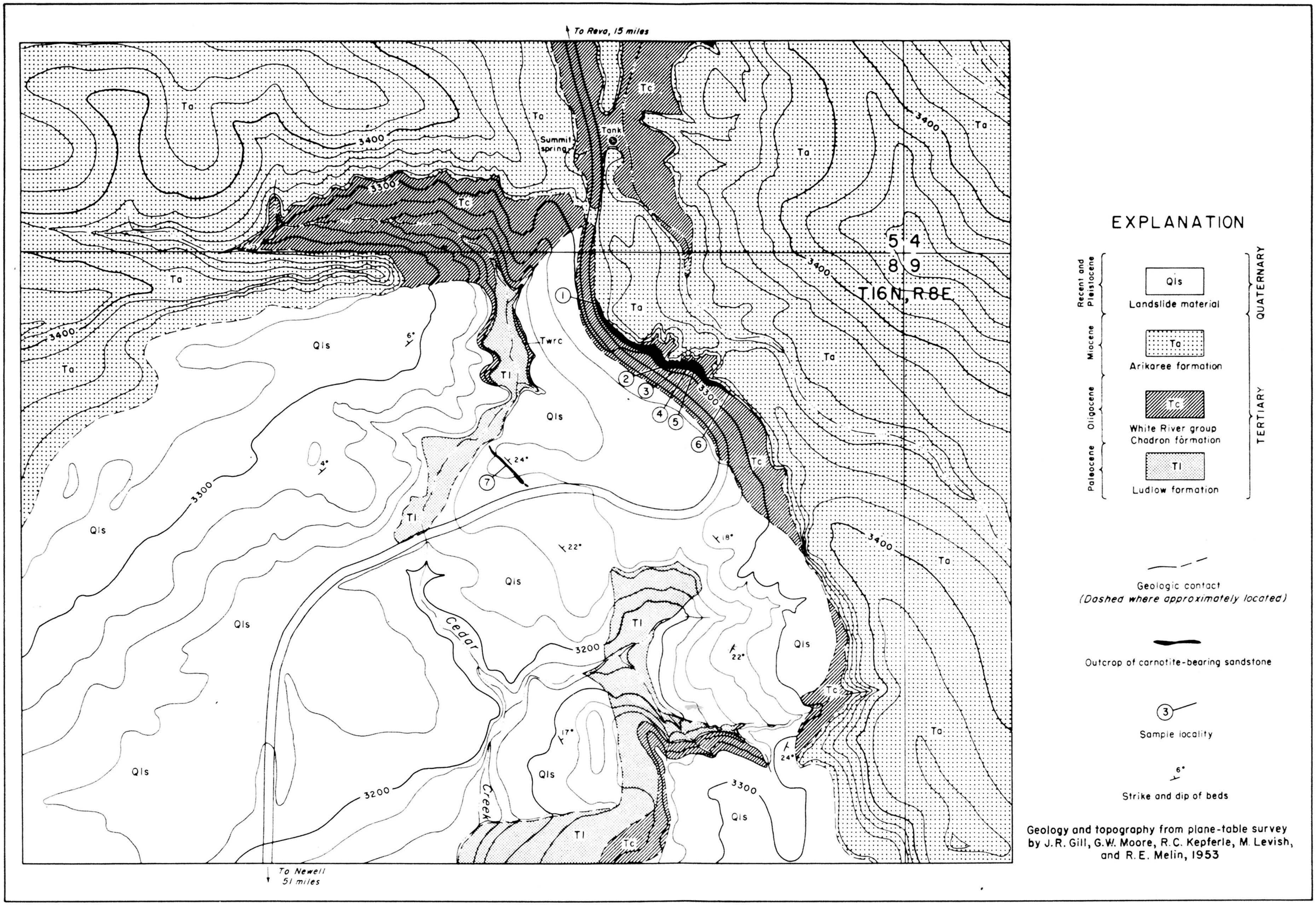

FIGURE 1.--GEOLOGIC AND TOPOGRAPHIC MAP OF CEDAR CANYON, HARDING COUNTY, SOUTH DAKOTA

0 100 200 300 400 500 feet

Contour interval 20 feet

Datum is approximately sea level established with altimeter

The Slim Buttes form a rugged and imposing topographic feature in contrast to the surrounding gently rolling plains. Steep cliffs as much as 250 feet high, broken at several places by V-shaped canyons, form the margins of the Buttes. Steep-walled gullies and landslide blocks make travel along the base of the cliffs difficult. Springs along the base of the cliffs are common, but perennial streams are absent.

Previous work

The lignite resources of the Slim Buttes area have been investigated by Winchester and others (1916), the structural geology in relation to oil and gas by Toepelman (1923), the general geology by Baker (1952), and the uraniferous lignites by Denson and others (1950) and Zeller (1952).

Acknowledgments

The writers acknowledge the assistance received during the field work and in the preparation of this report from Roy C. Kepferle, Murray Levish, and Robert E. Melin. The work was under the general supervision of Norman M. Denson, who visited the area on several occasions giving valuable suggestions and assistance. James D. Bump, of the South Dakota School of Mines, visited the area and aided in the correlation of the Oligocene rocks with those of the White River Badlands in Pennington and Washabaugh Counties, about 150 miles southeast of the Slim Buttes.

The writers express their appreciation to the local ranchers, particularly William and Esther Wammen, for the many courtesies extended.

Vernon Wammen was of great assistance in providing an opportunity to secure oblique aerial photographs of the Cedar Canyon carnotite occurrence.

This work was done on behalf of the Division of Raw Materials of the Atomic Energy Commission.

STRATIGRAPHY

The rocks exposed in the southern part of the Slim Buttes area range in age from Late Cretaceous to Recent. All of the rocks are continental in origin but conditions of sedimentation ranged from those favoring the deposition of lignite to those favoring the accumulation of volcanic ash. The sequence of sedimentation has been broken by at least two major periods of erosion which are shown by two unconformities--one at the base of the rocks of Oligocene age and another at the base of the rocks of Miocene age.

The stratigraphic nomenclature used in this report follows that of Darton (1951) on the geologic map of South Dakota.

Upper Cretaceous rocks

Hell Creek formation

The oldest rocks exposed in the mapped area of the southern part of the Slim Buttes are those which have been assigned to the Hell Creek formation. The Hell Creek formation is Upper Cretaceous in age and is composed of continental sediments that are about 400 feet thick. Seventeen miles south of the mapped area, along the north fork of the Moreau River, the Hell Creek formation rests on the marine Fox Hills formation, also of Cretaceous age.

The Hell Creek formation in the mapped area consists largely of medium-grained greenish-gray friable sandstone and dark-gray sandy bentonitic shale. Thin beds and concretions of medium-grained sandstone cemented with siderite are generally abundant. These have usually weathered to limonite on the surface and are brownish black. Log-like dark yellowish-brown calcareous concretions as much as 10 feet long occur in the friable sandstone. Thin lenticular beds of lignite are found in the upper part of the formation.

The contact between the Hell Creek formation and the overlying Ludlow formation is not sharp in this area. The units have been separated by earlier workers (Winchester and others, 1916, p. 19) on the basis of the lithologic change from the somber-colored rocks of the Hell Creek formation to the yellowish-brown rocks of the Ludlow formation. In the southern part of the Slim Buttes area this criterion is difficult to apply as these lithologic types alternate with one another over a vertical distance of 100 feet or more. In this report the contact has been placed at the base of the lowermost persistent lignite bed (Brown, 1952). Throughout most of the area this lignite lies below a resistant dark yellowish-brown sandstone bed.

Tertiary rocks

Ludlow formation

Conformably overlying the Hell Creek formation and separated from it by a transitional zone is the Ludlow formation of Paleocene age. The Ludlow formation is composed largely of poorly cemented moderate yellowish-brown very fine-grained sandstone interbedded with carbonaceous shale and lignite, but moderately well-indurated medium-grained sandstone also occurs.

The Ludlow formation ranges in thickness in the mapped area from a feather edge to about 100 feet. Exposures of this formation to the north of the mapped area indicate that it was originally over 300 feet thick, but the erosion preceding deposition of the White River group has truncated the northeastward dipping Ludlow formation, resulting in the thinning of the formation in the mapped area and, locally, in its complete removal.

Lignite has been mined from the Ludlow formation at several localities within the mapped area. The discovery was made in 1949 (Denson and others, 1950; Beroni and Bauer, 1952) that some of the beds contain uranium. No uranium minerals are apparent in the lignite, however, and the uranium is thought to be retained as a metalo-organic constituent (Breger and Deul, 1952).

The uranium in the lignites is considered to be of secondary origin having been derived from volcanic material in the overlying rocks of the Arikaree formation and the White River group. The introduction of uranium by groundwater took place prior to the decomposition of the volcanic material present in these rocks and the subsequent formation of impervious beds of bentonite that now form the base of the perched water table at or near the contact between the Chadron formation of the White River group and the overlying Arikaree formation.

White River group

Unconformably overlying both the Ludlow and Hell Creek formations is the White River group of Oligocene age. The White River group consists of the Chadron and Brule formations. The Chadron formation is the basal formation and is the only part of the group normally present throughout most of the mapped area, as pre-Arikaree erosion has generally removed the overlying Brule formation. The lower part of the Chadron formation locally contains much material reworked from the Ludlow and Hell Creek formations. The lower part of the formation consists of moderate yellow to dark yellowish-orange sandstone and siltstone, and at a few places contains beds of detrital lignite as much as 6 inches thick derived and reworked from the underlying Ludlow formation. The upper part of the Chadron formation is composed dominantly of white fine-grained to coarse-grained pebbly sandstone and light olive-gray bentonite. Tuffaceous sandstone and opalized clay are present locally. Where the reworked material is absent, the white coarse-grained sandstone of the upper part of the Chadron formation rests on older rocks.

The Brule formation is exposed at only two localities within the mapped area--at the north end of Flat Top Butte, chiefly in secs. 29 and 30, T. 17 N., R. 9 E., and west of Square Top Butte in sec. 31, T. 17 N., R. 8 E. In both of these areas the Brule formation is preserved in landslide blocks which were down-dropped prior to deposition of the Arikaree formation. The contact between the Brule and Chadron formations is exposed at the north end of Flat Top Butte. Following practice in the Big

Badlands area of the classic White River exposures, the contact is placed at the top of a freshwater limestone bed which separates the uppermost bentonite bed of the Chadron formation from the moderate orange-pink sandy claystone and tuffaceous sandstones of the Brule formation (Bump, 1951) (fig. 3). The Brule formation is composed of thin-bedded to massive sandy claystone and tuffaceous sandstone, which are well indurated and contrast sharply with the poorly cemented sandstone and bentonitic clay of the Chadron formation.

In some areas the White River group is absent and the Arikaree formation rests directly on the older rocks. This condition occurs in secs. 11 and 14, T. 16 N., R. 8 E. Prior to White River deposition, resistant sandstone beds in the Ludlow and Hell Creek formations formed hills with as much as 100 feet of relief. Only a thin mantle of Chadron was deposited on these hills and subsequent pre-Arikaree erosion removed this thin mantle exposing some of these ancient hills.

Rocks of the White River group contain on the average about 0.001 percent uranium.

Arikaree formation

Unconformably overlying the rocks of the White River group is the Arikaree formation of Miocene age. No diagnostic fossils have been found in this unit in northwestern South Dakota and the correlation with the Arikaree formation of Miocene age is made on the basis of lithologic similarities. A beaver of upper Miocene age has been described by Wood (1945)

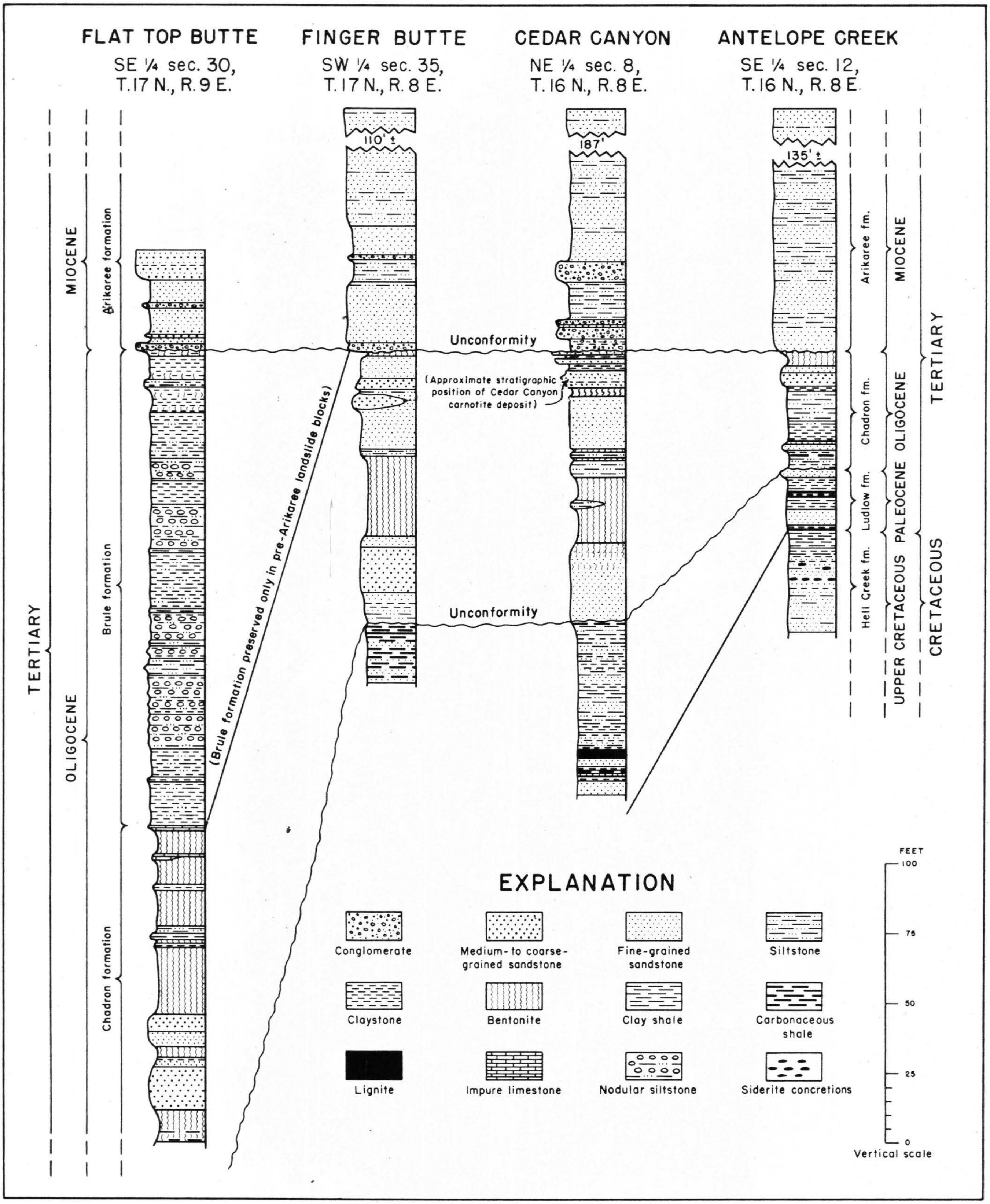

FIGURE 3.--STRATIGRAPHIC SECTIONS OF ROCKS EXPOSED IN THE SOUTHERN PART OF SLIM BUTTES, HARDING COUNTY, SOUTH DAKOTA

from rocks in southeastern Montana, which may correlate with those in the Slim Buttes area.

The Arikaree formation is resistant to erosion and is the rock unit that causes Slim Buttes to stand more than 500 feet above the surrounding plains. The formation is composed dominantly of yellowish-gray very fine-grained tuffaceous sandstone and is over 250 feet thick. The basal 50 feet contains much material reworked from the White River group and is thin-bedded in contrast with the more massive upper part. Locally one or more beds of conglomerate occur at or near the base of the Arikaree formation. These beds of conglomerate are usually made up of claystone pebbles and cobbles averaging 2 inches in diameter. Most of these pebbles and cobbles appear to have been derived from the Brule formation. Very coarse sand and pebbles from the Chadron formation are also incorporated into the basal part of the Arikaree formation.

Rocks of the Arikaree formation like those of the White River group contain on the average about 0.001 percent uranium. It is thought that this uranium was introduced into the formation with the volcanic material of which the formation is largely composed.

Quaternary deposits

Terrace deposits

Deposits of probable Pleistocene age are present as fans extending from the bases of the cliffs and as terraces along many of the stream valleys. Many of these deposits look like the White River rocks, as much of the material of which they are composed was derived from these rocks. The terrace deposits have flat upper surfaces, and recent erosion has cut into these surfaces at many places, leaving the deposits as isolated "tables." These deposits were not mapped.

Landslide material

Landsliding was extensive around the periphery of Slim Buttes during the Pleistocene and extending into Recent time. Blocks and masses made up largely of Arikaree material, but also containing White River and older rocks, extend at some places over three-quarters of a mile from the cliff faces. Coherent blocks as much as half a mile long locally have moved as a single unit, but more commonly the landslide material is made up of smaller blocks and rubble. On the south and west sides of Slim Buttes the landslide material obscures the contacts between the older rocks for long distances.

STRUCTURE

The main structure of the Ludlow and Hell Creek formations of the southern part of the Slim Buttes area is that of a homocline that dips to the northeast generally less than one degree. This uniform structure is modified locally by minor undulations.

The rocks of the Chadron and Arikaree formations reflect little of the structure of the underlying rocks because of the unconformity at the base of the Chadron formation. These upper units are preserved in a gentle syncline, the axis of which approximately follows the topographic crest of the Buttes. On the west side of the area this axis is nearly north-south, and it curves to the southeast at the east end of the Buttes.

No faults have been recognized in the southern part of the Slim Buttes area. Pre-Arikaree landslide blocks are bounded by fractures that resemble faults, but it is thought that there are no examples of surface displacement in the area which reflect tectonic activity.

After the deposition of the White River group and prior to deposition of the Arikaree formation, landsliding took place on a large scale in the Slim Buttes area. Enormous blocks, some of which have remained intact, have slipped down as much as 200 feet. The interpretation of these features presented a problem to early workers, and they were first considered fault blocks (Todd, 1895, p. 303) and later cross-bedding (Winchester, 1913). Toepelman (1923) first recognized that they were slump blocks which had slipped into steep-walled canyons cut into the White River and Ludlow sediments. A good exposure of one of these blocks may be seen at the north end of Flat Top Butte where tilted White River material lies more than 50 feet below the White River-Ludlow contact. A thin lignite bed in the Ludlow formation can be recognized on both sides of the block in the undisturbed nearly horizontal rocks behind the landslide block. Only in these downdropped blocks can the Brule formation be found in the Slim Buttes area. The age of the slumping is indeterminate; it may be either Oligocene or Miocene.

CARNOTITE DEPOSITS

At the head of Cedar Canyon (fig. 1) carnotite occurs near the top of the Chadron formation in inclined thin lenticular beds of silicified fine-grained tuffaceous sandstone and thin beds of sandy claystone which are truncated by sandstone and conglomerate of the basal part of the Arikaree formation. The mineral carnotite was identified by A. J. Gude, 3rd, of the U. S. Geological Survey, by X-ray diffraction methods.

The unit of interbedded fine-grained tuffaceous sandstone and sandy claystone in which the carnotite occurs is as much as 9 feet thick. Individual lenses of sandstone range from 0.5 to 2.5 feet in thickness and are separated by beds of claystone ranging from 0.1 to 1.5 feet in thickness. The lenses of sandstone contain disseminated carnotite, and small amounts of carnotite also occur in the adjacent claystone. Some carnotite is found at intervals through the entire 9-foot unit, but the principal mineralization has been in the upper 4 feet. The carnotite occurs through a distance of about 300 feet along the outcrop. The greatest concentration of carnotite occurs as thin coatings on fracture surfaces in the sandstone with lesser amounts disseminated throughout the sandstone. Carnotite is also present as a thin coating around sand grains in the sandy clay adjacent to the sandstone.

The Chadron formation in Cedar Canyon consists of light-gray to yellowish-gray fine- to very fine-grained sandstone, siltstone, and yellowish-gray and grayish-olive bentonite. This formation unconformably overlies light-brown carbonaceous shale, lignite, and light-brown slightly carbonaceous fine-grained sandstone of the Ludlow formation. The rocks of the Chadron formation are unconformably overlain by rocks of the Arikaree formation that are composed of medium- to coarse-grained yellowish-gray sandstone which locally contains pebbles and cobbles, and very fine-grained light- to yellowish-gray tuffaceous sandstone. A section measured through the mineralized portion of the Chadron formation exposed at the Cedar Canyon carnotite occurrence, and including a portion of the overlying Arikaree formation, is as follows:

Arikaree formation	Feet
Conglomerate, pebble to cobble, yellowish gray, weathers dark yellowish orange, lenticular, poorly indurated. Pebbles and cobbles are limy yellowish-gray claystone typical of the Brule formation. Waterworn bone fragments reworked from the White River group are numerous	2.0+
Sandstone, very fine grained, light gray, tuffaceous, forms cliff	15.0
Conglomerate, as above, well indurated	2.6
Sandstone, medium- to coarse-grained, yellowish gray; contains few claystone pebbles	3.1
Sandstone, medium- to very coarse-grained, conglomeratic; the clay matrix contains numerous light olive-gray subangular to rounded claystone fragments. Locally the sandstone contains thin lenses of well indurated coarse-grained sandstone less than 4 inches thick	3.1
Total thickness measured of Arikaree formation	25.8

Chadron formation	
Sandstone, very fine grained, light gray, silicified; has carnotite coating on sand grains	0.2
Claystone, sandy, light gray, soft	0.1
Sandstone, as above; contains no visible carnotite	1.2
Claystone, as above	1.2
Sandstone, as above; with carnotite	0.7
Claystone, as above	0.1
Sandstone, as above; contains no visible carnotite	0.5
Claystone, as above	0.5
Sandstone, as above; with carnotite	0.6

Chadron formation, continued	Feet
Claystone, as above	1.0
Sandstone, as above; contains no visible carnotite	0.7
Sandstone, as above, less silicified, poorly indurated, contains carnotite	0.6
Sandstone, very fine grained, light gray, silicified; has carnotite coating on sand grains	0.9
Claystone, as above	0.5
Sandstone, fine grained, pale olive; contains many pebbles of very sandy pale-olive claystone derived from underlying units	3.3
Sandstone, very fine grained, pale olive streaked with dark yellow-orange, poorly indurated. Contains a few pebbles of very sandy claystone eroded from underlying unit	0.6
Bentonite, sandy, pale olive with a few dark yellow-orange streaks	2.1
Sandstone, very fine grained, clayey, very light gray, weathers in fluted columns	8.0+
Total thickness measured of Chadron formation	22.8

Base of section in ditch north side of road.

Figure 4, an aerial view of Cedar Canyon, illustrates the general topography of the area, and figure 5 shows the stratigraphic relationship of the carnotite-bearing sandstone in the Chadron formation to the overlying Arikaree formation. The geologic map of the Cedar Canyon area (fig. 1) indicates the areal extent and relation of the various formations to the area of mineralization in the Chadron formation. Much of the Chadron and Ludlow outcrop is obscured by talus and recent landslide blocks. Where possible, the attitude of the landslide blocks has been indicated on the map (fig. 1) because the block directly south of the outcrop of mineralized sandstone also contains carnotite.

The mineralized area in this landslide block has a lateral extent of about 100 feet, and is as much as much as 0.8 foot in thickness.

Analyses of six samples from the Cedar Canyon carnotite occurrence are listed in table 1.

Figure 4.--Aerial view of Cedar Canyon. Arrow indicates outcrop of mineralized sandstone.

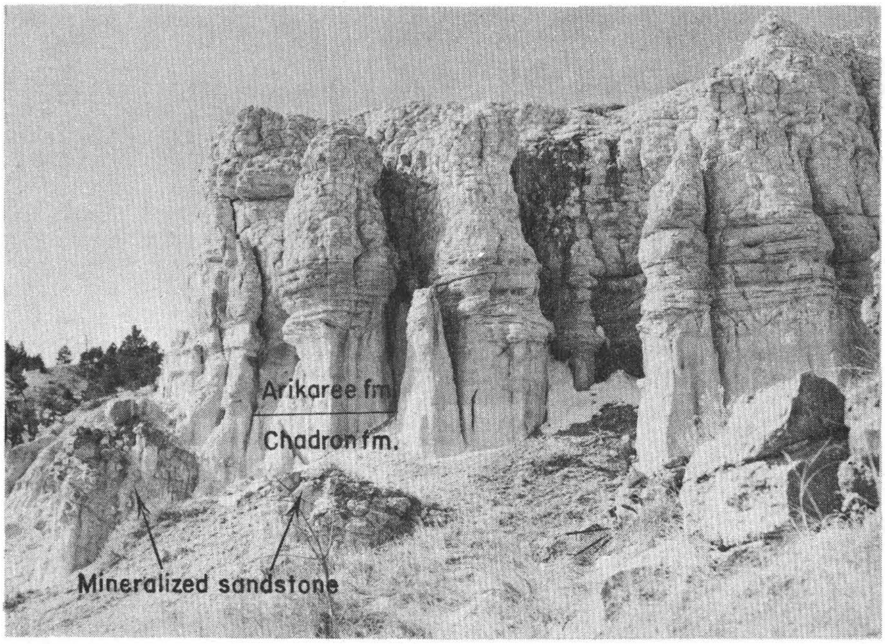

Figure 5.--Stratigraphic relationship of the carnotite-bearing sandstone in the Chadron formation to the overlying Arikaree formation in Cedar Canyon, Slim Buttes, South Dakota.

Table 1.--Analyses of samples collected from the Cedar Canyon carnotite deposit. (See fig. 1 for location of samples.)

Locality No.	Serial No.	eU (percent)	U (percent)	Description of samples
1	92321	0.036	0.037	Claystone, sandy, yellowish gray; contains no visible carnotite. 1 foot channel sample.
2	92322	.14	.10	Claystone, sandy, yellowish gray; has carnotite coating on sand grains. 0.3 foot channel.
3	87613	.13	.23	Sandstone, fine-grained, light gray, silicified; carnotite is concentrated on fracture surfaces. Selected grab sample.
4	87612	.055	.080	Sandstone, fine-grained, light gray, silicified; contains disseminated carnotite. Grab sample.
5	92323	.091	.19	Sandstone, fine-grained, light gray, silicified; has carnotite disseminated throughout. Grab sample.
6	92324	.018	.001	Sandstone, very fine-grained, light gray, silicified; contains no visible carnotite. Grab sample.

A grab sample of carnotite-bearing sandstone (sample locality No. 7) collected from the landslide block about 300 feet south of the mineralized outcrop contains 0.086 percent uranium. The mineralized sandstone in this landslide block is similar to that exposed in the outcrop.

Carnotite has been noted at two other localities in the southern part of the Slim Buttes and abnormal radioactivity readings have been obtained at the White River-Arikaree contact at numerous localities throughout the

Slim Buttes. At sample locality 8, in the SW 1/4 sec. 9, T. 16 N., R. 8 E., carnotite coats quartz granules in sandstone and sand grains disseminated in bentonitic clay of the Chadron formation in a large landslide block. Carnotite can be observed through only about 5 feet of outcrop as the exposures are poor in the area. A grab sample of clay containing carnotite-coated sand grains contains 0.025 percent uranium.

On the south side of Square Top Butte, at sample locality 9, in the SW 1/4 sec. 29, T. 17 N., R. 8 E., carnotite occurs as fracture-surface coatings along the basal 0.2 foot of a 1.0 foot opalized clay bed. This opalized clay occurs in the Chadron formation, 19 feet below the Chadron-Arikaree contact, and is overlain and underlain by beds of bentonite. Laterally, this opalized clay grades into non-opalized bentonite. Small amounts of carnotite are present for about 100 feet along the outcrop.

ORIGIN

The Arikaree formation and formations of the White River group exposed in the Slim Buttes contain large quantities of volcanic glass and altered volcanic material, including bentonite. In the southern part of the Slim Buttes, about 250 feet of very fine-grained tuffaceous sandstone is present in the Arikaree formation, with an unknown thickness having been removed by erosion. Throughout the Slim Buttes area, springs issue from the base of the Arikaree formation or, at a few places, from the upper few feet of the Chadron formation. These springs result from a perched water table that is formed by impervious bentonite and bentonitic sandstone in the upper part of the Chadron formation. Water samples from these springs contain much more uranium than do water samples collected from wells and springs in the underlying Ludlow and Hell Creek formations. For example, water from Summit Spring (sec. 5, T. 16 N., R. 8 E.), issuing from the base of the Arikaree formation, contains 51 parts per billion uranium, and water from Phillips Spring (sec. 34, T. 17 N., R. 8 E.), which flows from the same stratigraphic horizon, contains 170 parts per billion. On the other hand, water from Section 17 Spring (sec. 17, T. 16 N., R. 9 E.), which issues from the Hell Creek formation, contains only one part per billion uranium. Thirty-four analyses of water from springs and wells within the mapped area (fig. 2 and table 2) indicate the contrast in uranium content between water in the Arikaree and Chadron formations and that in the underlying formations.

The water from Summit Spring contains 0.42 grams per liter of residue and the residue from 48 liters (12.6 gals.) of water from this spring was analyzed chemically by the Geochemical Prospecting Unit and spectrographically by the Trace Elements Section Denver Laboratory, both of the U. S. Geological Survey. These chemical and spectrographic analyses are tabulated in tables 3 and 4, respectively.

Chemical analyses of tuffaceous sandstone from the Arikaree formation indicate the rock contains about 0.001 percent uranium. It is postulated that the uranium, vanadium, silicon, and other elements found concentrated in the Cedar Canyon area as carnotite and silicified sandstone were leached from the weakly radioactive volcanic material present in the

Table 2.--Analyses of water samples collected from wells and springs in the southern part of Slim Buttes, Harding County, South Dakota

Well or spring	Location (Sec. T., R.)	U content (ppb)	Formation
Road Draw No. 2 Spring	25-17N-7E	30	Chadron
Road Draw No. 1 Spring	25-17N-7E	22	"
J. B. Spring	36-17N-7E	46	"
Rabbit Creek Spring	36-17N-7E	39	Arikaree
Frandsen well	26-17N-8E	5	Hell Creek
Thybo well	28-17N-8E	2	"
Unnamed spring	30-17N-8E	40	Chadron
Red Tank Spring	31-17N-8E	27	"
Guard Station Spring	32-17N-8E	41	"
Unnamed spring	32-17N-8E	2	Ludlow
Phillips Spring	34-17N-8E	170	Arikaree
Unnamed spring	32-17N-9E	5	Ludlow
Unnamed spring	2-16N-8E	14	Chadron
Unnamed spring	2-16N-8E	200	Arikaree
Unnamed spring	3-16N-8E	14	"
Unnamed spring	3-16N-8E	32	"
Thybo Spring	4-16N-8E	10	"
Summit Spring	5-16N-8E	51	"
Deer Draw Spring	5-16N-8E	12	"
Fish Spring	6-16N-8E	20	Chadron
Mountain Ranch Spring	8-16N-8E	15	"
Unnamed spring	9-16N-8E	56	"
Antelope Spring	10-16N-8E	66	Arikaree
Rock Spring	10-16N-8E	38	"
Unnamed spring	13-16N-8E	24	"
Unnamed spring	13-16N-8E	13	"
Unnamed spring	14-16N-8E	13	Chadron
Unnamed spring	14-16N-8E	46	"
Hines Spring	24-16N-8E	11	Ludlow
Section 17 Spring	17-16N-9E	1	Hell Creek
Wolf Spring	19-16N-9E	13	Arikaree
Unnamed spring	20-16N-9E	2	Chadron
Moonshine Kelly Spring	31-16N-9E	4	Ludlow
Rimrock Spring	32-16N-9E	5	"

Table 3. Chemical determinations of metals in residue from 48 liters (12.6 gals.) of water from Summit Spring. Sample serial number D-86659. Analysts: H. E. Crowe, W. Mountjoy, and P. Schuch.

Element	Percent
Vanadium	0.070
Uranium	.010
Nickel	.0010
Copper	.0008
Lead	.0006
Molybdenum	.0002
Cobalt	.0001

Table 4. Semiquantitative spectrographic determinations of residue from 48 liters (12.6 gals.) of water from Summit Spring. Sample serial number D-86659, spectrographic plate number II-720. Analyst: A. T. Myers.

Element	Percent	Element	Percent
Sodium	xx.	Vanadium	0.ox
Silicon	x.	Titanium	.oox
Potassium	.x+	Manganese	.oox-
Iron	.x	Zirconium	.oox-
Boron	.x	Strontium	.oox-
Aluminum	.x-	Copper	.ooox+
Calcium	.x-	Barium	.ooox
Magnesium	.ox+	Chromium	.ooox-

Looked for but not detected as amount present below threshold amount of element: Ag, As, Au, Be, Bi, Cd, Ce, Co, Dy, Er, Ga, Gd, Ge, Hf, Hg, In, Ir, La, Li, Mo, Nb, Nd, Ni, Os, P, Pb, Pd, Pt, Re, Rh, Ru, Sb, Sc, Sn, Sm, Ta, Th, Tl, Te, U, W, Y, Yb, and Zn.

Arikaree formation by moving groundwater. These substances were then deposited in sandstone and claystone along the base of the perched water table near the top of the White River group.

The mechanism for the localization of carnotite in the Cedar Canyon area is not clearly evident but it seems likely that slight surface irregularities on the pre-Arikaree surface, and, therefore, on the base of the perched water table, might exert some structural influence on the deposition of carnotite by controlling the flow of groundwater. Throughout most of the southern part of the Slim Buttes area the base of the perched water table is coincident with the top of the uppermost bentonite bed in the Chadron formation. At the Cedar Canyon carnotite occurrence, however, this bentonite bed has been removed by pre-Arikaree erosion, and tuffaceous sandstone of the Arikaree formation directly overlies sandstone and sandy clays of the Chadron formation. Differences in porosity and permeability of the individual layers caused by alternating fluviatile sandstone and sandy clay might have formed a restricted channel for groundwater migration beneath the normal perched water-table horizon. Conditions in this zone have been favorable for the deposition of carnotite, though the specific physical and chemical factors which have made this a good host rock have not been determined.

SUGGESTIONS FOR PROSPECTING

Occurrences of carnotite in the southern part of the Slim Buttes are found in sandstone and clay in the upper few feet of the Chadron formation where it is unconformably overlain by the Arikaree formation. In areas where pre-Arikaree slumping has taken place and the Arikaree formation unconformably overlies the Brule formation, abnormally high radioactivity readings are commonly obtained at the contact of these two formations. One such anomaly was recorded at the contact between the Arikaree and Brule formations in the NE1/4 SE1/4 NW1/4 sec. 31, T. 17 N., R. 8 E.

Thirty-four analyses for uranium of water from springs and wells are shown on figure 2 and in table 2. Water from springs issuing from the Arikaree and Chadron formations contain much greater amounts of uranium than do waters from the Ludlow and Hell Creek formations. The uranium content of water from springs in the Arikaree and Chadron formations has a considerable range. These ranges in content may be due in part to differences in rates of water flow, as springs of low flow generally contain more uranium than springs of high flow. A uranium content of 10 to 20 parts per billion in water is representative for springs issuing from the Arikaree and Chadron formations in the Slim Buttes. A uranium content of 30 or more parts per billion is apparently abnormally high and may indicate the concentration of uranium minerals nearby.

Particular attention should be given to the areas around the following springs:

Unnamed spring	200 ppb U*		NE SW sec. 2, T. 16 N., R. 8 E.
Phillips Spring	170	"	NW SE sec. 34, T. 17 N., R. 8 E.
Antelope Spring	66	"	SW NE sec. 10, T. 16 N., R. 8 E.
Unnamed spring	56	"	NE SW sec. 9, T. 16 N., R. 8 E.
Summit Spring	51	"	SE SE sec. 5, T. 16 N., R. 8 E.
Unnamed spring	46	"	NW SW sec. 14, T. 16 N., R. 8 E.
J. B. Spring	46	"	NW NE sec. 36, T. 17 N., R. 7 E.
Guard Station Spring	41	"	SW SW sec. 32, T. 17 N., R. 8 E.
Unnamed spring	40	"	SW SE sec. 30, T. 17 N., R. 8 E.
Rabbit Creek Spring	39	"	SE SE sec. 36, T. 17 N., R. 7 E.
Rock Spring	38	"	NE SE sec. 10, T. 16 N., R. 8 E.

*Parts per billion uranium

Other favorable areas for the concentration of uranium minerals may be found where the rocks are folded into synclines or where sandstone channel deposits occur. Commonly silicification of the rocks has accompanied carnotite mineralization. Prospecting should not be restricted to the Arikaree, Brule, and Chadron formations but should also include an investigation of the sandstones of the Ludlow and Hell Creek formations, particularly where they are unconformably overlain by the Arikaree and formations of the White River group.

The recent discovery of uranium-bearing sandstone in the Chadron formation in the White River Badlands, Pennington County, S. Dak.

(Moore and Levish, report in preparation) suggests that areas where the Arikaree formation and the White River group are present should be prospected. These units or their equivalents crop out in parts of North and South Dakota, Wyoming, Montana, Colorado, Nebraska, and adjacent states.

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Reserves

Not enough samples can be obtained from surface outcrops to make complete reserve estimates as the rocks containing the most intensive mineralization are partly covered by a thick mantle of talus, soil and vegetation. Trenching is necessary to obtain adequate surface samples. The concentration of uranium minerals on fractures and the exposed face of the sandstone is suggestive of a "caliche" type of deposit. Until a few shallow (less than 60 feet) drill holes are put down behind the outcrop the areal extent of the mineralized rocks will be impossible to determine.

Accepting the assumption that the uranium content of the rocks does not decrease behind the outcrop, the reserve estimates given herein are based on the thickness and lateral extent of mineralized rock exposed along the outcrop. The third dimension, possible area of mineralization, was obtained by constructing a segment of a circle with the length of the mineralized outcrop as the diameter. The area of potentially mineralized rock behind the outcrop obtained by this method is 2,000 square feet. This area is estimated to be underlain by mineralized sandstone and clay having an aggregate thickness of 4 feet and a uranium content of 0.04 percent. Based on these assumptions this area would contain an inferred reserve of about 400 tons of mineralized rock containing about 320 pounds of uranium.

The area directly behind sample localities 2-5 is thought to contain most of the uranium, and by using the above method to determine area it is postulated that 900 square feet is underlain by sandstone and clay having an aggregate thickness of 2 feet and a uranium content of 0.15 percent. These assumptions suggest that an inferred reserve of about 90 tons of rock containing 270 pounds of uranium are present.

These estimates are based on a factor of 20 cubic feet of sandstone per ton.