Geology and Uranium Deposits in the Cave Hills Area, Harding County, South Dakota

GEOLOGICAL SURVEY PROFESSIONAL PAPER 476–A

Prepared partly on behalf of the U.S. Atomic Energy Commission

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By G. N. PIPIRINGOS, W. A. CHISHOLM, *and* R. C. KEPFERLE

URANIUM INVESTIGATIONS IN THE CAVE HILLS AREA, HARDING COUNTY, SOUTH DAKOTA

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Stratigraphy, structure, and other factors controlling the distribution of uranium in the Fort Union Formation of northwest South Dakota. Prepared partly on behalf of the U.S. Atomic Energy Commission

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GEOLOGY AND URANIUM DEPOSITS IN THE CAVE HILLS AREA HARDING COUNTY, SOUTH DAKOTA

By G. N. Pipiringos, W. A. Chisholm, and R. C. Kepferle

ABSTRACT

The results of field and laboratory investigations of uranium deposits that occur locally in coal, carbonaceous clayey siltstone, and phosphatic silty claystone in the Fort Union Formation of Paleocene age in the Cave Hills area are presented.

The Cave Hills area includes 215 square miles of rolling farmland or grazing land and flat-topped timbered buttes and ridges that rise 200–500 feet above the surrounding country. Maximum relief is about 800 feet. The area is drained principally by southeastward-flowing tributaries of the South Fork of the Grand River.

The rocks exposed in the Cave Hills area are, in ascending order, the Hell Creek Formation of Late Cretaceous age, the Ludlow and Tongue River Members of the Fort Union Formation of Paleocene age, and the Chadron Formation of early Oligocene age. Eocene rocks being absent, the Chadron Formation rests disconformably on the Tongue River Member. The rocks exposed below the Chadron consist mainly of swamp and stream deposits, together with lesser amounts of brackish-water or near-shore-marine deposits, all of Late Cretaceous and Paleocene age. Their aggregate thickness is about 800 feet. A small remnant of gravel on McKensie Butte in the southern part of the area is of probable Pleistocene age.

The Hell Creek Formation consists principally of sandstone, siltstone, shale, and carbonaceous shale. Coal beds were not noted in the formation. Only the upper part of the formation is exposed, but logs of holes drilled in the area suggest that the formation may range from 435 to 575 feet in thickness. The contact with the overlying Ludlow Member of the Fort Union Formation is gradational.

The Ludlow Member consists principally of gray clay shale, greenish-gray siltstone, gray yellowish-weathering fine-grained sandstone, coal, and minor amounts of carbonaceous shale, carbonaceous siltstone, and phosphatic claystone. Analcite spherulites are abundant in the upper 90 feet of the Ludlow Member. The thickness of the member ranges from 310 to 420 feet and averages about 365 feet. The contact with the overlying Tongue River Member appears conformable and is marked by a change from slope-forming interbedded shale, siltstone, and sandstone in the upper part of the Ludlow Member to cliff-forming massive sandstone at the base of the Tongue River Member.

The Tongue River Member consists principally of massive, locally crossbedded, sandstone but includes lesser amounts of interbedded claystone, siltstone, coal, and carbonaceous shale. The lowermost 110 feet of this member is a cliff-forming homogeneous sandstone sequence whose base throughout much of the area is marked by springs. Analcite beds and spherulites are abundant throughout this member. Locally, it contains fossil shark remains indicative of a marine or brackish-water environment of deposition. The maximum thickness observed (about 260 ft.) is less than the original thickness of the Tongue River Member because of erosion prior to deposition of the overlying Chadron Formation.

The Chadron Formation consists of a basal conglomerate, very coarse grained sandstone, tuffaceous sandstone and claystone, silicified limestone, bentonite, and tuffaceous bentonitic claystone. It does not contain coal. A maximum thickness of 50 feet was measured at the outlier that caps the south-central part of the South Cave Hills. The surface on which the Chadron was deposited had a maximum relief of about 60 feet. In the South Cave Hills the Chadron Formation contains vertebrate fossils of early Oligocene age.

A small remnant of poorly consolidated conglomerate on McKensie Butte consists of a variety of rock fragments that probably were derived from Miocene rocks in adjacent areas. The conglomerate probably is of Pleistocene age.

In general the rocks in the Cave Hills area dip eastward and northeastward into the Williston Basin at an average rate of about 25 feet per mile. Locally the regional dip is interrupted by shallow synclinal and anticlinal folds; the most clearly defined of these folds in the Cave Hills area is a syncline trending northwestward across the South Cave Hills. The folding is probably of late Eocene age.

Coal occurs in beds that range in thickness from a few inches to 21 feet and are within a stratigraphic interval of about 550 feet in the Fort Union Formation. In ascending stratigraphic order these beds are the lower coal beds, Lonesome Pete coal zone, coal beds B and C, and Carbonate coal zone of the Ludlow Member and coal beds E and F of the Tongue River Member. Those in the Ludlow Member are more numerous, generally thicker, and of better fuel quality than those in the Tongue River Member. Analyses of some of the coal beds indicate that they are lignite. The ash content of the coal beds ranges from 11 to 94 percent and averages about 40 percent.

Nearly all the coal beds in this area contain at least 0.001 percent uranium, but ore-grade (0.1 percent, or more) occurrences are confined to the Lonesome Pete coal zone, the C coal zone, the Carbonate zone of the Ludlow Member, and coal beds E and F of the Tongue River Member. Discrete uranium minerals are meta-autunite, metatorbernite, metazeunerite, saleeite, and sodium autunite.

The Chadron Formation contains about 0.001 percent uranium, and most rocks in the Fort Union Formation contain less than 0.001 percent uranium.

The uranium content of water from springs, wells, streams, ponds, and reservoirs ranges from less than 1 to about 2,250 parts per billion. The water samples with high uranium content were found near localities containing relatively high concentrations of uranium, and the uranium in the water was probably derived from leaching of the uranium deposits. The pH ranges from 7.4 to 9.6 but apparently does not correlate with the uranium content of the water samples.

Analytical data on the 716 rock samples collected include 716 radiometric and chemical analyses for percent equivalent uranium (eU) and uranium (U) and 556 chemical analyses for percent ash (A) and percent uranium in ash (UA).

Eight stratigraphic units of the Fort Union Formation were chosen for study of the distribution of uranium and for study of radioactivity equilibrium relations. These units include the coal beds, the Lonesome Pete ore zone—a phosphatic silty claystone bed that occurs within the first few feet above the Lonesome Pete coal bed—and the Carbonate ore zone—a carbonaceous siltstone facies of the Carbonate No. 1 coal bed. In general, the uranium content of these units decreases stratigraphically downward. All the higher-grade-uranium occurrences are closely related to aquifers; the lower coal beds, being farthest from the aquifers, contain the least uranium. The degree of radioactive disequilibrium (U>eU or U<eU) likewise is apparently associated with proximity to aquifers. The unit that overlies, and the three units that underlie, the principal aquifer are the only ones with ratios indicating an excess of equivalent uranium (eU) over uranium (U); in all other beds the ratio is U>eU except for one sample in the Lonesome Pete zone which contains a small excess of equivalent uranium. Presumably those samples with excess equivalent uranium have been leached of some of their uranium; samples with excess uranium have had uranium added at some time during the last 250,000 years, and samples in radioactivity balance (which includes most samples) were mineralized more than about 250,000 years ago.

The close stratigraphic association of analcite with the more highly mineralized zones suggests that analcitization and initial principal uranium mineralization were penecontemporaneous. Field relations in this and adjacent areas indicate that analcitization occurred in post-Miocene and pre-late Pleistocene time. Probably most uranium mineralization occurred during the late Miocene or early Pliocene time.

The studies in the Cave Hills area indicate that pyroclastic debris, principally in the Arikaree Formation (Miocene) and to a lesser extent in the Chadron Formation (Oligocene), was the source of uranium and that the uranium was leached from the formations by ground water. Circulation of uranium-bearing ground water subsequently resulted in the concentration of uranium in favorable host rocks. The probable sequence of Cenozoic events that resulted in the localization of uranium deposits in the Cave Hills area is summarized in the following paragraphs.

The Cave Hills area was the depositional site of coal-bearing rocks of Paleocene and probably of Eocene age. Sometime before deposition of the Oligocene rocks, the Paleocene rocks were jointed and gently folded; and erosion removed any Eocene rocks that may have been present as well as the upper part of the Fort Union Formation (Paleocene). The surface of erosion formed at that time coincides approximately with the highest parts of the Cave Hills. During this period of erosion, ground water circulated in some of the rocks of the Cave Hills area; but the depth and the extent to which weathering and erosion affected rocks in the Tongue River and Ludlow Members of the Fort Union Formation are unknown.

During Oligocene time and again during Miocene (and probably Pliocene) time, the erosion surface was buried by slightly uraniferous tuffaceous rocks. Uplift and erosion occurred after each of these periods of sedimentation, and during the Pleistocene as well. Some uranium may have been deposited by circulating ground water during each period of erosion, but most of it was deposited during the weathering and erosion of Miocene rocks. Most of the uraniferous rocks tested are in radioactive balance, which indicates that they have not been subjected to further mineralization within about the last 250,000 years.

The samples that are now in radioactive disequilibrium indicate that erosion and progressive lowering of the water table has continued, probably intermittently, since about the middle of the Pleistocene Epoch. During this time, uranium was leached from mineralized rocks and redeposited; probably little, if any, uranium was added to the Fort Union rocks, as most of the Oligocene and Miocene source rocks had been removed by erosion and the remnants depleted of most of their uranium by the beginning of late Pleistocene time. The formation of visible uranium minerals and, locally, the complete separation of uranium from its daughter products probably occurred in the late Pleistocene and Recent.

INTRODUCTION

LOCATION

The Cave Hills area, in the north-central part of Harding County at the northwest corner of South Dakota, comprises about 215 square miles and includes Tps. 20–22 N., Rs. 4 and 5 E. The east edge of the area is about 3 miles west of Ludlow, S. Dak. (fig. 1).

EARLIER INVESTIGATIONS

The general geology, coal geology, and structural geology of the Cave Hills area were described by Winchester and others (1916) and by Baker (1952). The occurrence of uranium in small quantities in the lignitic coal beds of this area was discussed by Wyant and Beroni (1950) and by Denson, Bachman, and Zeller (1959, p. 40–44). Denson, Bachman, and Zeller (1959, p. 30–40) first advocated the ash-leach hypothesis that is accepted here as the most probable explanation for the occurrence of uranium deposits in the Cave Hills area.

Gill and Moore (1955) investigated the carnotite deposits at Cedar Canyon in the southern part of the Slim Buttes area. Their conclusions on the origin of those deposits and the source of the uranium are very similar to those proposed in this report for the Cave Hills deposits. Preliminary results of the present investigation were reported by Kepferle and Chisholm (1956, 1955) and by Pipiringos, Chisholm, and Kepferle (1957). White (1958) studied samples from the uranium deposits in a coal bed in the South Riley Pass district and

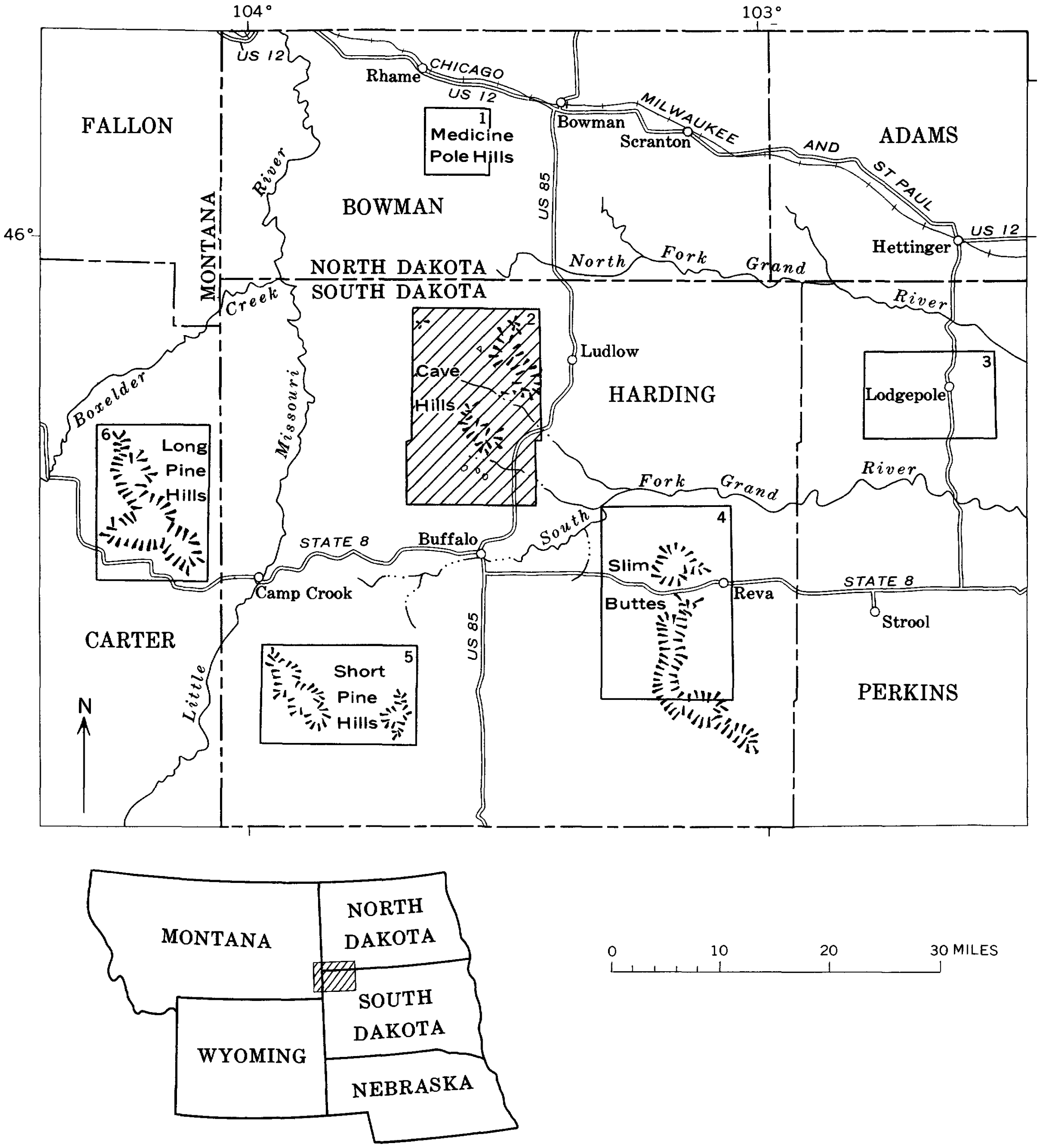

Figure 1.—Location of Cave Hills area in relation to adjacent areas of previous uranium investigations.

Principal references describing uranium occurrences in areas shown on index map (fig. 1)

Authors	Areas 1	2	3	4	5	6
Anonymous (1956)		×		×		
Burton (1955)		×		×	×	
Curtiss (1955, 1956)		×	×	×	×	
Denson, Bachman, and Zeller (1955a, b, 1959)	×	×	×	×		×
Denson and Gill (1956)		×		×		
_____ (1965)	×	×	×	×	×	×
Erickson (1956)		×				
Gill (1954a, b, 1955)		×		×	×	×
Gill and Denson (1955, 1956)				×		
Gill and Moore (1955)				×		
Gill, Zeller, and Schopf (1959)				×		
Kepferle and Chisholm (1955, 1956)		×				
King and Young (1956)		×		×		
Miller and Gill (1954)	×	×		×		
Petch (1955a, b)				×		
Pipiringos, Chisholm and Kepferle (1957)		×				
Schulte (1956)					×	
Stevenson (1956a, b)		×	×			
White (1958)		×		×		
Zeller (1955)				×		
Zeller and Schopf (1959)	×		×	×		

from a uranium occurrence in another coal bed in the southern part of the North Cave Hills. His findings are largely applicable to the other uranium occurrences in the area.

Denson and Gill (1965) summarized the results of investigations begun in 1950 concerning the structural and stratigraphic relations of uranium occurrences in eastern Montana and in adjacent parts of North and South Dakota. These and other general or reconnaissance reports on the uranium geology of the Cave Hills and surrounding areas that have been published are listed in the table with figure 1.

PURPOSE OF PRESENT INVESTIGATION

In the present investigation the uranium deposits in the Cave Hills area were studied to ascertain the origin of the deposits and the source of the uranium. The Cave Hills area is one of several areas in the northern Great Plains region in which uranium is known to occur in carbonaceous rocks of the Fort Union Formation. Information gathered in the Cave Hills area may be applicable to the study of many of the other deposits in the surrounding region. Deposits in the Cave Hills are particularly advantageous for study because the uranium is present in three types of rocks—coal, carbonaceous siltstone, and phosphatic claystone. Detailed information was gathered on the stratigraphic and structural relations of the outcropping rocks to aid in understanding the uranium deposits. Coal is potentially an important fuel resource in the area, aside from its importance as a host rock for uranium, and some information is presented on the quality and distribution of the most important coal beds; however, calculation of coal and uranium reserves is beyond the scope of this report.

METHODS OF WORK

Detailed geologic mapping and sampling of surface sections and auger cuttings were done in five selected areas in the North and South Cave Hills (pl. 1) in the summers of 1955 and 1956. The North and South Riley Pass districts, the Carbonate prospect, and the Lonesome Pete mine were mapped with planetable and alidade; the Traverse Ranch district was mapped by using aerial photographs.

In addition, miscellaneous samples were collected, stratigraphic sections were measured, and vertical control was established in areas adjacent to those studied in detail. The stratigraphic sections were measured with Brunton compass and tape measure, and the altitudes were established by planetable methods and single-base altimetry.

More than 700 lithologic samples were collected for the purposes of chemical, radioactivity, X-ray, and semiquantitative spectrographic analyses and microscopic examination. Most of the chemical and radioactivity analyses made during the course of the work are listed in tables at the end of this report under the heading "Analytical data." Results of the study of the semiquantitative spectrographic analyses and of the microscopic examination of samples will be given in subsequent reports in this Professional Paper series.

ACKNOWLEDGMENTS

Most of the fieldwork on the Cave Hills project was done by R. C. Kepferle and W. A. Chisholm in 1955, and much of the compilation of plates 1, 3, and 4 and figures 5, 7, and 11 was done by Kepferle. The remainder of the fieldwork was done in 1956 by G. N. Pipiringos and Chisholm, and much of the compilation of plates 2, 3, and 4 and figures 6–14 (not 13) was done by Chisholm. J. M. Link, H. R. Burrous, and R. H. Shubert assisted Pipiringos in the compilation of the other illustrations.

Fossil collections were identified by D. H. Dunkle of the U.S. National Museum, Washington, D.C., and by G. Edward Lewis of the U.S. Geological Survey, Denver, Colo. Proximate and ultimate analyses of coal were made at the U.S. Bureau of Mines, Central Experiment Station, Pittsburgh, Penn., by Roy F. Abernethy, chemist in charge. Radiometric and chemical analyses of samples were made by U.S. Geological Survey laboratories at Washington, D.C., and Denver, Colo. The Peter Kiewit Sons' Co. and the Homestake Mining Co. kindly furnished, and granted permission to publish, the uranium-assay and structure-contour data shown in figure 7.

Special thanks are due to J. N. Rosholt, Jr., who made the radiochemical analyses shown in table 5 and compiled figure 18 for this report. His many valuable suggestions are incorporated under the heading "Radioactivity equilibrium in samples."

GEOGRAPHY

SURFACE FEATURES

The most prominent topographic features of the Cave Hills area are several level-topped timbered buttes and ridges that rise 200–500 feet above the surrounding prairie. North and South Cave Hills, Table Mountain, and McKensie Butte are the largest of these features. All the flat-topped buttes are capped by thick beds of yellow, brown, and moderate pink sandstone that make steep cliffs 50–100 feet high. Locally, weathering of the sandstone results in a honeycombed surface and many small caves—from which the North and South Cave Hills derive their name. Altitudes within the map area range from about 3,620 feet above sea level, at the western tip of Table Mountain, to about 2,800 feet, at the point where Bull Creek leaves the east margin of the area.

DRAINAGE AND WATER SUPPLY

The Cave Hills area (pl. 1) is drained by southeastward-flowing tributaries of the South Fork of the Grand River and by northward- and northeastward-flowing tributaries of the Little Missouri River and of the North Fork of the Grand River (fig. 1). Natural springs are numerous in the upper part of the Ludlow or at the contact of the Ludlow and Tongue River Members of the Fort Union Formation along the flanks of Table Mountain and the North and South Cave Hills. The area also contains some water wells and artificial ponds (pl. 1).

CLIMATE AND VEGETATION

The Cave Hills are in a semiarid region that has an average annual rainfall of about 15 inches. Predominant vegetation includes willows, cottonwoods, and boxelders along streams and yellow pines on top of the buttes. Other vegetation includes grasses, scattered patches of sagebrush, and some "buffalo berry" and wild plum along streams and around springs.

SETTLEMENTS, ROADS, AND INDUSTRY

The Cave Hills area is populated only by the residents of small farms that occupy the valleys and the more level parts of the area. The nearest settlements are Ludlow and Buffalo, S. Dak., and Bowman, N. Dak. Ludlow (population 5 according to 1960 census) is about 3 miles east of the map area; Buffalo (population 652) is about 22 miles south of Ludlow; and Bowman (population 1,730), which has the nearest railway terminal, is about 24 miles north of Ludlow (fig. 1). These settlements are connected by U.S. Highway 85. Graded dirt roads leading west from Highway 85 in the vicinity of Ludlow and a graded road leading north from the highway at the north edge of Buffalo provide easy access to most of the area (pl. 1).

The buttes of Cave Hills and the peripheral slopes are a part of Custer National Forest and are used for cattle raising. Formerly the mining of coal and lignite was a major industry in the region, but lack of markets and problems of transportation have caused this industry to deteriorate in recent years.

LAND SURVEY

The base map was compiled from aerial photographs, and land control was established from Bureau of Land Management land plats. The Cave Hills and adjacent areas in northwest South Dakota were surveyed by the General Land Office in the period 1885–95. Most of the section corners were marked by notched stones, but some were marked by wooden stakes and pits. Probably most of the stones, if not the pits, are still in place and recognizable because many of the stones were recovered during field mapping. Magnetic declination was 14° E. in 1964.

Altitudes in the area were established by planetable and telescopic alidade in a traverse extending from the U.S. Coast and Geodetic Survey bench mark V–26 (alt. 2,975 ft; see pl. 1, sec. 35, T. 21 N., R. 5 E.) to the South Cave Hills and thence to the North Cave Hills. From these control points, altitudes were established on key beds by single-base altimetry. Spot checks revealed that most of the altimeter altitudes are within 5 feet of the planetable altitudes. The altitudes of the U.S. Coast and Geodetic Survey triangulation station "Cave" (shown in fig. 10) and that of "Sheep Mountain" (near the top of the small butte where stratigraphic section 18 was measured (pl. 1)) were not available from the U.S. Coast and Geodetic Survey as of 1962. An altitude of about 3,441 feet was established by planetable for "Cave" and an altitude of about 3,587 feet was established by altimeter for "Sheep Mountain."

STRATIGRAPHY

The rock units exposed in the Cave Hills are, in ascending order, the Hell Creek Formation of Late Cretaceous age, the Ludlow and Tongue River Members of the Fort Union Formation of Paleocene age, and the Chadron Formation of early Oligocene age. A small remnant of gravel on McKensie Butte in the southern part of the area is probably of Pleistocene age. (The remnant is too small to be shown on pl. 1.)

The rocks consist mostly of swamp and stream deposits but include brackish-water or near-shore-marine deposits. Their aggregate exposed thickness is about 800 feet. The general distribution of these rocks is shown on the geologic map (pl. 1); their lithology, stratigraphic position, and correlation are shown on the composite columnar section (fig. 2) and on the correlation chart (pl. 2).

The thickest coal beds in the area are in the Ludlow Member of the Fort Union Formation (fig. 2). The coal beds in the Tongue River Member for the most part are thin and impure.

Small quantities of uranium occur throughout the Fort Union Formation, but ore-grade concentrations (0.1 percent or more) are confined to the coal beds E and F of the Tongue River Member and to the Carbonate ore zone, coal zone C, and the Lonesome Pete ore zone of the Ludlow Member (pl. 2, fig. 2).

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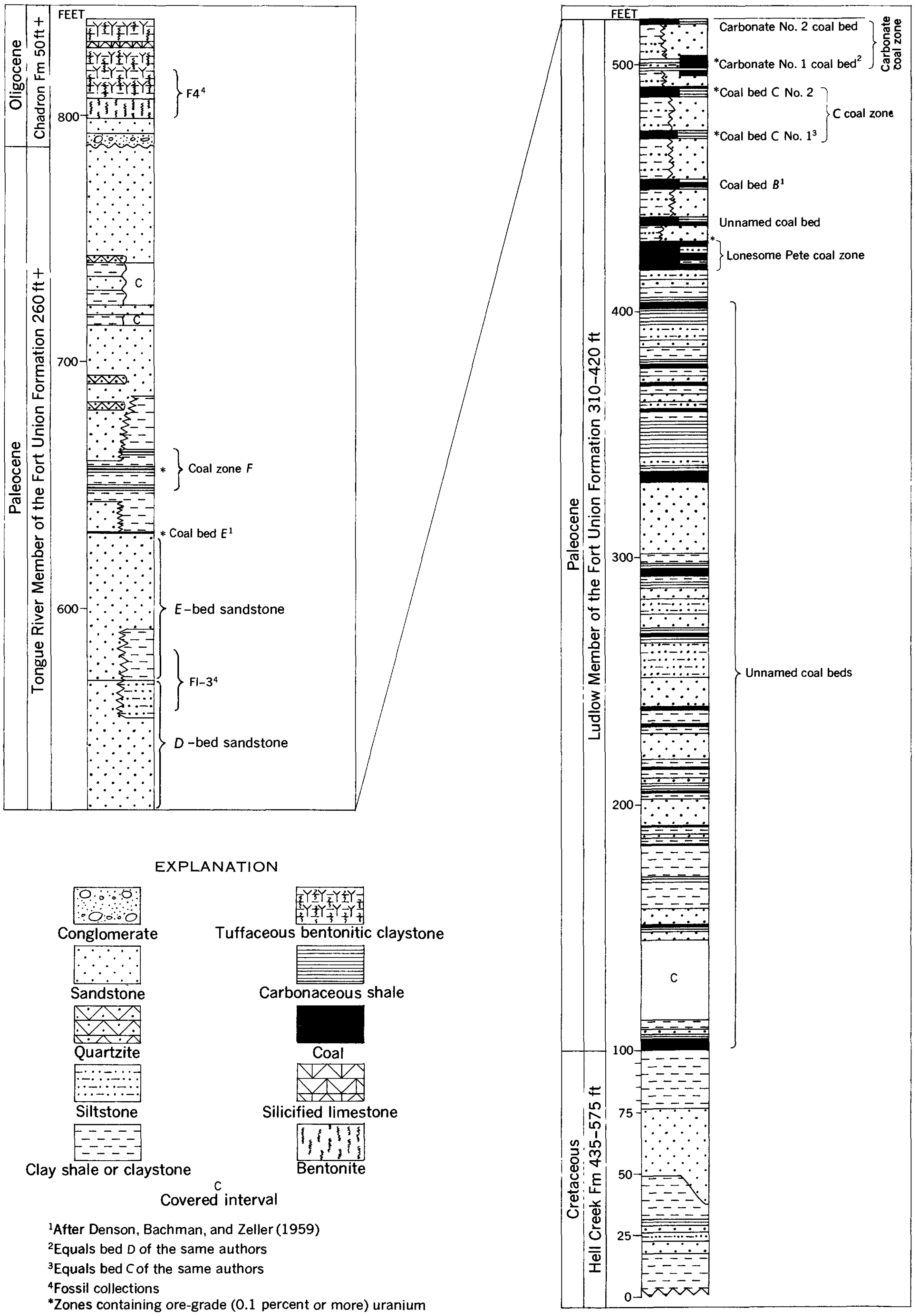


FIGURE 2.—Stratigraphic position of the principal coal beds in the Cave Hills area, Harding County, S. Dak.

CRETACEOUS ROCKS

HELL CREEK FORMATION

The Hell Creek Formation is the oldest formation in the area. Its age has been debated in the literature for many years but is now generally regarded as Late Cretaceous.

The Hell Creek, which crops out along stream valleys, consists chiefly of clay shale, carbonaceous shale, siltstone, and sandstone. Although the lower part is not exposed, logs of the holes drilled in the area suggest that the formation is probably more than 435 feet thick and that it may be as much as 575 feet thick. The uncertainty as to thickness stems partly from the difficulty of recognizing the Hell Creek-Ludlow contact, which is gradational and generally poorly exposed, being observable at only one locality in the area (fig. 3). In this report the contact is placed at the base of the lowest coal bed, as recommended by Brown (1952, p. 92). The difference of this interpretation from that of Winchester and others (1916) is shown in plate 2.

No fossils were found in the Hell Creek Formation by the authors. Plant- and vertebrate-fossil collections made by Winchester and others (1916) in nearby areas to the west, south, and east of the Cave Hills indicate that this formation is of Late Cretaceous age.

The Hell Creek Formation does not contain uranium deposits and was not studied in detail.

TERTIARY ROCKS

FORT UNION FORMATION

The age of the Fort Union Formation was very controversial in the past but is now generally accepted as being Paleocene. The Fort Union Formation is represented in the area of the present report by the Ludlow Member and the overlying Tongue River Member.

LUDLOW MEMBER

The Ludlow Member consists of gray clay shale, greenish-gray siltstone, gray fine-grained sandstone that weathers yellowish gray, and beds of coal. Some of the sandstone beds are well indurated locally by calcite and analcite, and they weather to slabby ledges. Analcite occurs sporadically throughout the member, either as cementing material or as discrete spheroidal crystal aggregates; but it is abundant only locally in the upper 90 feet. Ironstone concretions are common throughout the member. Nearly all the thicker, better fuel quality coal beds in the area are in the Ludlow Member.

The Ludlow Member crops out in most of the area. It forms smooth slopes around the buttes and rolling hills on the divides between the main streams. The member is well exposed at the southern end of the North Cave Hills (type area of the Ludlow) and in the southwestern part of the area (fig. 3). The Ludlow was measured at stratigraphic sections 8 and 19 (pls. 1, 2) where it is 420 and 310 feet thick, respectively.

The Ludlow Member conformably underlies the Tongue River Member. The contact is marked by a change from interbedded shale, siltstone, and sandstone in the Ludlow to a massive sandstone sequence at the base of the Tongue River. In many places this contact is expressed topographically as a change from slopes to cliffs as much as 110 feet high. In some places, as at locality 13, the upper part of the Ludlow also forms cliffs, and the contact is not as conspicuous as nearby at locality 12 (fig. 17). Fossils diagnostic of age were not collected from the Ludlow Member by the authors, but the Paleocene age of the member was established by Brown (1949, 1952).

Rocks of the Ludlow Member are interpreted, for the most part, as having been deposited in fluviatile and paludal environments. Locally the sandstone beds in the upper 90 feet of the Ludlow Member may be of marine or brackish-water origin, but some doubt exists as to the origin of the Lonesome Pete ore zone.

The Lonesome Pete ore zone is a phosphatic silty claystone bed less than 1 foot thick that occurs just above the Lonesome Pete coal bed along the west side of the South Cave Hills. That this zone may be of marine or brackish-water origin is indicated by the following observations:

1. The Ludlow is known to interfinger eastward with the marine Cannonball Member of the Fort Union Formation (Winchester and others, 1916, p. 15).
2. Phosphatic rocks, such as are present in the Ludlow, are generally considered to be indicative of marine or brackish-water environments of deposition (Pettijohn, 1957, p. 473–476).
3. The sandstone beds at the top of the Ludlow exposed on the west side of South Cave Hills are lithologically similar to marine or brackish-water sandstone beds at the base of the overlying Tongue River Member in nearby areas (Pipiringos, Chisholm, and Kepferle, 1957, p. 259; Kepferle and Chisholm, 1955, p. 246; and Kepferle and Chisholm, 1956, p. 251).

As opposed to rocks of a marine or brackish-water origin, samples of the Lonesome Pete ore zone contain abundant pollen from swamp-type plants among which *Taxodium* (bald cypress) is dominant. Microalgal forms that would suggest a brackish-water environment were looked for but not found (Estella Leopold, written commun., 1959).

TONGUE RIVER MEMBER

The Tongue River Member is the upper part of the Fort Union Formation in the Cave Hills area. Farther north in western North Dakota and eastern Montana the Tongue River Member is overlain by the Sentinel Butte Member of the Fort Union Formation (Brown, 1948) and is several hundred feet thick. In the Cave Hills area, pre-Oligocene erosion removed the upper part of the Tongue River Member. A maximum exposed thickness of Tongue River is 260 feet near the South Riley Pass district (NE¼ sec. 35, T. 22 N., R. 5 E., pl. 1). The top of the exposure is near triangulation station "Cave" (figs. 8, 10).

The Tongue River Member consists mostly of white, gray, buff, and tan massive, locally crossbedded, sandstone with thinner interbedded gray to green claystone and clayey siltstone. The sandstone forms cliffs and ledges; the claystone and siltstone form slopes and reentrants. Thin impure coal beds are present in a claystone and siltstone sequence 110–150 feet above the base of the member. The Tongue River contains ironstone concretions and abundant analcite. The ironstone concretions are concentrated principally in coal bed E and immediately overlying rocks; they are rare in the sandstone beds.

The basal 100 feet of the Tongue River Member consists of sandstone that generally forms steep vertical cliffs. In the South Cave Hills, in Table Mountain, and in the buttes and outliers in the southern and southwestern parts of the area, this basal sandstone sequence is homogeneous in appearance and lithology. In the North Cave Hills, however, the sequence is divisible into an upper and a lower part. The lower part, which is directly above coal bed D of Denson, Bachman, and Zeller (1959), is here called the D-bed sandstone for convenience of discussion; the upper part, which is directly below the coal bed E, is here called the E-bed sandstone (fig. 2). The D-bed sandstone is white and gray, whereas the E-bed sandstone is buff and tan. In the northern part of the North Cave Hills, the E-bed sandstone occurs in slopes, and the underlying D-bed sandstone is exposed in vertical cliffs. However, in the southern part of the North Cave Hills, the E-bed sandstone forms vertical cliffs, and the underlying D-bed sandstone forms slopes. Change in topographic expression of these beds is attributable principally to the fact that both of these sandstone units intertongue with and grade laterally into less resistant siltstone and shale beds.

Crossbedding and channelling occur in sandstone beds throughout the Tongue River Member, especially in the D-bed sandstone. Some of the crossbedding occurs in channels, but some occurs in original swales in the top of the E-bed sandstone. A cross section through one such swale can be seen on a spur between the two northward-trending branches of a valley on the east side of the North Cave Hills (west-central part of sec. 28, T. 22 N., R. 5 E.). Coal bed E, about 0.1 foot thick, lies along the bottom of the swale, which is at least 10 feet deep; and it is overlain by crossbedded sandstone. In a similar swale at a nearby locality (SW¼ NW¼ NW¼ sec. 21, T. 22 N., R. 5 E.), coal bed E is about

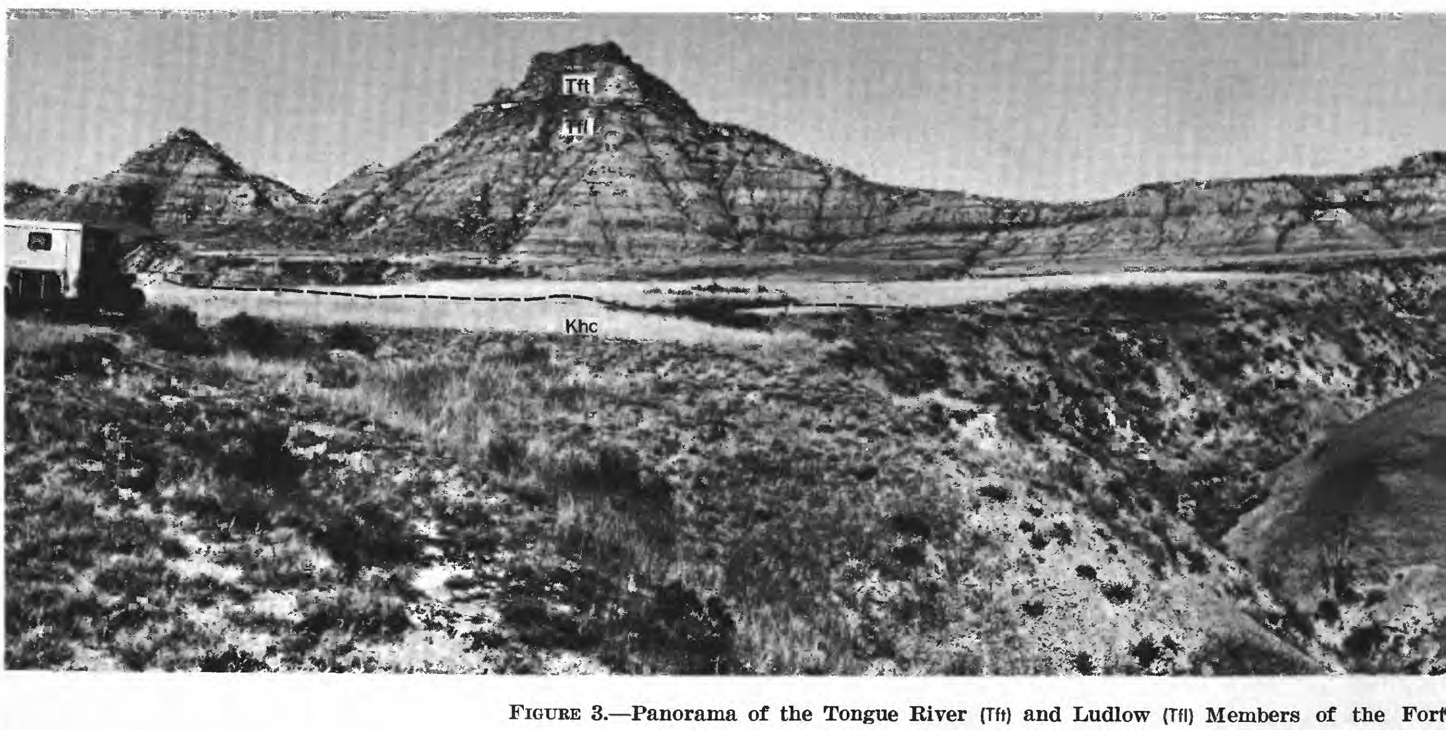


FIGURE 3.—Panorama of the Tongue River (Tft) and Ludlow (Tfl) Members of the Fort

4 feet thick, which is the greatest thickness for that bed recorded in the area.

Channels in the D-bed sandstone are well exposed along the north side of McKensie Butte. The channel-filling sandstone is crossbedded and locally contains blocks of sandstone similar to that into which the channel is cut. Some of these blocks are as much as 6 feet in diameter. Most of the channels are filled with reddish-pink and reddish-brown sandstone that contrasts with the generally buff, tan, yellow, gray, or white sandstone of the channel sides. The distribution of the reddish colors within these channels, as discussed in the following section, suggests that the channels and the crossbedded parts of the D- and E-bed sandstones have locally been more porous and permeable and that ground water has circulated more freely through the channels than in the more homogeneous main body of the sandstone.

The reddish-pink, reddish-brown, and yellow coloration of the sandstone beds in this member has erratic areal and vertical distribution. Most of these colors can be seen locally throughout the North Cave Hills, but they are especially conspicuous in the Riley Pass district and to the south along the west margin of the North Cave Hills. They are fairly common in McKensie Butte and in some of the outliers farther to the south and southwest, but they were not seen in Table Mountain and are rarely seen in the South Cave Hills. Samples of pink sandstone from about 4 feet below the base of the Tongue River Member (stratigraphic section 10, pl. 2), collected by N. M. Denson (oral commun., 1958), contain hematite.

The origin and significance of the zone of reddish-pink and associated colors in the Cave Hills area are similar to the origin and significance suggested for the same zone in adjacent areas by Gill (1962, p. 731), Denson and Gill (1965), and Gill and Denson (1955, p. 233). The zone, comprising oxidized rocks from Late Cretaceous to Paleocene age, lies beneath the pre-Oligocene erosion surface throughout northwestern South Dakota and the adjacent parts of Montana and North Dakota. The reddish sandstone beds of the Tongue River Member in the Cave Hills area probably were produced also as a result of oxidation of iron compounds by ground-water movement during pre-Oligocene erosion.

The distribution of red colors (hematite) apparently was controlled by the presence or absence of sandstone beds in the Tongue River Member near the pre-Oligocene erosion surface and by the relative permeability of individual sandstone beds. Where the upper part of the Tongue River is mainly sandstone, the reddish color extends stratigraphically down to or below coal bed E. Where this sequence contains claystone and shale, only the uppermost sandstone bed is red. Similarly, where channellike sandstone is present just above coal bed E, the red color extends much farther into the sandstone underlying coal bed E.

The 100-foot thick cliff-forming sequence of sandstone at the base of the Tongue River Member is the

tion and the Hell Creek Formation (Khc). Northeastward view of locality 19, plates 1 and 2.

principal aquifer in the area. Most of the natural springs in the Cave Hills area are at or near the base of this aquifer. Samples of two cores from the E-bed sandstone (USGS core hole and core hole R-45, fig 6) were tested for permeability. Both samples were from the top 1-foot interval directly below coal bed E. One sample had an effective porosity of 33.1 percent and a permeability to air of 1,305 millidarcies parallel to the bedding. The permeability perpendicular to the bedding was 705 millidarcies. The other sample had an effective porosity of 32.7 percent and a permeability of 1,222 millidarcies parallel to the bedding. The permeability perpendicular to the bedding was 0.8 millidarcies. The difference in permeability perpendicular to the bedding in the two samples is the result of "very tight, clayey partings which are parallel to the bedding plane" (R. F. Gantnier, U.S. Geol. Survey lab., written commun., 1956) in the second sample described. Other sandstone beds in the Tongue River Member and in the upper part of the Ludlow Member probably have similar permeability characteristics. Consequently, vertical movement of ground water would be relatively less than horizontal movement.

Analcite is abundant throughout the Tongue River Member and the upper 90 feet of the Ludlow Member, but it is scarce in stratigraphically lower beds. Analcite is most abundant in the aquifers and in rocks directly overlying and underlying them. It forms beds and lenses as much as 6 inches thick or constitutes the cementing material of the sandstone beds. Analcite, in the form of nucleated crystals, crystal aggregates, and, most commonly, as spherulites, is the most abundant mineral present in some of the coal beds (Schopf and Gray, written commun., Dec. 1956).

Schopf and Gray concluded that analcite was formed from ionic solutions that migrated into the coal after the organic matter had reached its present state of compaction. Accordingly, they regarded the presence of analcite spherulites as an indication of groundwater circulation in coal beds. Study of thin sections during the present work also indicates movement of analcite-forming solutions in post-Paleocene time. Analcite crystals were observed in ash from burned coal beds and as fracture fillings in ironstone concretions. The burned coal beds and the fractures in concretions probably resulted from exposure to surface or near-surface oxidizing conditions during the erosion that preceded the deposition of Oligocene rocks; the analcite probably formed after the Oligocene rocks were deposited.

Two, and possibly three, ledge-forming quartzite beds are present in a zone from 60 to about 100 feet above the top of the E-bed sandstone. These quartzite beds are from 0.5 to 3 feet thick and contain tubular cavities that are probably fossil root holes. They are interpreted as having had the same origin as similar quartzite beds in the Fort Union Formation of western North Dakota (Brown, 1948, p. 1269). Brown stated,

> the megascopic fossilized plant debris in these beds includes chiefly roots and stumps of trees and suggests strongly that the beds are silicified soils or swamp mucks. As such, if silicifying conditions had been favorable, the top or bottom of every incipient coal seam might have been a likely possibility for the development of such a bed.

The quartzite beds have an erratic areal distribution. They occur on Table Mountain, in the Riley Pass district of the North Cave Hills, and as the capping rocks on a number of buttes north and east of the North Cave Hills. The erratic distribution of these quartzite beds is attributable to change in lithology and degree of cementation. In the North Riley Pass district, a quartzite bed can be traced laterally into a poorly cemented soft layer of silica-kaolinite flour that contains abundant analcite spherulites. Spherulites occur only in the silica-kaolinite flour. This flourlike rock is well exposed in the west-central part of the North Riley Pass district (fig. 6 near the top of stratigraphic section 5, just below the 3,360-foot contour south of drill hole J-16). On the south side of a low hill north of Anarchist Butte in the northeast corner of Harding County, a quartzite bed (probably correlative with quartzite beds capping the buttes in the vicinity of Ludlow and with the bed shown at the top of stratigraphic section 8, pl. 2) was traced laterally into a poorly consolidated quartz sandstone that directly underlies a thin coal bed. The matrix consists principally of kaolinite and minor amounts of quartz. No analcite is present. An explanation for the lateral change in lithology and cementation is hypothetical; but the possibility exists, at least in the North Riley Pass occurrence described above, that the changes were effected by the same solutions that formed the analcite spherulites now found in the silica flour. At Anarchist butte, however, the reason for gradation from quartzite to poorly consolidated sand in a kaolinite matrix is not readily apparent.

Vertebrate-fossil collections (table 1, F1–F3) from 40 to 65 feet above the base of the Tongue River Member do not negate the Paleocene age of the Tongue River but do indicate that this part of the member was deposited in a marine or brackish-water environment (fig. 2; table 1), whereas the shale and siltstone beds probably were deposited in near-shore swamps and streams. This suggests a close relation between the Tongue River Member and the marine Cannonball Member of the Fort Union Formation. The latter is known to have extended at least as far westward as the northeast corner

TABLE 1.—*Fossils collected from the Cave Hills area, Harding County, S. Dak.*

[Collected in 1955 by R. C. Kepferle and W. A. Chisholm]

Collection	Locality			Stratigraphic position above base, in feet (fig. 2, pl. 2)	Fossil identification	Age
	Sec.	T. N.	R. E.			
					Chadron Formation [Fossil identifications by G. E. Lewis, U.S. Geol. Survey (written commun., May 14, 1958)]	
F4	SE¼NW¼NW¼ 5	20	5	10–30	*Mesohippus* sp. brontothere, gen. and sp. undetermined (?)*Leptomeryx* sp.	Early Oligocene.
					Tongue River Member of the Fort Union Formation [Fossil identifications by D. H. Dunkle, U.S. Natl. Mus. (written commun., May 2, 1956)]	
F2	NW¼NW¼NE¼ 32	21	5	65	Selachii: asterospondylic vertebral centrum very possibly pertaining to one of the isuroid (porbeagle) families of sharks.	Late Cretaceous through Eocene.
F1	SE¼SE¼SW¼ 10	22	5	50	*Odontaspis macrota* var. *striata* Winkler; Teleostei: indeterminate vertebrae, skull bones, and scales.	Paleocene through Eocene.
F3	SE¼SE¼SW¼ 12	21	5	40	*Lamna obliqua* Agassiz; Crocodilia: Indeterminate dermal scute.	Late Cretaceous through Eocene.

of Harding County, South Dakota. Perhaps the Cannonball shoreline at times extended as far west as the west side of the North Cave Hills where it had a northward trend, because the lateral change eastward from siltstone and shale to sandstone occurs within a few hundred feet in that area. Stratigraphic equivalents of the D- and E-bed sandstones persist eastward for many miles beyond the map area where they occur as outliers capping isolated buttes. The basal sandstone sequence of the Tongue River Member in the Cave Hills area may represent a beach-and-bar sandstone phase of the Cannonball sea.

CHADRON FORMATION

The small remnants of the Chadron Formation that cap the highest buttes in the Cave Hills area are of early Oligocene age. The largest and thickest remnant, which caps the south-central part of the South Cave Hills (fig. 4), is about 50 feet thick and consists of conglomeratic very coarse grained sandstone, tuffaceous sandstone and claystone, bentonite, tuffaceous bentonitic claystone, and silicified limestone. Other outliers of the Chadron in the west-central part of the North Cave Hills are lithologically similar except for the smallest and thinnest remnant, found at the Carbonate prospect (stratigraphic section 11, Pl. 2), which consists of a residuum of limestone 2 feet thick and silicified wood of a type common to the Chadron of adjacent areas. Early Oligocene fossils collected from South Cave Hills are listed in table 1.

Within the area of this report, the surface on which the Chadron was deposited has a relief of about 70 feet. Altitudes around the base of the large outlier in the South Cave Hills range from about 3,370 to 3,380 feet and average about 3,375 feet above sea level. The residuum at the Carbonate prospect is at an altitude of about 3,400 feet, and the northernmost small outlier in the North Cave Hills is about 3,430 feet above sea level.

Remnants of rocks of late Oligocene, Miocene, and Pliocene age occur in some of the surrounding areas. Probably, rocks of similar age were also deposited in the Cave Hills area but have since been removed by Quaternary erosion.

QUATERNARY(?) ROCKS

Near one of the highest parts of McKensie Butte (pl. 1, NW¼SW¼ sec. 20, T. 20 N., R. 5 E.), a poorly consolidated conglomerate is exposed in a prospect pit to a depth of about 3 feet. Because of the grass cover, the areal extent and the total thickness of the conglomerate could not be ascertained. The conglomerate appears not to exceed 100 quare feet in area and to be not more than 4 feet thick. The coarser constituents of the conglomerate are pebbles of quartzite, chalcedony, silicified wood, silicified limestone, and tuffaceous sandstone. These rocks were probably derived from the Arikaree Formation of adjacent areas (N. M. Denson and J. R. Gill, oral commun., 1956), and probably are a remnant of a Pleistocene terrace deposit.

STRUCTURE

The Cave Hills area lies on the southwest flank of the Williston basin. The area is very little deformed; there are no faults or sharp folds, although joints are conspicuous in the Paleocene rocks. The rocks dip gently northeastward at an average rate of 25 feet per mile into the Williston basin and have only slight local reversals of dip. These features, shown on plate 1 by structure contours at 25-foot intervals, are generally in agreement with the work of Winchester and others (1916, p. 37), Rothrock (1937, p. 33), and Baker (1952, geologic map) as well as with the previous structure map of this area by Kepferle and Chisholm (1955, p. 241).

As a basis for constructing the structure contours, altitudes were established on the E-bed sandstone throughout the North Cave Hills and on the Carbonate No. 1 coal bed or its equivalent throughout the rest of the area. All altitudes were then converted to the same datum—the base of the Tongue River Member. Well data were used in compilation of the structure-contour map of the southeastern and west-central parts of the area where the E-bed sandstone and the Carbonate No. 1 coal bed have been eroded. A thick carbonaceous shale near the middle of the Ludlow Member (at the bottom of stratigraphic section 10, pl. 2) was used to correlate between the North and South Cave Hills. Although the sequence is predominantly carbonaceous shale in the South Cave Hills, it is definitely recognizable in stratigraphic sections in the North Cave Hills (section 9, pl. 2) where it is predominantly carbonaceous siltstone. This correlation allowed conversion of structure control points, established on various horizons throughout the area, to a single datum plane—the Tongue River-Ludlow contact.

Joints do not occur in the Chadron Formation, but in the Fort Union Formation the more firmly cemented sandstone beds of the Ludlow Member and the massive well-cemented sandstone beds of the Tongue River Member show two conspicuous sets of joints (fig. 8). The joint pattern correlates well with direction of stream flow (fig. 5). The trend of the most conspicuous joint system approximates the trend of the syncline in the South Cave Hills, suggesting that the folding of the syncline and the formation of the joints may have been contemporaneous.

A system of sandstone dikes is exposed in prospect pits at the Carbonate prospect (fig. 16, pl. 3*C*). These dikes thin and pinch out upward. The thickest dike, about 6 inches thick, is in the north pit. The dikes range in vertical length from 2 to 5 feet, and they apparently originate in the sandstone bed directly beneath the carbonaceous siltstone bed in which they occur (lateral equivalent of the Carbonate No. 1 coal). In plan view the dikes are essentially parallel to nearby joints (pl. 3*c*) and probably were intruded along former joint planes or along planes of weakness related to the joints. Intrusion of the sandstone dikes probably occurred after consolidation of the Paleocene sequence in general but, in particular, before the underlying source bed was com-

TABLE 2.—*Analyses of coal samples from the Fort Union Formation, Cave Hills area, Harding County, S. Dak.*

[Analyses by U.S. Bur. Mines. Form of analysis: A, as received; B, air dried; C, moisture free; D, moisture and ash free]

Laboratory	Source	Member	Coal bed	Feet		Form of analysis	Proximate			Ultimate					Forms of sulfur			Heating value, Btu	ASTM coal symbol and rank [2]
				Thickness	Depth		Moisture	Volatile matter [1]	Fixed carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur	Sulfate	Pyritic	Organic		
F-5061	Prospect pit in the SE¼SW¼NW¼ sec. 21, T. 22 N., R. 5 E.	Tongue River.	E	3.6	17–20.6	A	41.6	23.1	24.9	10.4	7.0	33.4	0.4	47.7	1.1	0.12	0.26	0.73	5,680	(53–64)
						C	-----	39.5	42.7	17.8	4.1	57.1	.8	18.3	1.9	.19	.45	1.25	9,720	Lignite.
						D	-----	48.1	51.9	-----	4.9	69.4	.9	22.5	2.3	.23	.55	1.52	11,810	
E-83320	USGS core hole in the SE¼NW¼NW¼ sec. 26, T. 22 N., R. 5 E.	do	F	.45	31.00–31.45	A	46.0	16.7	20.2	17.1	-----	-----	-----	-----	0.5	.04	.27	.21	4,170	(57–51)
						C	-----	30.9	37.4	31.7	-----	-----	-----	-----	1.0	.07	.50	.39	7,720	Lignite.
						D	-----	45.3	54.7	-----	-----	-----	-----	-----	1.4	.10	.74	.58	11,300	
E-83321	do	do	F	.3	32.42–32.72	A	41.9	20.1	21.0	17.0	-----	-----	-----	-----	.8	.02	.24	.49	4,940	(53–61)
						C	-----	34.6	36.1	29.3	-----	-----	-----	-----	1.3	.03	.42	.84	8,510	Lignite.
						D	-----	48.9	51.1	-----	-----	-----	-----	-----	1.8	.05	.59	1.19	12,030	
E-83322	do	do	F	.27	32.88–33.15	A	41.4	22.8	28.0	7.8	7.2	34.9	.4	48.5	1.2	.03	.47	.71	6,240	(56–68)
						C	-----	38.9	47.8	13.3	4.4	59.6	.7	19.9	2.1	.05	.80	1.21	10,650	Lignite.
						D	-----	44.9	55.1	-----	5.0	68.7	.8	23.1	2.4	.06	.92	1.40	12,290	
E-83323	do	do	F	.52	33.15–33.67	A	33.9	17.4	13.8	34.9	-----	-----	-----	-----	1.0	.03	.53	.45	3,530	(50–57)
						C	-----	26.3	21.0	52.7	-----	-----	-----	-----	1.5	.05	.81	.67	5,340	Lignite.
						D	-----	55.5	44.5	-----	-----	-----	-----	-----	3.2	.11	1.71	1.42	11,280	
E-83324	do	do	F	.78	33.67–34.45	A	42.3	24.4	24.1	9.2	7.3	34.3	.4	48.2	.6	.01	.05	.57	5,980	(51–67)
						C	-----	42.3	41.7	16.0	4.5	59.4	.7	18.3	1.1	.02	.08	.99	10,360	Lignite.
						D	-----	50.4	49.6	-----	5.4	70.7	.8	21.8	1.3	.03	.10	1.18	12,340	
E-83325	do	do	E	.3	48.80–49.10	A	49.2	12.9	4.8	33.1	-----	-----	-----	-----	.3	.04	.10	.14	-------	(33)
						C	-----	25.4	9.5	65.1	-----	-----	-----	-----	.6	.09	.21	.27	-------	
E-83326	do	do	E	.23	49.97–50.20	A	46.9	18.1	9.8	25.2	-----	-----	-----	-----	.3	.07	.13	.13	-------	(39)
						C	-----	34.1	18.4	47.5	-----	-----	-----	-----	.6	.13	.25	.24	-------	
						D	-----	64.9	35.1	-----	-----	-----	-----	-----	1.2	.25	.48	.45	-------	
13221	Hilton mine in the NW¼SE¼ sec. 6, T. 20 N., R. 5 E.[3]	Ludlow	Lonesome Pete.	9.2	------------	A	39.8	25.3	23.8	11.1	-----	-----	-----	-----	.96	-----	-----	-----	5,480	(50–62)
						B	10.2	37.8	35.5	16.5	-----	-----	-----	-----	1.44	-----	-----	-----	8,110	Lignite.
						C	-----	42.0	39.6	18.4	-----	-----	-----	-----	1.59	-----	-----	-----	9,110	
						D	-----	51.6	48.4	-----	-----	-----	-----	-----	1.95	-----	-----	-----	11,160	

[1] Determined by modified method.

[2] Fixed carbon on the dry basis (to the nearest whole percent) and Btu on the moist basis (in hundreds of Btu, to the nearest hundred), respectively, calculated on the mineral-matter-free basis. Rank was determined as specified by the American Society for Testing Materials (1939).

[3] From Winchester and others (1916, p. 42, 67).

pletely consolidated and penecontemporaneously with the formation of the joints. The absence of joints in the Chadron Formation indicates that the joints and folds in the Paleocene rocks probably formed before Oligocene time. The drainage pattern of the major streams probably was established during the period of pre-Oligocene erosion that followed the folding and jointing and preceded the deposition of the Chadron Formation. After uplift and erosion of the Oligocene and younger rocks, the pre-Oligocene stream valleys were exhumed and reoccupied by streams.

COAL

The stratigraphic position and thickness of the coal beds are shown in figure 2. Correlation of these beds and the lithology of the enclosing rocks are shown on plate 2. The coal beds of both members of the Fort Union Formation in the Cave Hills area are of lignite rank (table 2). The coal beds of the Ludlow Member are generally more than 2½ feet thick and are fairly free of impurities. Analyses of coal in the Ludlow, other than those in table 2, are given by Erickson (1956) and Stevenson (1956a). Most of the coal beds in the Tongue River Member are less than 1 foot thick and are impure and interbedded with lignitic silty shale.

COAL BEDS IN THE LUDLOW MEMBER

Coal beds in the Ludlow Member have not been mapped throughout the Cave Hills area; however, information is available on their correlation, thickness, and physical and chemical properties. A coal bed that crops out over a considerable area along both sides of Bull Creek in T. 21 N., R. 5 E., at the base of the Ludlow (stratigraphic section 8) was considered by Winchester and others (1916, p. 68) to be "* * * about 50 or 60 feet below the base of the Ludlow lignitic member * * *." In the present report, this bed, which is about 3–6 feet thick, is considered to be the basal bed of the Ludlow Member.

Information on coal beds in the Ludlow Member above its base and below the Lonesome Pete coal zone is meager. Some of these coal beds are as much as 5 feet thick, and analyses of samples collected from stratigraphic localities 8, 11, and 15 (pl. 1) indicate that their ash contents range from 15 to 76 percent and average about 34 percent (table 7).

The stratigraphically lowest coal bed studied in this investigation is the Lonesome Pete coal bed, which attains its maximum thickness of 21 feet at the Lonesome Pete mine (pl. 4). Elsewhere it splits into two or more beds and constitutes the Lonesome Pete coal zone (pl. 2). The coal bed formerly mined at the Hilton mine is correlative with the Lonesome Pete coal bed.

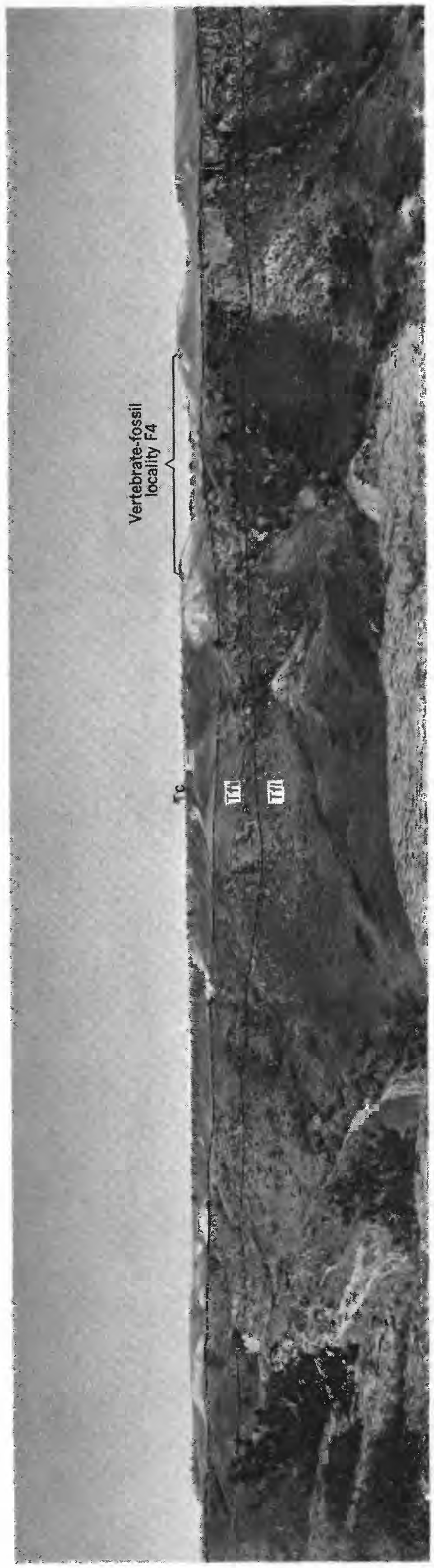


FIGURE 4.—The Chadron Formation (Tc), and the Tongue River (Tft) and Ludlow (Tfl) Members of Fort Union Formation, South Cave Hills. Eastward view of vertebrate fossil locality F4 (table 1).

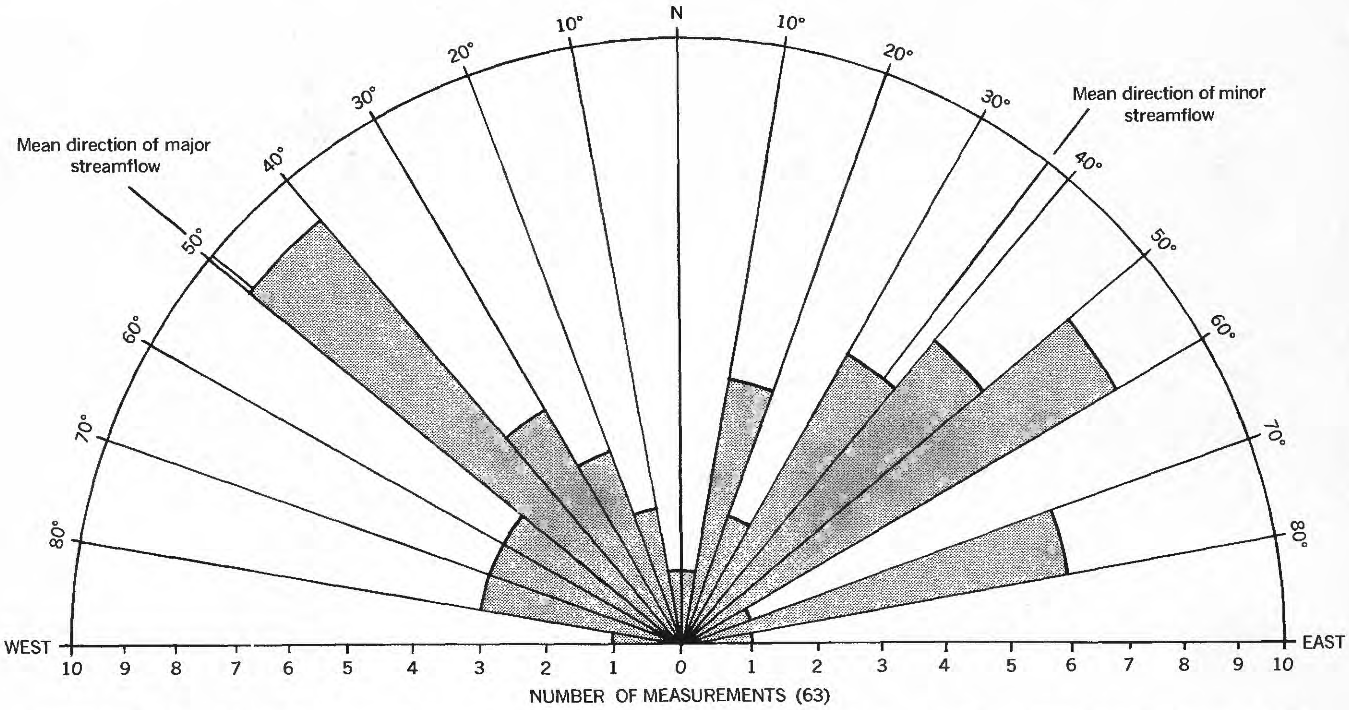


FIGURE 5.—Strike of vertical joints in the Tongue River Member of the Fort Union Formation, North Cave Hills, Harding County, S. Dak.

According to Winchester and others (1916, p. 67), the coal at the Hilton mine has a total thickness of about 14 feet and contains three shale partings 0.5–2 feet thick; the lignite itself is only about 9 feet thick. This bed, or its carbonaceous shale equivalents, is known to extend from the southwestern part of the area northeastward to the south end of the North Cave Hills. It was not recognized in the areas to the north and northwest, but it is probably present. The ash content of the Lonesome Pete coal zone ranges from 11 to 71 percent and averages about 33 percent (tables 7, 9). The interval from the top of the Lonesome Pete coal bed to the top of the next overlying coal bed (B) ranges from 25 to 32 feet in thickness and averages about 28 feet.

The next overlying coal bed of the Ludlow Member is coal bed B (named by Denson, Bachman, and Zeller, 1959). The maximum observed thickness of coal bed B is at the south end of the North Cave Hills (stratigraphic section 8, pls. 1, 2), where it consists of an upper coal bed 5 feet thick separated by 5 feet of carbonaceous shale and clayey siltstone from a lower unnamed coal bed 1 foot thick. The lower bed can be traced westward for about 1 mile (stratigraphic section 9, pls. 1, 2) but is not present elsewhere. Coal bed B occurs throughout most of the South Cave Hills, but it was not recognized in the areas to the south or southwest. According to Denson, Bachman, and Zeller (1959, pls. 4, 6), it is widespread in the North Cave Hills and Table Mountain areas where it ranges in thickness from about 3 to 10 feet. The ash content of coal bed B ranges from 11 to 75 percent and averages 33 percent (table 7). The interval from the top of coal bed B to the top of the next overlying coal bed (C No. 1) ranges from 14 to 26 feet and averages 20 feet.

Coal zone C (named by Denson, Bachman, and Zeller, 1959) occurs throughout the area at about 30 feet below the top of the Ludlow. Generally it consists of a single lignitic coal bed as much as 6 feet thick, but, locally, as in the northern part of the North Cave Hills, it includes both a lower bed split by two or three carbonaceous shale partings and an upper bed as much as 4 feet thick. The lower bed is designated coal bed C No. 1, and the upper bed is called coal bed C No. 2. The two beds constitute coal zone C and are separated by an interval ranging in thickness from 15 to 25 feet. The ash content of coal in the coal zone C ranges from 15 to 70 percent and averages about 36 percent (tables 6, 7).

The coal zone at the top of the Ludlow Member at the Carbonate prospect, here named the Carbonate coal zone, consists of three coal beds. The uppermost one, Carbonate No. 2, is about 1 foot thick and is about 4 feet below the Tongue River-Ludlow contact. Carbonate No. 1 is about 14 feet below Carbonate No. 2, and the third unnamed bed of the zone is about 7 feet below Carbonate No. 1.

The Carbonate No. 2 coal bed occurs only in the vicinity of the South Cave Hills and McKensie Butte. Locally, in the southern part of the area (stratigraphic sections 16 and 18, pls, 1, 2) it consists of carbonaceous shale. The Carbonate No. 1 coal bed is about 20 feet below the top of the Ludlow and occurs in Table Mountain, the South Cave Hills, and McKensie Butte. It has not been recognized in the North Cave Hills. It is generally a purplish-black-weathering carbonaceous siltstone, but locally it contains coal (pl. 2). The uranium deposit at the Carbonate prospect is in the Carbonate No. 1 coal bed (see p. A22). This bed is probably correlative with coal bed D of Denson, Bachman, and Zeller (1959) in the Table Mountain area and in the South Cave Hills.

The unnamed coal bed at the base of the Carbonate coal zone merges with the Carbonate No. 1 bed in the vicinity of the Lonesome Pete mine (stratigraphic section 12, pls. 2, 4; see also fig. 17). It has a distribution similar to that of the Carbonate No. 1 bed and consists of a coal or carbonaceous shale bed between the Carbonate No. 1 and C No. 1 coal beds (sections 14, 18, and 19, pl. 2). It has not been recognized in the North Cave Hills or in Table Mountain, but it may be correlative with coal bed C No. 2 in the north-central part of the area (stratigraphic sections 2 and 3, pl. 2). The ash content of the Carbonate coal zone, excluding the carbonaceous siltstone facies of the Carbonate No. 1 bed, ranges from 24 to 92 percent and averages about 45 percent (tables 7, 9).

COAL BEDS IN THE TONGUE RIVER MEMBER

Only in the North Cave Hills area does the Tongue River Member contain coal beds E and F (fig. 2). These beds consist of thinly interbedded lignite, impure lignite, and lignitic silty shale. They are generally less than 1 foot thick; but, locally, as in the vicinity of the Traverse Ranch (fig. 15, NW¼ sec. 21, T. 22 N., R. 5 E.), bed E reaches a thickness of about 4 feet, and its quality is comparable to that of the coal beds in the Ludlow Member. (See analyses F-5061 and 13221, table 2.) The interval from the top of coal bed E to the top of coal zone F averages about 30 feet in thickness (fig. 2).

Analyses, made by the U.S. Bureau of Mines, of core samples from coal beds E and F (lab. Nos. E–83320 to E–83326, table 2) in the U.S. Geological Survey drill hole in the North Riley Pass district (fig. 6) indicate that this coal is generally similar in composition and heating value to coal in the coal bed E and coal zone F in the Traverse Ranch district but that the coal in coal bed E in the Riley Pass district is of considerably poorer quality. The ash contents of coal beds E and F range from 11 to 94 percent and average about 51 percent (tables 6, 7).

URANIUM

DISTRIBUTION AND SIZE OF THE DEPOSITS

Uranium has been found at several places in the Cave Hills area. The main deposits are in the Traverse Ranch, North Riley Pass, and South Riley Pass districts, all of which are in the North Cave Hills, and at the Lonesome Pete mine and the Carbonate prospect, which are in the western and eastern parts of the South Cave Hills, respectively. For convenience of discussion, rock containing 0.1 percent or more uranium in quantities of many tons shall be termed a uranium "deposit." All other uranium concentrations, which may locally contain as much as 0.1 percent uranium but in quantities of only a few tons or less, shall be termed uranium "occurrences."

The largest and richest deposits are in coal bed E in the Tongue River Member and in a phosphatic claystone bed just above the Lonesome Pete coal zone in the Ludlow Member of the Fort Union Formation. Known uranium deposits in coal bed E total about 200 acres, and those in the phosphatic claystone total about 50 acres.

In addition, fairly rich concentrations of uranium of much smaller areal extent occur fairly commonly in coal zone F in the Tongue River Member and in coal zone C and the carbonaceous siltstone facies of the Carbonate No. 1 coal bed in the Ludlow Member.

The richest sample of uranium-bearing rock collected in the area was from coal from coal bed E in the South Riley Pass district; it contained 2.76 percent uranium. Several samples from nearby parts of the same coal bed and from coal in zone C in the Traverse Ranch and South Riley Pass districts contained almost as much uranium. For the most part, however, the average grade of the larger deposits is less than 0.5 percent uranium. Minor occurrences of uranium have been found in other coal beds of the Ludlow Member, but none contained more than 0.085 percent uranium.

MINERALOGY

Most of the uranium in the host rocks of the Cave Hills area is probably in the form of organouranium complexes (Breger, Deul, and Rubinstein, 1955, p. 226). Uranium in this form is not visible and can be detected only be radiometric instruments or by chemical analyses.

Relatively minor amounts of uranium occur as visible films and scaly masses of yellowish uranium minerals encrusting cleat faces of the coal or more rarely as small concretionary mineral aggregates. The uranium minerals that occur in the area are, in order of decreasing abundance:

Metatorbernite $Cu(UO_2)_2(PO_4)_2 \cdot nH_2O$ [n=4–8]
Meta-autunite $Ca(UO_2)_2(PO_4)_2 \cdot nH_2O$ [n=2½–6½]
Metazeunerite $Cu(UO_2)_2(AsO_4)_2 \cdot 8H_2O$
Saléeite $Mg(UO_2)_2(PO_4)_2 \cdot 8\text{–}10H_2O$
Sodium autunite $Na_2(UO_2)_2(PO_4)_2 \cdot 8H_2O$

These minerals were identified by A. J. Gude III, of the U.S. Geological Survey laboratory, Denver, Colo., with the exception of sodium autunite which was identified by E. W. White, of the Pennsylvania State University, Department of Mineralogy. The mineral names and formulas are from Frondel and Fleischer (1955, p. 184–188) and from White (1958, p. 37). X-ray-diffraction, crystallographic, and other data were given by Frondel (1958) and by White (1958).

URANIUM MINING

Prospecting for uranium in the Cave Hills area began about 1950. Potential commercial deposits were reported in 1954 when autunite-bearing lignite was discovered in coal bed E of the Riley Pass district. Shortly afterward, uranium deposits were discovered in carbonaceous siltstone beds at the Carbonate prospect and in phosphatic claystone beds at the Lonesome Pete mine. Later, in 1955, sporadic occurrences were reported from coal zone C along the west margin of the North Cave Hills. Prospecting of this zone was concentrated in the Traverse Ranch district (fig. 15). Abandoned workings along the southeastern slopes of Table Mountain and in the isolated buttes near the southern tip of Table Mountain indicate that some uranium concentration was also found in a zone that is probably correlative with coal zone C of that area. From 1954 to 1956 (when the area was last visited by the authors) several truckloads of mineralized rock was mined, mostly for assaying; and several acres was prospected by trenching, stripping, and shallow core drilling.

LOCALIZATION OF URANIUM

The localization of uranium in the Cave Hills area requires (in addition to the presence of suitable host rocks) access to the host rocks for circulating uranium-bearing ground water. General ground-water movement depends on the structural attitude, whereas local ground-water movement depends on differential permeability of aquifers. Structural and stratigraphic controls are closely interdependent, and it is difficult to say which predominates.

Inspection of plate 1 shows that most of the districts containing relatively rich uranium concentrations are on the flanks of synclines, but smaller folds revealed by 5-foot contours in the North and South Riley Pass districts (figs. 6, 10, 12, 14) show no consistent relations to uranium concentration. Uranium deposits occur near crests of anticlines in the western and eastern parts of the South Riley Pass district (figs. 12, 14); but they are also found in the troughs of synclines in the western (fig. 12), in the central (fig. 13), and eastern (fig. 14) parts of the district.

In the Traverse Ranch district, the principal structural feature is the depression whose lowest part is outlined by the 3,175-foot contour (pl. 1, fig. 15). This district contains more springs per unit area than any other part of the Cave Hills. Data on plate 1, which shows all the water-sample localities, suggest that the next largest concentration of springs, on the north side of the North Riley pass district, occurs in another part of the structural depression. Most of the uranium occurrences in the Traverse Ranch district lie within or near this structural depression; but, inasmuch as the relation to structure of other such uranium occurrences along the west margin of the North Cave Hills is unknown, this relation may be coincidental.

The close relations of uranium deposits to the structure and permeability of enclosing rocks are illustrated in sections A–A′ and B–B′ of the central part of the South Riley Pass district (fig. 13). Section A–A′ shows uranium deposits in coal that are not only underlain by the E-bed sandstone but also are bounded laterally by sandstone bodies within the coal bed itself. One of the sandstone bodies interfingers with and grades laterally into the coal. The other sandstone body is a well-defined ridge that is in sharp contact with the coal. The ridge was formed prior to the deposition of the coal, probably by current action, and may have variable permeability that allowed uranium-bearing solutions to flow in restricted directions. The permeability-barrier effect of the sandstone ridge on the distribution of the uranium deposits is well illustrated in the central part of the South Riley Pass district (loc. 23, fig. 13) where the uranium deposits end abruptly against the south side of the ridge. For another part of the same district (near locs. 61, 68), section B–B′ shows that the uranium content of the coal ranges from less than 0.1 percent where it underlies sandstone to as much as 1 percent where it underlies shale. These relations suggest that, at this locality, uranium-bearing solutions moving laterally through permeable sandstone met impermeable shale and were forced to pass through the coal bed itself; thus the coal was more intensively mineralized here than where the solutions were free to pass through the permeable sandstone overburden.

Another example of the close interdependence of structural and permeability controls on the localization of uranium concentrations is found at the Carbonate prospect. This prospect is on the north side of a syncline (pl. 1). Smaller structural features associated with uranium occurrences are joints and several small sandstone dikes. The dikes originate in the sandstone bed directly beneath the Carbonate No. 1 coal bed, cut vertically through the host rocks, and pinch out in the overlying sandstone bed (fig. 16, middle and lower). The close relationships of the sandstone dikes with uranium and certain elements associated with uranium are shown in the cross sections of the pits, plate 3*A*. These relations suggest that uranium-bearing ground water entered the host rocks through the dikes. The sharp decrease in uranium content of samples only a few feet away from the dikes further suggests that the relative impermeability of the host rocks prevented the uranium-bearing ground water from penetrating the host rocks farther. It is unlikely that uranium occurrences associated with sandstone dikes will be found in commercial quantity. Sandstone dikes are scarce; even where they may occur in other host rocks such as coal or phosphatic claystone, which are no more permeable than the carbonaceous siltstone of the Carbonate prospect, the mineralization of such host rocks will probably be as localized as it is at the Carbonate prospect.

Study of the radioactivity-equilibrium status in samples from various stratigraphic units indicates that leaching of uranium also is closely associated with structural and permeability controls. For example, samples from coal bed E in the Traverse Ranch and North Riley Pass districts and in the western part of the South Riley Pass district contain the greatest percentage of disequilibrium both in favor of equivalent uranium and in favor of uranium. These areas are near anticlines or synclines. Samples from coal bed E in the central and western parts of the South Riley Pass district show the smallest percentage of radioactivity disequilibrium. These areas are not near well-defined structural features.

The close relations of the radioactivity-equilibrium status of uranium deposits and occurrences to permeability and stratigraphic position of the enclosing rocks are discussed in detail under the heading "Radioactivity-equilibrium status of samples from different stratigraphic zones."

DESCRIPTION OF THE URANIUM DEPOSITS AND OCCURRENCES

The uranium deposits and occurrences are here grouped for discussion according to the lithology of the host rock. Because deposits in coal are the most numerous, they are described first, followed by descriptions of deposits and occurrences in carbonaceous siltstone, phosphatic claystone, and all other lithologies. Deposits and occurrences in coal are further grouped according to their stratigraphic position, the youngest and largest being described first. In general, the richer deposits are stratigraphically higher, and the less mineralized occurrences are successively lower.

URANIUM IN COAL

COAL BEDS E AND F

NORTH RILEY PASS DISTRICT

The North Riley Pass district is in the east-central part of the North Cave Hills (pl. 1). The areal distribution of coal beds E and F in the district, the structure of the coal bed E, and the distribution of uranium in the coal bed E are shown in figures 6 and 7. Assay data shown in figure 7 as well as the structure-contour data are taken principally from study of drill cores, but they include data from several surface prospects. In addition to the sample localities shown in figures 6 and 7, coal bed E was sampled in adjoining districts to the north and east of the North Riley Pass district, as listed in table 7 (samples 5–63).

The meager information available on coal zone F indicates that mineralization is restricted in area, principally because of erosion of the zone. It is improbable that valuable uranium deposits will be discovered in coal zone F. Samples of zone F from five core holes contained from a trace to as much as 0.33 percent uranium (core hole R–24). A sample from coal zone F in one other core hole (R–48) contained 0.1 percent uranium. The thickness of the coal tested ranged from 0.7 to 1.5 feet.

According to Schopf and Gray (written commun., December 1956), coal zone F in the USGS core hole (fig. 6) is about 3.5 feet thick and has an average uranium content of about 0.02 percent. The lower part of the principal coal bed in zone F (comparable to that part of zone F just described) is about 1.6 feet thick and averages about 0.024 percent uranium. The upper few inches of this zone contains 0.11 percent uranium; the rest contains considerably less than 0.1 percent. Two samples collected from coal zone F in the district adjacent to the North Riley Pass district on the north (samples 1, 2, table 7) contain 0.22 percent and 0.027 percent uranium, respectively, and the average thickness of the bed is 0.25 foot at those localities. Unidentified uranium minerals visible locally in coal zone F are probably similar to uranium minerals that have been identified in coal bed E.

Coal bed E is generally less than 1 foot thick and contains an average of about 0.2 percent uranium in the North Riley Pass district (samples 10–18, table 7; com-

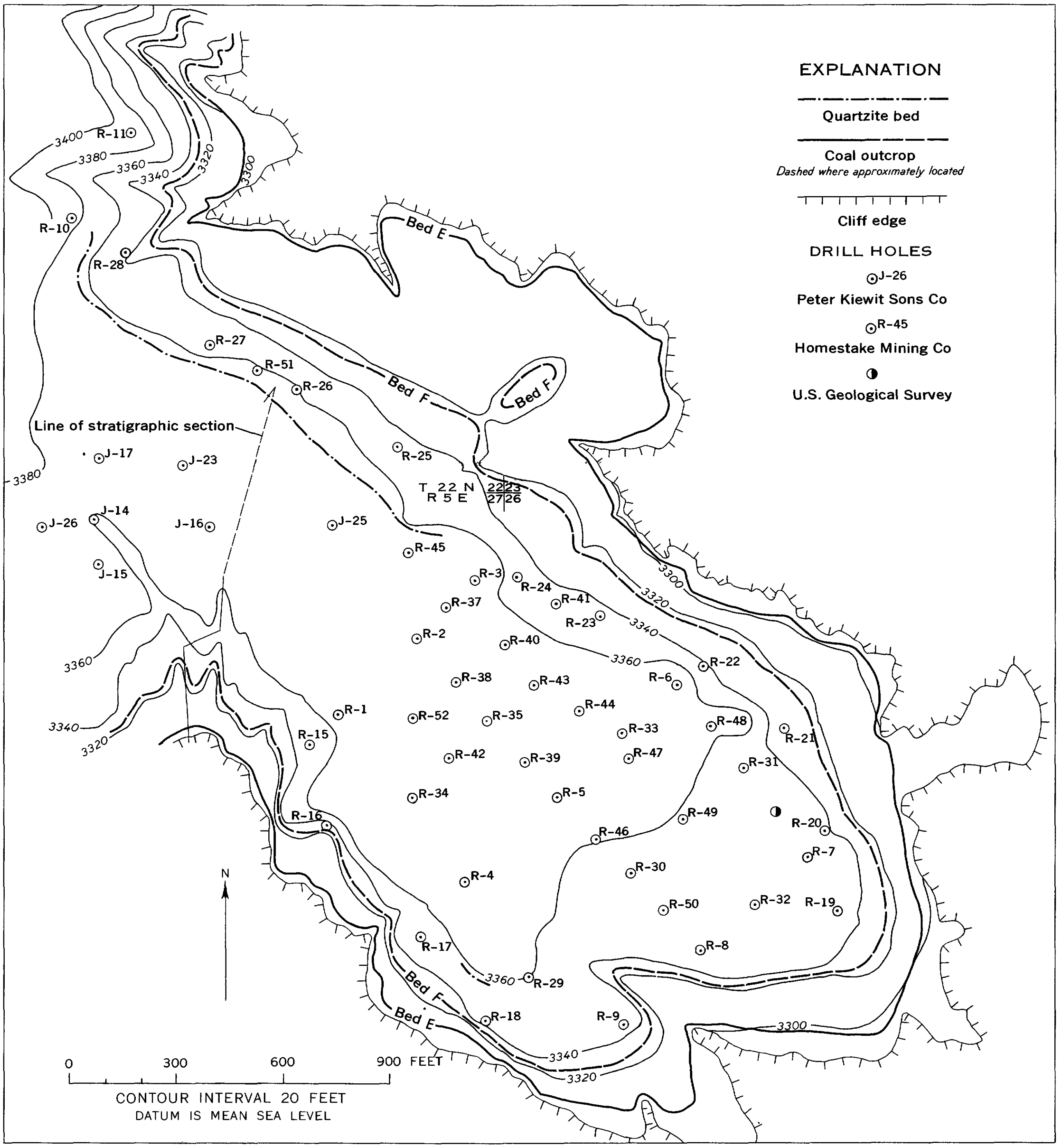


FIGURE 6.—Geology of the North Riley Pass district. Entire area shown is in Fort Union Formation. Coal bed E rests directly on a cliff-forming sandstone whose top is about 110 feet above the base of the Tongue River Member of the Fort Union Formation. (See stratigraphic section 5, pl. 2.) Planetable survey by G. N. Pipiringos and W. A. Chisholm, 1956.

pany data, fig. 7). Channel samples from adjacent districts (samples 19–63, table 7) indicate that the thickness of the bed ranges from 0.1 to 2.2 feet and averages about 1.25 feet. The uranium content ranges from 0.003 to 0.85 percent and averages about 0.13.

The principal visible uranium mineral in coal bed E in the North Riley Pass district is meta-autunite, which occurs mainly as thin films on the cleat faces of the coal and was first recognized by Gill (1954b, p. 149). Metatorbernite is apparently a minor constituent

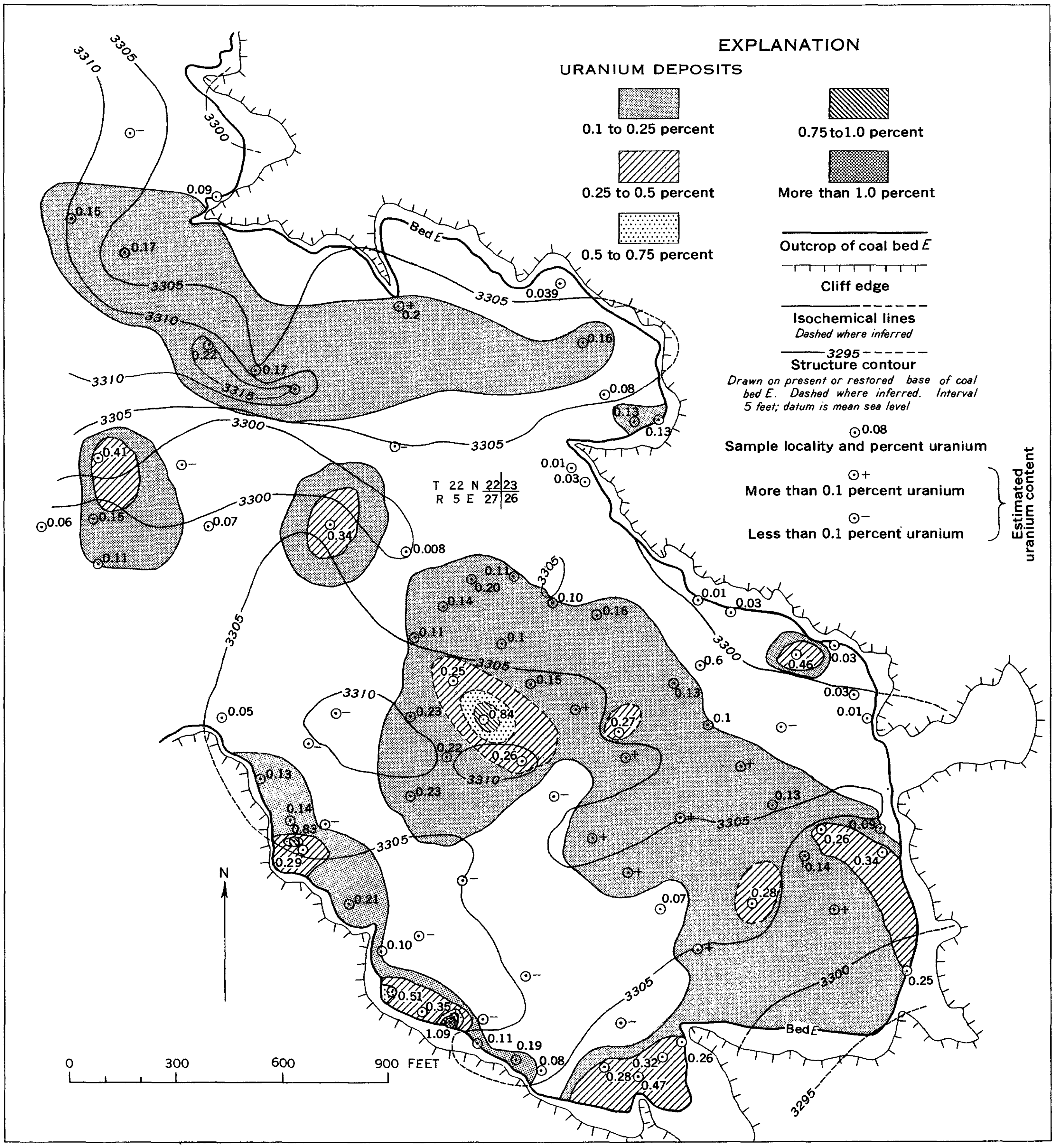


FIGURE 7.—Structure contours and variation in grade of uranium deposits in coal bed E, North Riley Pass district. Chemical assays supplied in part by Homestake Mining Co. and by Peter Kiewit Sons' Co. (See fig. 6.) Planetable survey by R. C. Kepferle and W. A. Chisholm, 1955.

among the visible uranium minerals; it was identified in only one sample from the north-central part of the North Riley Pass district.

TRAVERSE RANCH DISTRICT

The Traverse Ranch district is in the northwestern part of the North Cave Hills (pl. 1). Coal zone F is absent in this district. Coal bed E, although present, was not studied in detail. Locally coal bed E is as much as 4 feet thick, but it probably averages less than 1 foot in thickness. Several samples collected from coal bed E in the vicinity of the Traverse Ranch district (samples 5–9, table 7) contain from 0.004 to 0.41 percent uranium and average about 0.084 percent. This average may not be representative for this district, inasmuch as considerable excavating was in progress at the close of the 1956 field season and several tons of mineralized rock had already been strip mined from bed E. Uranium minerals are visible in coal bed E in this district, but they were not identified.

SOUTH RILEY PASS DISTRICT

The South Riley Pass district is in the east-central part of the North Cave Hills (pl. 1). A southeastward view encompassing all the South Riley Pass district is shown in figure 8, and a northeastward view of Riley Pass is shown in figure 9. The areal distribution of coal beds E and F in the South Riley Pass district, the structure of coal bed E, and the general distribution of uranium deposits in the coal bed E are shown in figures 10 and 11.

The rectangular areas on figure 11 show the location of the subareas here referred to as the western part (fig. 12), the central part (fig. 13), and the eastern part (fig. 14) of the South Riley Pass district. The maps of these subareas show the structure of coal bed E and the variation in grade of its uranium deposits. Hand-auger holes were drilled at 25-foot centers, and samples were collected at the numbered localities. Analyses of the samples from the western, central, and eastern parts of the South Riley Pass district are listed by map-locality number in table 6.

In the South Riley Pass district, the thickness of coal bed E ranges from 0.2 to 1.6 feet and averages 0.8 foot. The uranium content of the coal bed ranges from 0.002 to 2.76 percent. The uranium content of the samples from the western, central, and eastern parts of the district averages 0.3, 0.26, and 0.53 percent, respectively.

The most common uranium mineral in the South Riley Pass district is metatorbernite. It was identified by X-ray techniques in samples collected in the central part of the district at or near localities 14, 17, 20, 31, 36, 37, and 61 (fig. 13) and in samples from localities 20, 25, 31, and 32 in the eastern part of the district (fig. 14). The analyst noted that the X-ray patterns of metatorbernite and metazeunerite are nearly identical and that minerals from some of these localities may be metazeunerite.

In addition to the above, the mineral saléeite was identified from locality 14, figure 13, and meta-autunite was identified from locality 14, figure 14. White (1958, p. 18, 38) collected samples from coal bed E in the western and central South Riley Pass districts and from the flat-topped butte in the NW¼NE¼ sec. 36, T. 22 N., R. 5 E. He identified the mineral sodium autunite as a new member of the torbernite-metatorbernite series.

CARBONATE COAL ZONE

The uppermost bed of the Carbonate coal zone, the Carbonate No. 2 coal bed, contains only minor uranium occurrences; and it includes visible uranium minerals only at the Carbonate prospect. There (stratigraphic section 11, pls. 1, 2) it contains a maximum of 0.012 percent uranium. At the top of the first spur southeast of the Carbonate prospect and at stratigraphic section 19, this coal bed exceeds 4 feet in thickness but probably contains considerably less than 0.012 percent uranium. At the Lonesome Pete mine (stratigraphic section 12, pls. 1, 2) this bed contains only local occurrences of uranium, and these have maximum uranium concentrations of 0.053 percent.

The Carbonate No. 1 bed consists mostly of carbonaceous siltstone. Samples from the Carbonate prospect and vicinity, where the Carbonate No. 1 bed is mostly coal, contain a maximum uranium content of 0.056 percent. Except in the Carbonate prospect pits, the carbonaceous siltstone facies of this bed generally contains less than 0.01 percent uranium. (See columnar sections 1–10, pl. *3D*.) These uranium occurrences in the Carbonate No. 1 bed are discussed in the section on "Uranium in carbonaceous siltstone." The unnamed lowest coal bed in this zone, found only at the Carbonate prospect and at the Lonesome Pete mine, contains less than 0.03 percent uranium.

COAL ZONE C

Coal zone C contains sporadic uranium occurrences in an area extending from the vicinity of the Traverse Ranch southward along the western margin of the North Cave Hills to the vicinity of stratigraphic section 7 near the south end of these hills. Although selected samples from coal zone C (samples 18T, table 6, and 85B, table 7) contain 2.5 and 1.9 percent uranium, respectively, the rest of the samples average about 0.04 percent uranium. The average uranium content of all the samples collected from coal zone C is about 0.11 percent. Samples 84, 85T, and 85B (table 7) illustrate the erratic distribution of uranium. Sample 84 is a channel sample of a 1.4-foot-thick coal bed that contains 0.015 percent uranium. Six feet away, a small but strongly radioactive area was discovered at the base of the bed by means of a scintillation counter. Sample 85T from the upper 1-foot of this area contains 0.07 percent uranium, and the strongly radioactive area (sample 85B) contains 1.9 percent uranium. Samples 82 and 82a from a nearby locality also illustrate the unpredictable distribution of uranium in this coal zone.

Very little is known about coal bed C No. 2. Locally, it is as much as 4 feet thick, but the average thickness is probably considerably less. The uranium content of several samples that may be from coal bed C No. 2 is less than 0.1 percent. Because of uncertainties of correlation, analyses of samples from this coal bed have been combined with analyses of a much larger number of samples from coal bed C No. 1 bed and have been listed in table 7 (samples 69–91) under the heading "coal zone C." Coal bed C No. 2 is absent in the Traverse Ranch district.

Coal bed C No. 1 ranges in thickness from about 1 foot to 6 feet and averages about 4 feet in most of the area. It ranges in thickness from 2.7 feet to 4 feet and averages about 3.3 feet in the Traverse Ranch district. The geology and the localities at which coal bed C No. 1 was sampled in the vicinity of the Traverse Ranch are shown in figure 15. The uranium content of the samples from coal bed C No. 1 in the Traverse Ranch district is shown in table 6. Analyses of samples collected from coal zone C in other areas are shown in table 7 (samples 69–91).

Visible uranium minerals in the Cave Hills area are generally found at small but highly radioactive localities. A mineral sample from such a locality in the Traverse Ranch district could not be identified, but it was found to be similar to unnamed minerals reported from Karnes County, Tex. (A. J. Gude, 3d, written commun., Feb. 10, 1956). This mineral may be the same mineral that White (1958, p. 18, 40) identified as "impure sodium-autunite." White stated that it differed from sodium autunite "in that it is nearly opaque, does not fluoresce and is chemically impure." White collected his sample from the lower 5 inches of a 1.5-foot-thick coal bed in the upper part of the Ludlow Member. His locality, SW¼ sec. 2, T. 21 N., R. 5 E., and the other data indicate that his sample came from the coal zone C near where samples 79–85 were collected (table 7). At this locality "the mineral forms scaly masses on vertical joint surfaces in the lower one-third of the lignite seam" (White, 1958, p. 40).

COAL ZONE B

Coal zone B is only slightly mineralized despite its stratigraphic position about midway between coal zone C and the Lonesome Pete zone, both of which contain relatively high concentrations of uranium. No visible uranium minerals were found in this coal zone. Analyses of samples from this zone are listed in table 7, samples 92T–95B. The samples from coal zone B that contain the most uranium were collected from stratigraphic sections 11 and 15 in the eastern part of the South Cave Hills (pls. 1, 2; samples 94, 95T, 95B, table 7). Along the west margin of the South Cave Hills (stratigraphic sections 12, 13, 14) the interval normally occupied by coal zone B consists entirely of sandstone. The wedge-edge of coal zone B probably extends from a

FIGURE 8.—Panorama of the Riley Pass district. The high tree-covered hill on the skyline is in the South Riley Pass district and is the site of triangulation station "Cave" (△) shown on figure 10. The road in the right middle ground leads northeastward to Riley Pass shown on figure 9. The foreground is the south end of the North Riley Pass district. The bare surface is the top of the E-bed sandstone on which coal bed E was deposited. The dark color and the resistant character of the upper few feet of the cliff shown here and on figure 9 are caused by unusually large amounts of analcite cement in the matrix. All rocks are in Fort Union Formation: Tft, Tongue River Member; Tfl, Ludlow Member.

FIGURE 9.—Riley Pass. Cliff is formed by E-bed sandstone. Less resistant D-bed sandstone is exposed in roadcut. These two sandstone units form the basal 110 feet of the Tongue River (Tft) Member of the Fort Union Formation. Tfl, Ludlow Member of the Fort Union Formation.

point about midway between sections 15 and 14 northwestward, along a line approximating the 3,300-foot contour, to a point about midway between stratigraphic sections 11 and 12. If coal zone B does contain uranium deposits in this area, they are most likely to be found along this wedge-edge.

LONESOME PETE COAL ZONE

The Lonesome Pete coal zone contains neither high-grade-uranium occurrences nor uranium minerals despite its proximity to the overlying Lonesome Pete ore zone. Samples from the Lonesome Pete coal zone contain from 0.001 to 0.085 percent uranium and average about 0.012 percent uranium (coal samples, table 9; samples 96–97, table 7). The sample containing the most uranium was collected from the upper 0.6 foot of the coal at the Lonesome Pete mine (map loc. 9, pl. 4*C*; sample 9T, table 9).

LOWER COAL BEDS

Analyses of samples from coal beds stratigraphically below the Lonesome Pete coal zone are listed in table 7 (samples 99–120). These samples, collected from stratigraphic sections 8, 11, and 15 (pls. 1, 2), have an average uranium content of 0.003 percent. This quantity suggests that some uranium-bearing water circulated throughout the entire thickness of the Ludlow, as uranium is generally not considered to be a constituent of coal. No visible uranium minerals were found in these coal beds.

URANIUM IN CARBONACEOUS SILTSTONE

CARBONATE PROSPECT

Fairly rich concentrations of uranium have been discovered in a carbonaceous siltstone bed within a small area known locally as the Carbonate prospect. This prospect, in the northeastern part of the South Cave Hills (pl. 1), is a bulldozed excavation about 10 feet wide and 700 feet long that is cut into the upper part of the Ludlow Member of the Fort Union Formation at the stratigraphic position of the Carbonate No. 1 coal bed (pl. 3*B*). The carbonaceous siltstone bed is about 2 feet thick at the Carbonate prospect. It occurs throughout the western part of the South Cave Hills, in the buttes south and southwest of the South Cave Hills, and in Table Mountain; but it is absent in the North Cave Hills. Within a few hundred feet to the east of the Carbonate prospect, the carbonaceous siltstone bed grades laterally into the Carbonate No. 1 coal bed, which underlies much of the eastern part of the South Cave Hills. Despite the wide distribution of the carbonaceous siltstone bed and its equivalent, fairly high concentrations of uranium are known only from two prospect pits in the Carbonate prospect; these pits are where the carbonaceous siltstone bed is cut by a series of small sandstone dikes.

The host rock was sampled at several localities in the southern half of the prospect as well as at two prospect pits in the east wall of the excavation (pl. 3*C*, fig. 16). The host rock consists principally of siltstone, but it has a clay matrix and contains enough carbonaceous debris to impart a black coaly appearance to the bed. The uranium content of samples collected at the Carbonate prospect from localities other than the prospect pits, excluding the highest value (0.56 percent at columnar section 6, pl. 3*D*), averages about 0.007 percent, or about 0.01 percent if that sample is included. The prospect pits were sampled in detail at localities shown on plate 3*E*. Analyses of samples from the north pit range from 0.003 percent to 0.91 percent uranium and average about 0.14 percent uranium. Those from the south pit range from 0.006 percent to 0.55 percent uranium and average about 0.06 percent (table 8).

Uranium minerals are not common in the Carbonate prospect. The few minerals that have been found came from the prospect pits and were identified as meta-autunite (Kepferle and Chisholm, 1955, p. 246) and as metazeunerite or metatorbernite (Kepferle and Chisholm, 1956, p. 248).

URANIUM IN PHOSPHATIC CLAYSTONE

LONESOME PETE MINE AND VICINITY

The Lonesome Pete mine is at the northwest corner of the South Cave Hills (pl. 1). The deposit is in a bed of phosphatic silty claystone, generally less than 5 inches thick, that occurs from a few inches to 2 feet above the Lonesome Pete coal zone and about 90 feet below the top of the Ludlow Member. The areal extent of the deposit probably does not exceed 50 acres. The phosphatic claystonebed is referred to locally as the Lonesome Pete ore zone; it is a "uranium deposit" as that term was previously defined under the heading "Uranium."

The Lonesome Pete ore zone was sampled principally in auger holes drilled at 25-foot centers and at several surface localities in the Lonesome Pete mine (pl. 4*C*, fig. 17). In addition, several samples were collected from nearby localities in the surrounding area (pl. 4*B*, *D*). Study of the samples revealed that the host rock contains almost as much silt as it does clay and that analcite spherulites and amorphous carbonate fluorapatite are abundant. In addition, nodules and well-formed crystals of marcasite are common; and some dolomite is present as indicated by X-ray data.

Chemical analyses of the samples indicate that the phosphate content of the deposit (P_2O_5 in the carbonate fluorapatite) ranges from about 0.1 to 17 percent and averages about 1.2 percent, and that the uranium content ranges from 0.007 to 0.6 percent and averages about 0.16 percent uranium (table 9). A sample containing 0.5 percent uranium was leached of apatite and analcite (which formed 25 percent of the sample) and was reanalyzed. It then contained only 0.014 percent uranium. X-ray spectrometry indicated that the residue consisted of quartz, hydromica, and a trace of unidentified minerals (lab No. 143365, United States Geol. Survey lab., Washington, D.C.; analysts, William Virgin and Jerome Stone). In another sample the uranium was equally divided between the analcite and the apatite. In still other samples the uranium was associated principally with the carbonate fluorapatite (Kepferle and Chisholm, 1956, p. 251).

The foregoing statements suggest that the apatite and the analcite contain most of the uranium in the Lonesome Pete ore zone. This suggestion is partially supported by the parallelism in the distribution of the phosphate and the uranium in the Lonesome Pete mine (pl. 4*A*). Uranium minerals are scarce in the Lonesome Pete district. Metatorbernite was identified in one sample from the vicinity of columnar section 5 (pl. 4*D*). No other uranium minerals were identified from this district.

The extent of the Lonesome Pete ore zone is uncertain, but it is known from the vicinity of columnar section 1 to the vicinity of columnar section 5, a distance along the outcrop of about 2,000 feet. Holes drilled by private companies are reported to have penetrated the mineralized zone at localities near the trail (pl. 4*D*) that passes northeast of the Lonesome Pete mine. The extent of the Lonesome Pete ore zone still farther eastward is unknown.

URANIUM IN OTHER ROCKS

To determine the geographic and stratigraphic distribution of uranium, samples were collected from rocks overlying or underlying uranium-rich beds and from localities and stratigraphic units not known to contain ore-grade material. The analyses and the sources of these samples are listed in table 12. This information is useful in calculating the general level of uranium concentration in the potential uranium host rocks and in some of the possible uranium source rocks in this area. A few samples contain significant amounts of uranium. Most of these samples were collected near larger uranium occurrences or near deposits already described. In addition to the analyses reported in table 12, many other analyses are given by Denson and Gill (1965) for similar rocks in nearby areas.

LUDLOW MEMBER OF FORT UNION FORMATION

Most samples from the Ludlow Member were collected near uranium deposits and occurrences and therefore do not represent typical unmineralized rocks of the Ludlow Member of the Cave Hills area. The analyses of these samples are listed in tables 8 and 10 according to the districts from which they were collected. All except two samples were from either the Carbonate prospect or the Lonesome Pete district. The uranium content of the 48 samples analyzed ranges from 0.001 to 0.15 percent and averages 0.013 percent. Only four samples contain 0.002 percent or less uranium. Nearby uranium deposits indicate a favorable environment for concentration of uranium in these districts inasmuch as core samples of the Ludlow from the Slim Buttes district area contain an average of only 0.002 percent uranium.

Two samples of mineralized sandstone (samples 21, 22, table 10) were collected from a pit dug in the north slope of a canyon cut into the eastern margin of the North Cave Hills (NW¼NE¼NE¼ sec. 22, T. 22 N., R. 5 E.). No visible uranium minerals were found in

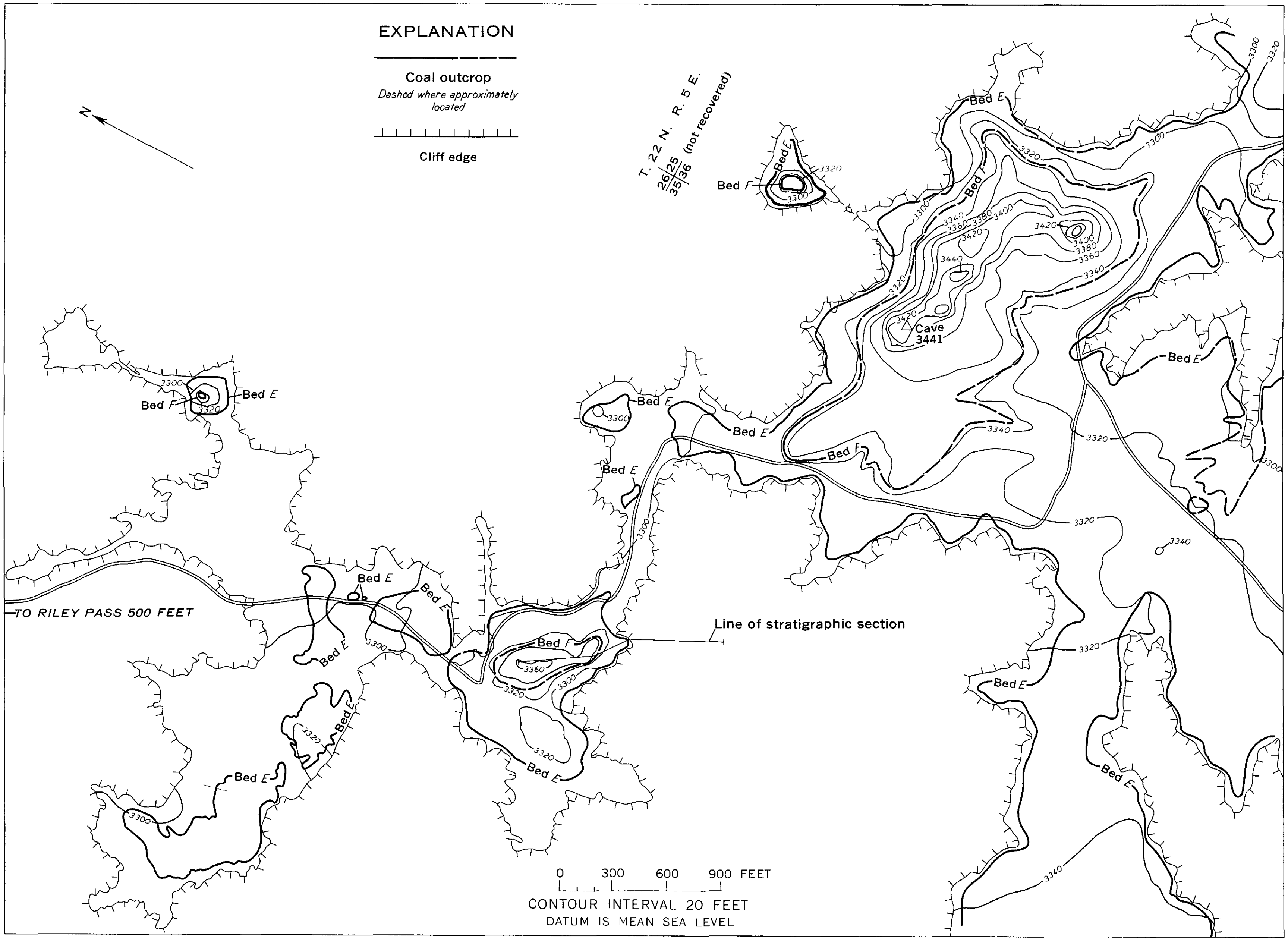


FIGURE 10.—Geology of the South Riley Pass district. Entire area shown is Fort Union Formation. Coal bed E rests directly on a prominent cliff-forming sandstone whose top is about 110 feet above the base of the Tongue River Member of the Fort Union Formation. (See stratigraphic section 6, pl. 2.) Planetable survey by G. N. Pipiringos and W. A. Chisholm, 1956.

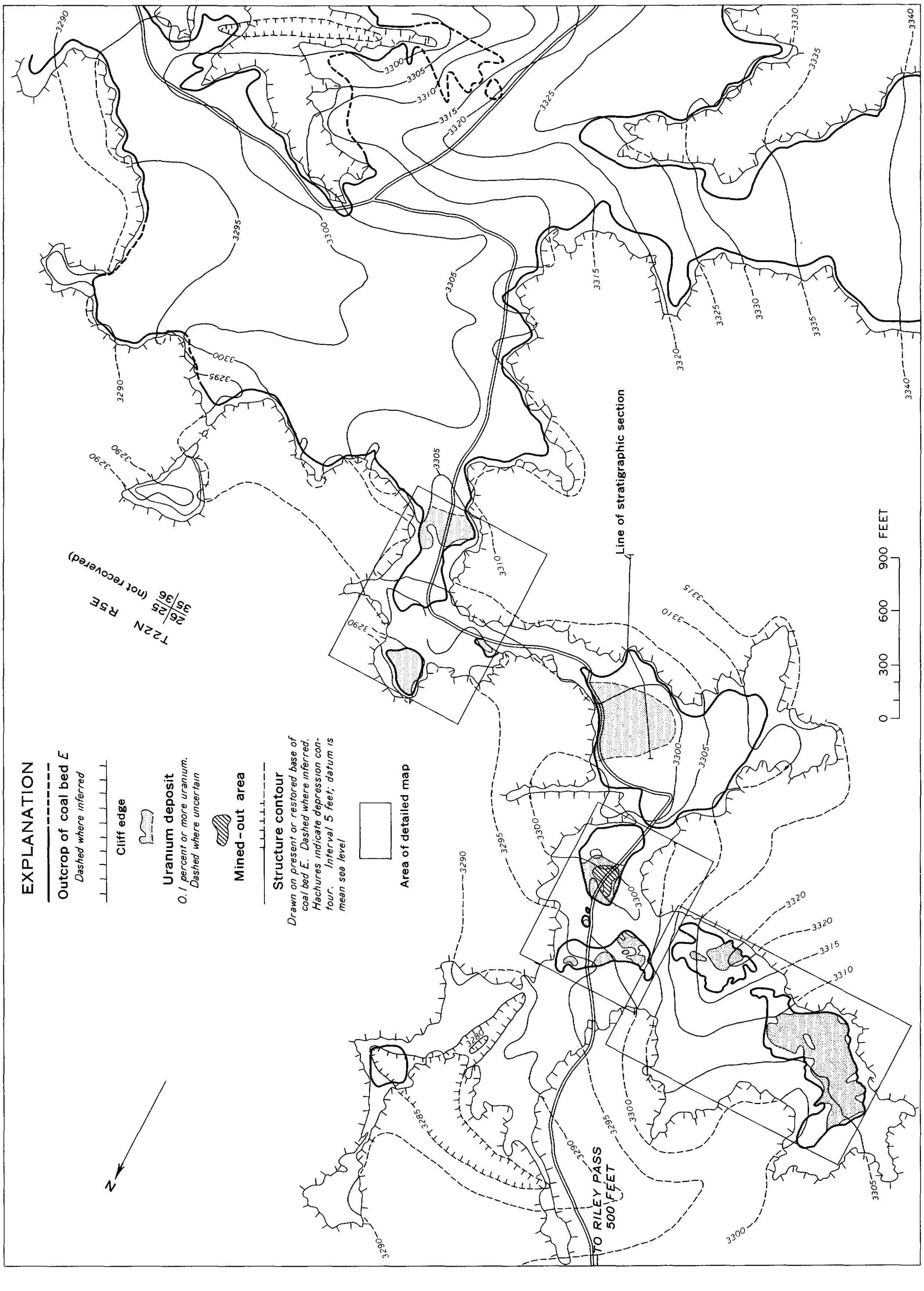


FIGURE 11.—Structure contours and uranium deposits in coal bed E, South Riley Pass district. Subareas of detailed maps, from left to right, refer to figures 12–14. Planetable survey by R. C. Kepferle and W. A. Chisholm, 1955.

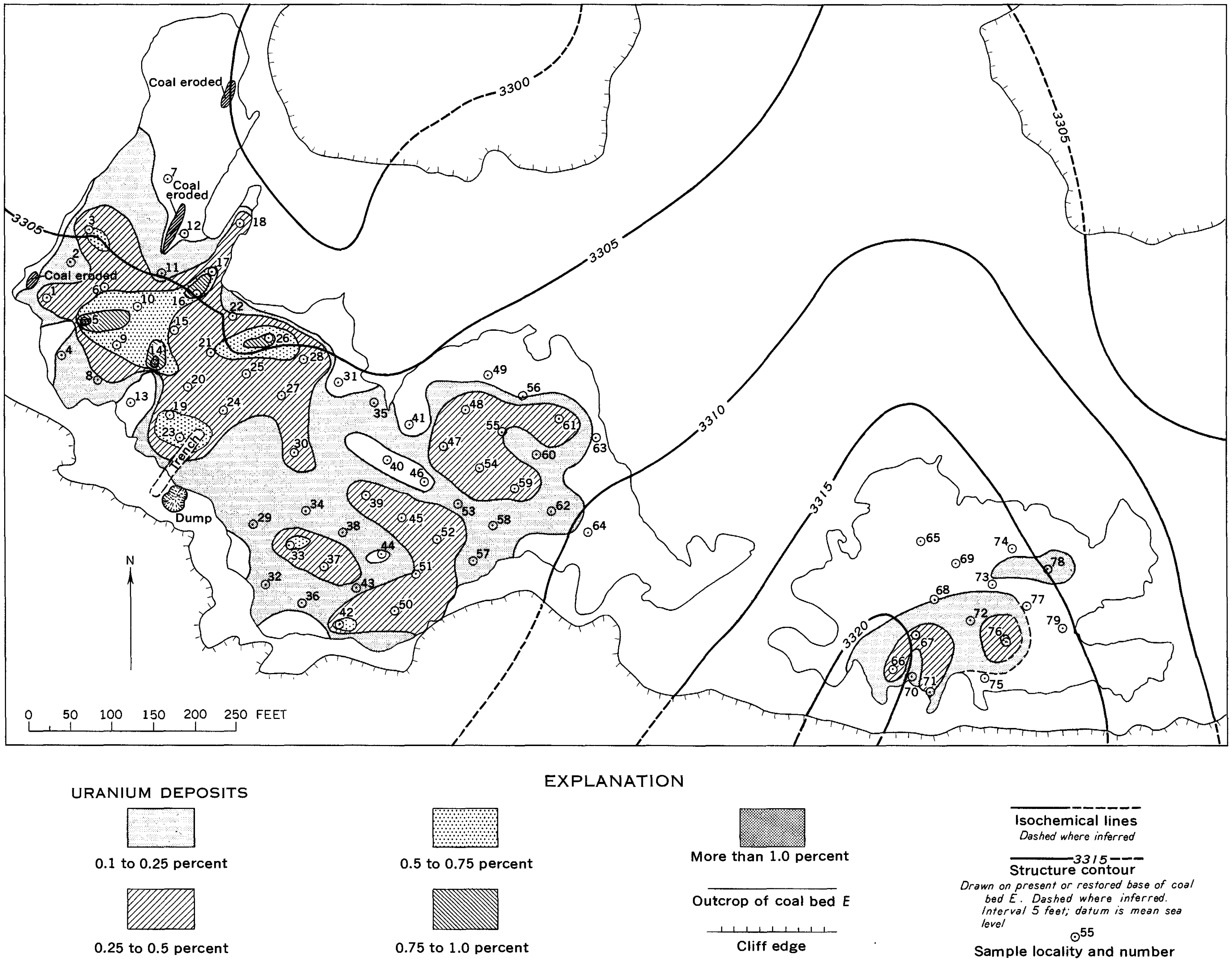


FIGURE 12.—Structure contours and variation in grade of uranium deposits of the western part of the South Riley Pass district, Harding County, S. Dak.

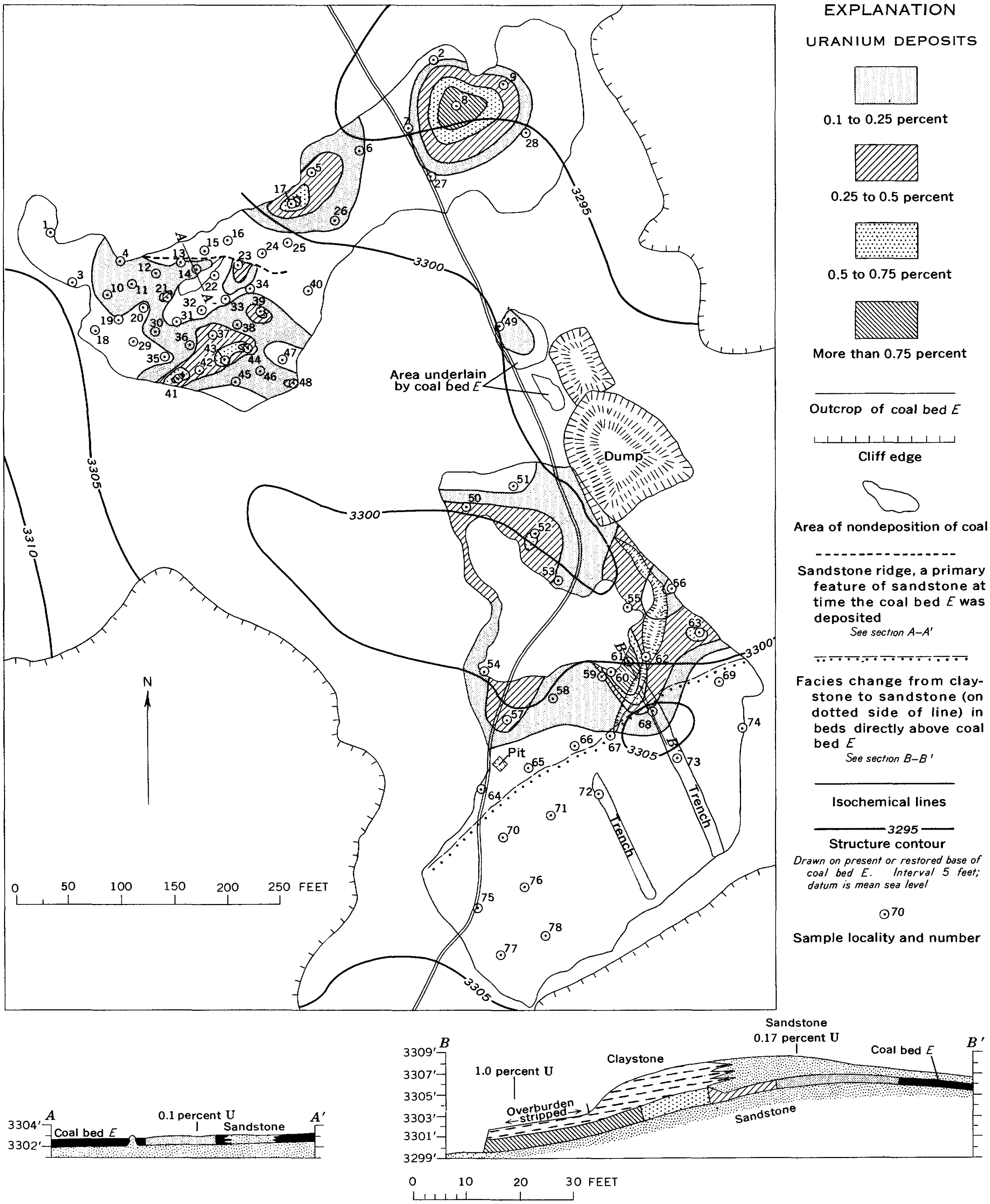


Figure 13.—Structure contours and sections of the central part of the South Riley Pass district, Harding County, S. Dak., showing variation in grade of uranium deposits.

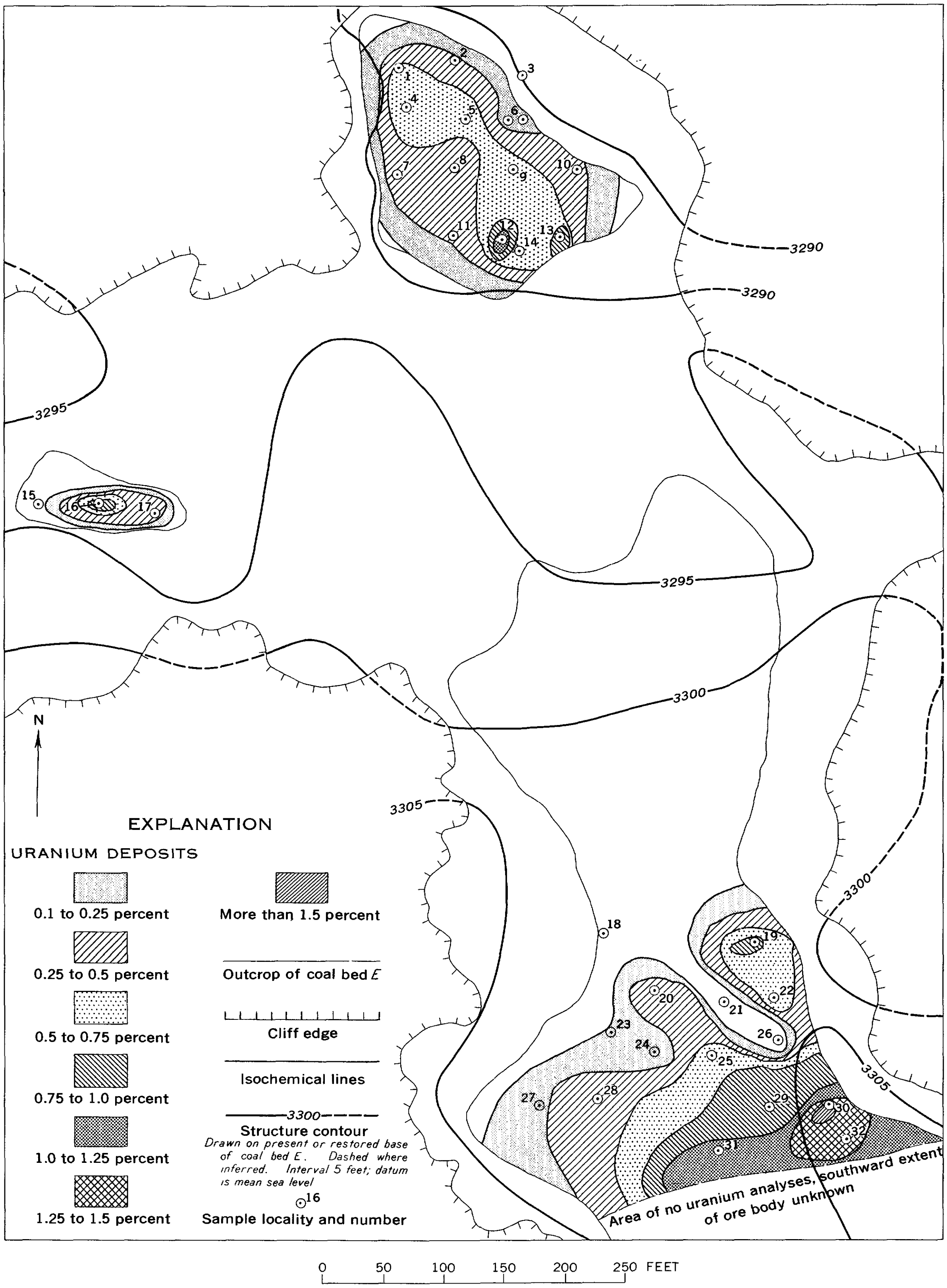


FIGURE 14.—Structure contours and variation in grade of uranium deposits of the eastern part of the South Riley Pass district, Harding County, S. Dak.

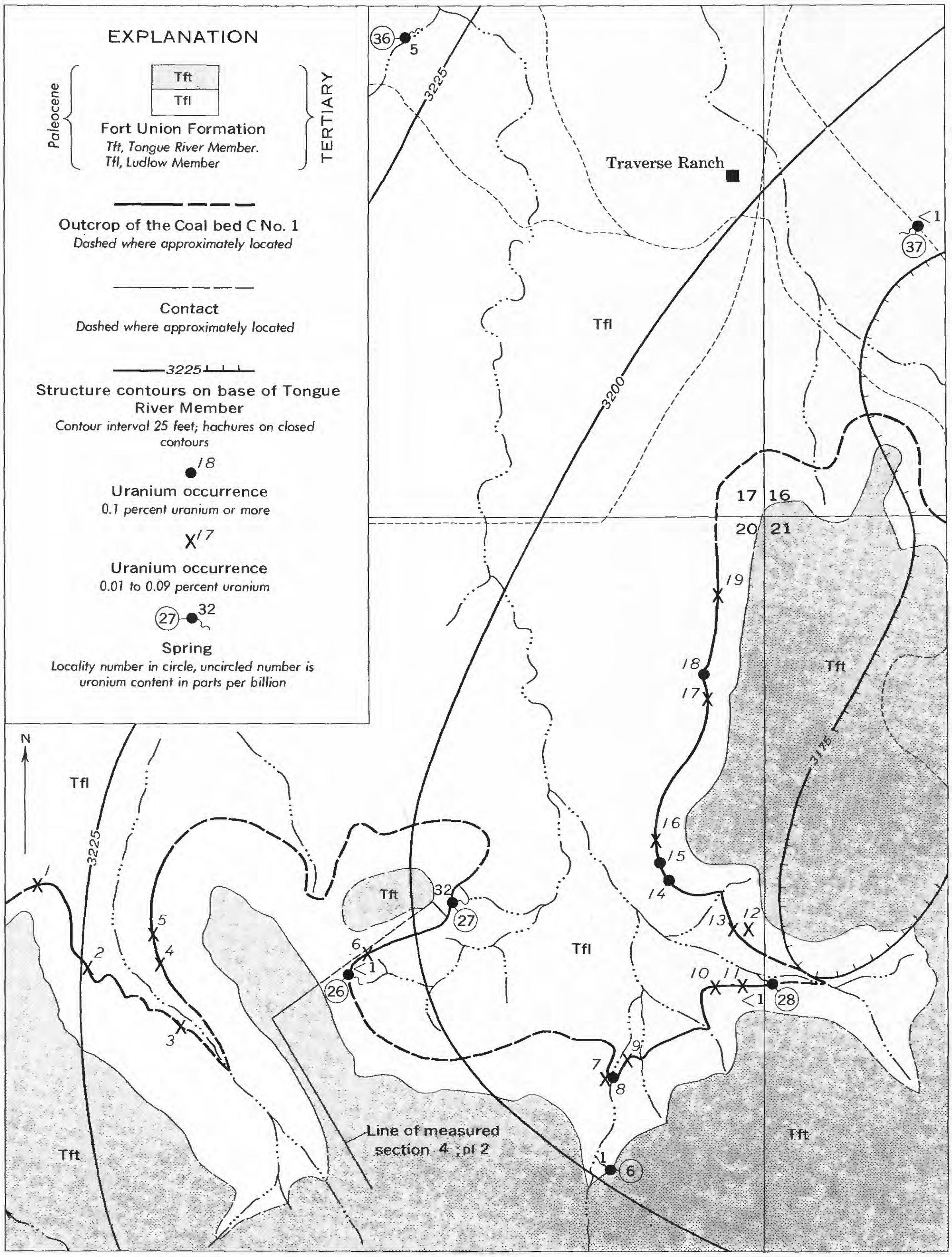


FIGURE 15.—Geology and uranium content of coal and water samples, Traverse Ranch district, T. 22 N., R. 5 E., Harding County, S. Dak.

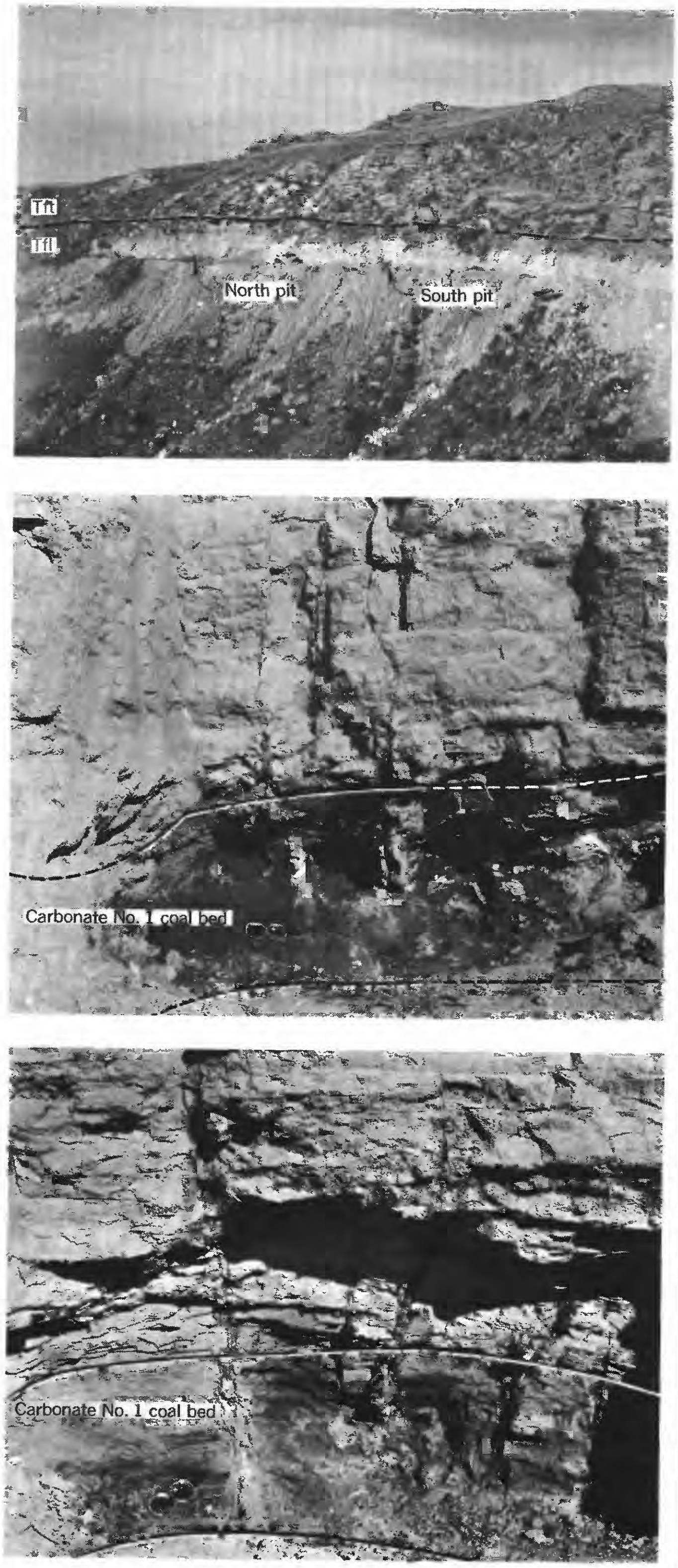


FIGURE 16.—The Carbonate prospect, South Cave Hills. Upper, View showing the contact of the Tongue River (Tft) and Ludlow (Tfl) Members of the Fort Union Formation, and the location of the prospect pits. Middle, North pit; Lower, South pit. Sandstone dikes and ore-grade uranium occurrences in the Carbonate coal zone are known only from the pits shown in middle and lower.

the pit, and a search of the adjacent talus- and vegetation-covered slope with a scintillation counter failed to discover evidence of other radioactivity anomalies in the vicinity. The exact stratigraphic position of the uranium occurrence can not be identified because of the covered slope, but it is within a few feet of the contact of the Ludlow and Tongue River Members. This stratigraphic position would place the deposit in the basal few feet of the D-bed sandstone or in the uppermost beds of the underlying Ludlow Member.

A similar occurrence was noted in a small canyon (NE¼ NE¼ SE¼ sec. 10, T. 22 N., R. 5 E.) slightly more than 1.5 miles directly north of the locality just discussed. It, too, seems to be within a few feet of the Ludlow–Tongue River contact. Rocks at this locality were not sampled, but the radioactivity is greatest near a weathered iron-oxide concretion and drops to background level a foot away from the concretion. The scarcity and small size of the known occurrences of uranium in sandstone in the Cave Hills area are discouraging factors in the prospecting for uranium in those beds.

TONGUE RIVER MEMBER OF THE FORT UNION FORMATION

Twelve samples of sandstone, siltstone, and claystone were collected mostly from coal beds E and F near the middle of the Tongue River Member of the Fort Union (samples 9–20, table 10). Some of the samples probably are not representative of unmineralized parts of the member, especially some of the claystone samples that were in close association with coal bed E. If the relatively rich uranium samples (Nos. 16, 17, 19, and 20) are disregarded, the other samples, principally composed of sandstone and siltstone, average less than 0.002 percent uranium.

CHADRON FORMATION

Tuffaceous sandstone and silicified claystone in all eight samples from the Chadron Formation at localities in the North and South Cave Hills contain 0.001 percent uranium (samples 1–8, table 10). Twenty-five samples from the Chadron Formation and from the overlying Brule and Arikaree Formations at the Slim Buttes (fig. 1) contain even less uranium despite the fact that all but one are unweathered core-hole samples (Denson and Gill, 1965).

Exceptions to the generally low uranium content of the Chadron Formation are the carnotite deposits near the top of the formation at the head of Cedar Canyon in the southern part of the Slim Buttes district. Analyses of seven samples from the Cedar Canyon deposits indicate uranium concentrations that range from 0.001 to 0.23 percent and average 0.1 percent (Gill and Moore, 1955, p. 259). These two writers concluded that the

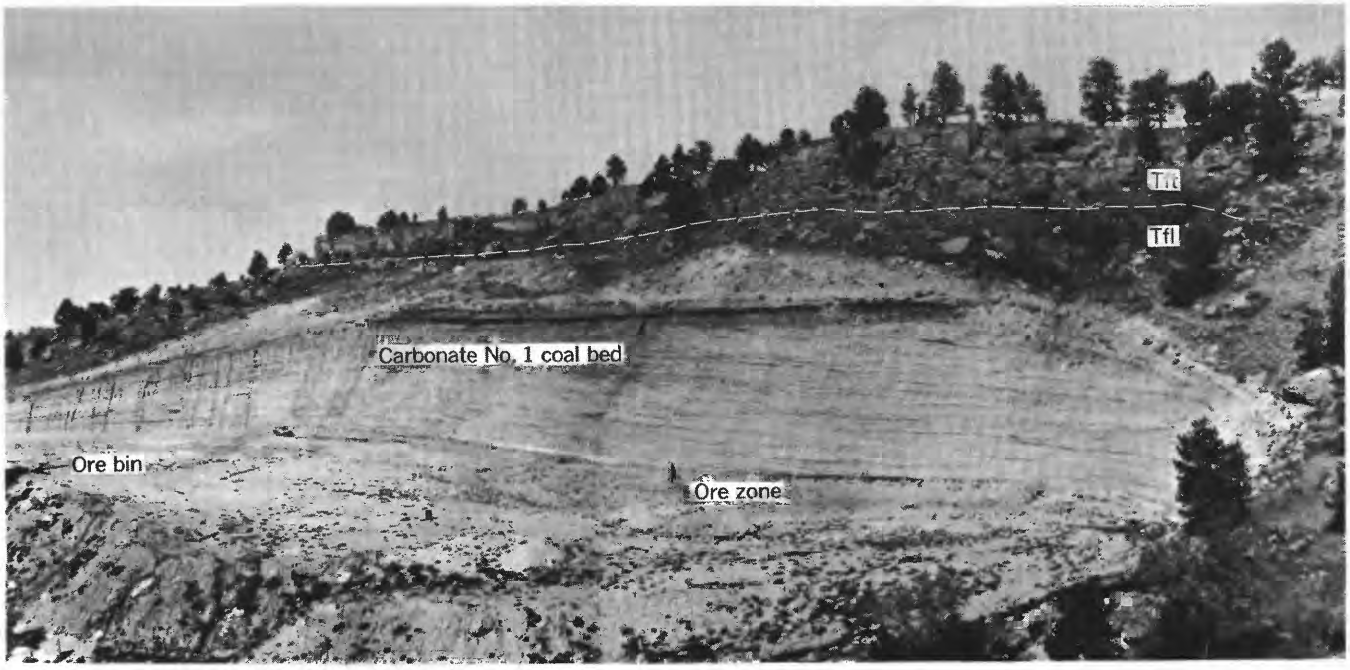


FIGURE 17.—The Lonesome Pete mine. The contact of the Tongue River (Tft) and Ludlow (Tfl) Members of the Fort Union Formation is approximately located.

uranium and other elements in the carnotite had been leached from the slightly uraniferous volcanic material present in the overlying Arikaree Formation by moving ground water. Uranium had then been deposited from ground-water solutions in the sandstone and claystone beds along the base of the perched water table near the top of the Chadron Formation. Thus, the Cedar Canyon deposits are not typical of deposits in the Chadron Formation but represent anomalous epigenetic concentrations of uranium within the Chadron.

URANIUM IN WATER

According to Fix (1956, p. 670): "The threshold of anomaly—a rough guide to waters requiring further investigation—is about 1.0 ppbU, or 10 times the regional background in the western United States generally." More specifically, ordinary ground water from rocks similar to those studied in the present investigation has an average uranium content of slightly more than 4 ppb (parts per billion) accordingly to Denson, Zeller, and Stephens (1956, p. 674, table). The work of these authors indicates that uranium deposits might be discovered by analyzing the ground water for unusual concentrations of uranium in solution.

Fix (1956, p. 670–671) concluded that in most uraniferous areas, samples of ordinary surface and ground waters whose pH ranged from 5.5 to 7.5 contained only moderate amounts of uranium, whereas generally the more acid the waters, the higher the uranium content. Denson, Zeller, and Stephens (1956, p. 680) concluded (with reference only to tuffaceous rocks of Oligocene and Miocene age in South Dakota and Wyoming): "In general the more alkaline waters from these rocks carry the most uranium * * *."

The uranium content and the pH of 60 water samples from springs, wells, streams, ponds, and reservoirs were determined to learn whether relationships existed between the uranium content of the samples and the location of the samples with respect to uranium deposits and to discover whether relationships existed between the pH and the uranium content of water samples in the Cave Hills area (table 3). The pH of many of these samples was determined by a portable pH meter in the field for comparison with laboratory results. The sample localities and their relation to the general distribution and structure of the rocks are shown on plate 1. The location of water samples from the Traverse Ranch district are also shown on figure 15. The uranium content of 53 water samples from springs in the Cave Hills area ranged from less than 1 ppb to 290 ppb and averaged 20 ppb. The pH of these samples ranged from about 7.4 to 9.3 and averaged 8.2. Field determinations of pH for the most part are about 0.5 pH lower than the laboratory results. Three well samples contained from 4 to 31 ppb uranium and averaged 16 ppb. The pH was 8 in two of the well samples and 7.9 in the other.

TABLE 3.—*Analyses, in parts per billion, of water samples from the Cave Hills area*

[Chemical analyses and laboratory pH determinations by R. L. Daywitt, E. J. Fennelly, Mary Finch, J. P. McClure, and J. P. Schuch, U.S. Geol. Survey Lab., Denver, Colo. Field pH determinations with a portable pH meter by G. N. Pipiringos, Sept. 18–20, 1956]

Sample No.	Laboratory No.	Location			Type of sample	Position in member	Uranium (ppb)	pH	
		Sec.	T. N.	R.E.				Laboratory	Field
Tongue River Member of Fort Union Formation (Paleocene)									
[1]1a	231952	22	22	5	Spring	Coal bed E	3	7.8	7.8
[1]1b	233532	22	22	5	do	do	3	8.3	
2	236925	26	22	5	Pond	do	2,250	7.4	8.6
3	233526	8	22	4	Spring	Base	50	8.9	
4	233525	8	22	4	do	do	1	8.8	8.0
5	233527	8	22	4	do	do	1	8.9	
[2]6	233523	20	22	5	do	do	<1	8.9	
7	231951	22	22	5	do	do	70	7.9	7.5
8	231950	22	22	5	do	do	27	7.8	
Ludlow Member of the Fort Union Formation (Paleocene)									
9	234972	5	22	4	Spring	Carbonate No. 2 coal bed	2	8.1	
10	233528	10	22	5	do	do	3	8.2	
11	236922	11	22	5	do	do	11	7.7	
12	231958	15	22	5	do	do	5	7.7	
13	233518	15	22	5	do	do	1	8.8	
14	231953	15	22	5	do	do	17	8.0	
15	231949	15	22	5	do	do	8	7.7	
16	231948	22	22	5	do	do	27	7.8	
17	231947	22	22	5	do	do	18	7.8	7.5
18	248599	29	22	5	do	do	78	7.9	
19	248600	28	22	5	do	do	1.3	8.4	
20	236918	36	21	4	do	do	5	7.8	7.0
21	236919	36	21	4	do	do	4	8.0	
22	234964	8	22	5	do	Coal zone C	6	7.9	
23	236924	11	22	5	do	do	<1	8.3	
24	234965	16	22	5	do	do	1	7.9	
25	234975	16	22	5	do	do	10	7.8	
[2]26	233521	20	22	5	do	do	<1	9.3	
[2]27	233522	20	22	5	do	do	32	9.1	
[2]28	233524	21	22	5	do	do	<1	9.0	
29	234974	21	22	5	do	do	2	7.7	7.5
[3]30a	231955	27	22	5	do	do	13	8.7	8.8
[3]30b	233531	27	22	5	do	do	13	8.7	
31	236926	26	22	5	do	do	128	8.2	
32	248595	6	20	5	do	do	18	7.9	7.0
33	248596	32	21	5	do	do	13	8.2	
34	234971	3	22	5	do	Coal zone B	3	8.3	
35	234968	18	22	5	do	do	17	8.6	
[2]36	234967	17	22	5	do	do	5	8.7	
[2]37	234966	16	22	5	do	do	<1	8.2	
38	234969	19	22	5	do	do	<1	7.7	6.6
39	233529	23	22	5	do	do	34	8.4	
40	231957	23	22	5	do	do	20	8.0	7.1
[4]41a	231956	26	22	5	do	do	290	7.7	7.4
[4]41b	234960	26	22	5	do	do	290	7.7	
42	234970	33	22	5	do	do	5	8.4	6.5
43	234963	3	20	5	do	do	2	7.6	6.9
44	248598	29	22	5	do	Sandstone(?) about 100 ft below top.	13	8.3	
45	234976	34	22	5	Reservoir	About 150 ft below top	28	9.6	
46	234977	34	22	5	Spring	Coal bed about 150 ft below top	2	8.0	
47	234973	34	22	5	Stream	About 150 ft below top	124	7.9	
48	236927	29	21	5	Spring	Coal bed about 150 ft below top	3	8.1	
49	248597	33	21	5	do	do	15	8.1	
50	231946	30	21	5	do	Coal bed about 180 ft below top	8	7.5	7.0
51	236921	2	22	5	do	Middle part	1	7.9	
52	236923	11	22	5	do	do	22	8.0	7.5
53	231945	33	21	5	do	Lower part, near Hell Creek contact.[5]	6	7.8	
Hell Creek Formation (Cretaceous)									
54	236920	1	22	5	Well	Upper part	4	7.9	
55	231944	15	21	5	do	do	12	8.0	8.0
56	236917	15	21	5	Stream	Upper part, near Ludlow contact	8	8.3	
57	231954	19	21	5	Well	Upper part	31	8.0	

[1] Sample 231952 collected by R. C. Kepferle, July 18, 1955; sample 233532 collected by W. A. Chisholm, August 8, 1955.

[2] Samples from the Traverse Ranch district shown also in figure 22.

[3] Sample 231955 collected by R. C. Kepferle, July 20, 1955; sample 233531 collected by W. A. Chisholm, August 8, 1955.

[4] Sample 231956 collected by R. C. Kepferle, July 20, 1955; sample 234960 collected by W. A. Chisholm, September 2, 1955.

[5] Upper part of Hell Creek as mapped by Winchester and others (1916).

The uranium content of the four stream, pond, and reservoir samples ranged from 8 to 2,250 ppb and averaged 485 ppb. The extremely uraniferous sample came from water that had gathered in a prospect pit in the central part of the South Riley Pass district. The pH of these samples ranged from 7.4 to 9.6 and averaged 8.3. No new uranium deposits were discovered. All the samples having anomalously high uranium values were from localities close to known ore-grade uranium occurrences. The uranium in the ground waters and in the surface waters probably was leached from the deposits. The waters are moderately alkaline, but no correlation seems to exist between the pH and the uranium content of samples.

RADIOACTIVITY EQUILIBRIUM IN SAMPLES

Chemical and radiometric analyses of samples from the Cave Hills area show a large percentage of the samples to be in radioactivity disequilibrium. A study of the relation of uranium to its radioactive daughter products in deposits at different stratigraphic levels suggests the origin of the deposits, the source of the uranium, and the time of mineralization.

The radioactivity of samples from the Cave Hills area probably is entirely due to the daughter products of uranium 238, thorium 230 and radium 226, and to the daughter product of uranium 235, protactinium 231. These radioactive uranium daughter products have been detected in Cave Hills samples (table 4, this report; White, 1958, p. 67). Other radioactive daughter products of these parent elements, with the exception of radon 222, which is discussed with total equivalent-uranium–uranium ratios, need not be considered because of their short half lives (Rosholt, 1959, fig. 1). Thorium 232 and potassium 40 also decay to radioactive daughter products, but neither element has been detected in any of the uranium-bearing coal samples analyzed from this area (J. N. Rosholt, Jr., oral commun., 1958); and their daughter products, therefore, are assumed to be absent.

The reported uranium includes three isotopes, U^{238}, its daughter product U^{234}, and U^{235}. The last-named, though not a daughter product of U^{238}, normally "will remain in constant abundance with U^{238} * * *" (Rosholt, 1959, p. 2), and it makes up only 0.7 percent of the total uranium present (Thode, 1954, p. 144). The radioactive decay series of U^{238} and U^{235} normally may be expected to be in equilibrium in unaltered uranium-bearing samples. Rocks containing an excess of equivalent uranium (eU) over uranium (U) have been subjected to processes other than spontaneous radioactive decay, and either have had daughter products added after the rock had achieved equilibrium or have had uranium removed. In rock containing an excess of uranium over equivalent uranium, radioactive daughter products have been removed after the rock achieved equilibrium or uranium has been added to the rock and has not yet reached equilibrium with its daughter products. Literature concerning the relative solubility of uranium and its daughter products is scant, but it reveals that uranium compounds are more soluble than compounds of daughter products responsible for the radioactivity reported as equivalent uranium. Therefore, where disequilibrium exists between equivalent uranium and uranium, it is probable that uranium compounds have been dissolved and moved in solution away from the locality of original deposition ($eU>U$) or that uranium compounds have been deposited out of solutions and have not yet reached equilibrium ($eU<U$).

Rosholt's (1957, 1959) preliminary studies of radioactivity disequilibrium indicate that:

1. Uranium deposited under conditions approximating those under which the Cave Hills coal beds probably were mineralized would normally attain equilibrium in about 250,000 years.
2. Samples showing an excess of uranium probably have had uranium added rather than daughter products removed.
3. Samples showing an excess of equivalent uranium probably have had uranium removed rather than daughter products added.

Theoretically the time in which uranium would achieve equilibrium with its daughter products is about 500,000 years. In practice, however, the exact quantities of uranium and daughter products cannot be determined. Rosholt (oral commun., 1959) conservatively estimated that analytical errors prevent correctly determining degrees of equilibrium beyond 90 percent. Thus, the figure 250,000 years used in this report is more realistic with regard to analytical results.

Figure 18 shows the rate of growth and the rate of decay of the longer lived daughter products of uranium 238—thorium (Th^{230}) and radium (Ra^{226})—and of uranium 235—protactinum (Pa^{231}). The half life of U^{238} (4.5 billion years) is about 56,000 times longer than the half life of its daughter product Th^{230} (80,000 years) and about 2.8 million times longer than the half life of its daughter product Ra^{226} (1,622 years). Therefore, the quantities of daughter products in a sample in radioactive balance would be extremely small compared to the quantity of the parent uranium. For that reason, it is more convenient to speak of equivalent rather than actual daughter-product quantities. Thus, in figure 38, eTh^{230} means that amount of U^{238} which would be in equilibrium with a given amount of Th^{230}.

The isotope-ratio scale at the left of figure 18 represents, in effect, percent equilibrium. In those samples containing an excess of uranium over daughter products, if the original quantity of uranium and daughter products has not been changed by processes other than spontaneous radioactive decay, the ratio of the individual daughter products to their parent can be used to determine the age of uranium deposition.

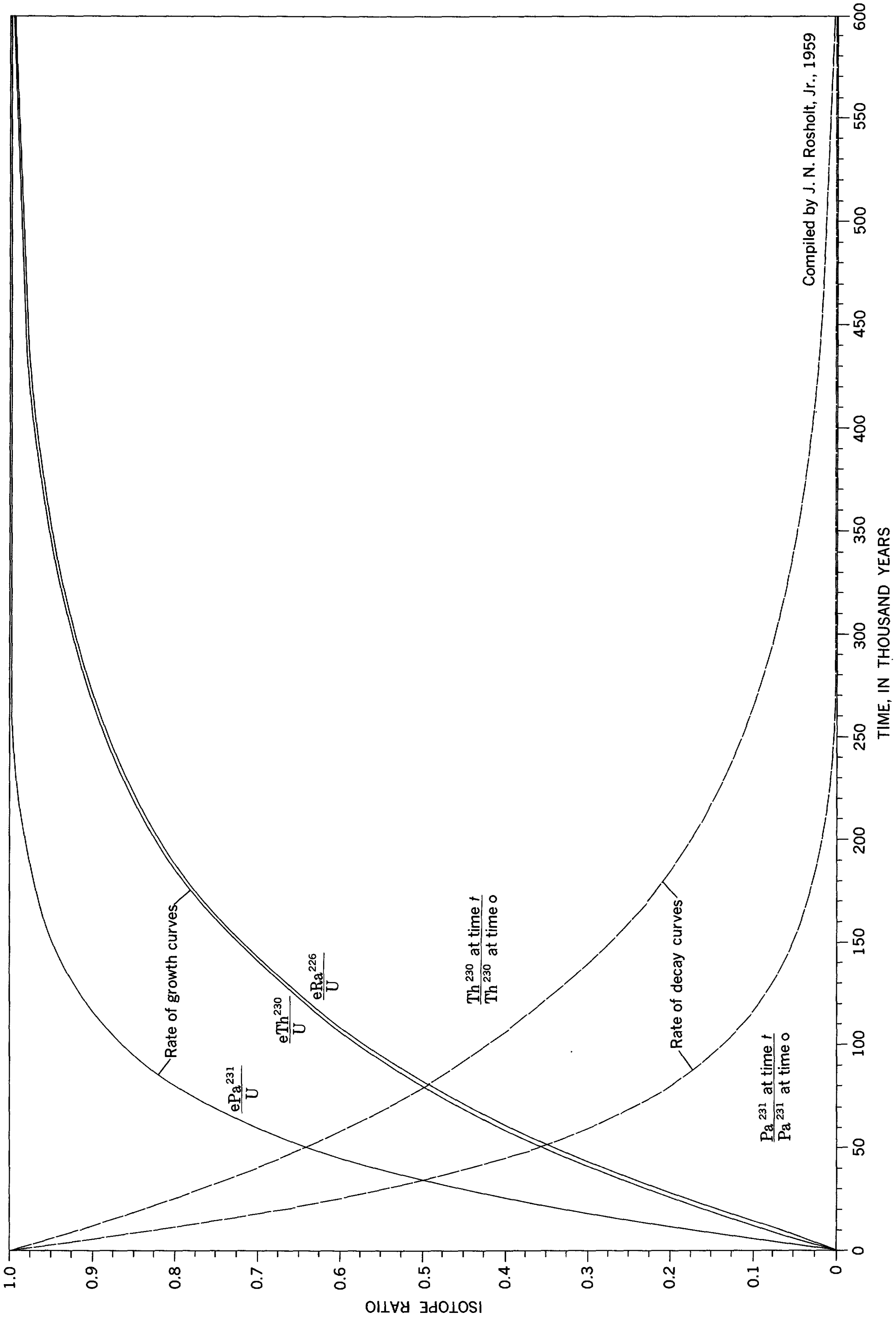


FIGURE 18.—Growth and decay rates of some radioactive daughter products.

TABLE 4.—*Radiochemical analyses and age determinations of uranium mineralization in seven samples from coal bed E in the central part of the South Riley Pass district and from the North Riley Pass district, Harding County, S. Dak.*

[Analyses of radioactive daughter products by J. N. Rosholt, Jr., U.S. Geol. Survey Lab., Denver, Colo.]

Locality	Laboratory No.	Analyses, in percent							Age of uranium mineralization: Isotope ratio			Age, in years, on the basis of[1]:		
		U in sample	eU in sample	ePa231	eTh230	eRa226	eRn222	ePb210	ePa231/U	eTh230/U	eRa226/U	Pa231	Th230	Ra226
17a	237052	1.17	0.99	2.08	2.02	1.96	0.89	0.96	------	------	------	------	------	------
17b	237053	.43	.24	.30	.21	.20	.12	.19	0.70	0.49	0.47	60,000	78,000	76,000
61a	237048	2.76	1.8	3.98	4.57	3.06	1.6	1.42	------	------	------	------	------	------
61b	237049	.67	.54	.92	.82	.70	.36	.45	------	------	------	------	------	------
61c	237050	.22	.12	.077	.055	.057	.05	.091	.35	.25	.26	22,000	34,000	38,000
61d	237051	.046	.037	.058	.038	.038	.03	.054	------	.83	.83	------	200,000	210,000
GSD-580[2]	223487	4.2	2.3	3.96	3.51	3.85	1.78	.91	.94	.84	.92	140,000	210,000	290,000

[1] Determined from figure 18.
[2] From Rosholt (1959, p. 25).

The fact that a sample with excess uranium will achieve equilibrium in a given time is fairly well known; somewhat less obvious is the fact that a sample with excess equivalent uranium will achieve radioactivity equilibrium in the same length of time. If a sample were to have all of its uranium leached, all of its radioactive daughter products would disappear in about 500,000 years. Similarly in a sample leached of only part of its uranium, the excess amount of radioactive daughter products would disappear in about 500,000 years, and again the sample would be in equilibrium.

Analyses of radioactive daughter products in one sample (GSD–580) from coal bed E in the North Riley Pass district were reported by Rosholt (1959, p. 25). These analyses together with analyses of six additional samples are shown in table 4. Samples 17a, 61a, and 61b are actually uranium deficient according to the isotope analyses, although radiometrically they appear to be in disequilibrium in favor of uranium; and they cannot be used for determinations of the age of uranium mineralization. The rest have an excess of uranium; and their age determinations, based on the ratio of equivalent isotope to uranium, are shown in the right half of table 4. Samples 17a, 61a, and GSD–580 contain uranium minerals coating analcite spherulites and fracture surfaces in the coal.

Geologic evidence discussed under the heading "Origin of the uranium deposits and source of the uranium" indicates that the principal uranium mineralization took place in late Miocene or early Pliocene time and that there have been minor periods of mineralization since. Therefore, it is probable that the ages of mineralization shown in table 4 are those of secondary enrichments of uranium that took place at various intervals throughout late Pleistocene time.

The amounts of radon (Rn^{222}) and of its daughter product lead (Pb^{210}) are small in all these samples (table 4). Some of the radon undoubtedly was removed from the coal by weathering, but most of it probably was lost during the grinding of the samples preliminary to analysis. Radon loss results in lowered apparent radioactivity in the sample so that some samples apparently in disequilibrium in favor of uranium are in reality in balance or may be uranium deficient, as are samples 17a, 61a, and 61b. The equivalent-uranium–uranium ratio in the seven samples under consideration does not exceed 2. Yet in four samples of the seven, apparent equivalent-uranium–uranium relationships are real. Thus most of the samples in tables 6, 7, 8, and 9 that reportedly contain an excess of uranium over equivalent uranium probably do contain an excess of uranium, particularly when the uranium content exceeds the equivalent uranium content by 2 or more times. Inasmuch as radon loss is not significant in samples that contain an excess of equivalent uranium, it is probable that radon loss does not seriously affect general conclusions drawn from overall equivalent-uranium–uranium relations as illustrated in most of the figures, such as in figures 20–23 which are discussed in the last part of this section.

To summarize the preceding discussion, the following conclusions seem valid:

1. Disequilibrium in rocks is the result of enrichment or leaching of uranium rather than of its daughter products.
2. Rocks in which U=eU were mineralized more than about 250,000 years ago and have not been subjected to either leaching or enrichment of uranium content within the last 250,000 years.
3. Rocks in which U>eU either were mineralized more than about 250,000 years ago and have been enriched in uranium approximately within the last 250,000 years, or the uranium was deposited within the last 250,000 years and has not reached equilibrium.
4. Rocks in which eU>U have been leached of uranium within the last 250,000 years.

RELIABILITY OF RADIOMETRIC AND CHEMICAL ANALYSES

Radiometric and chemical analyses for equivalent uranium and uranium were made for all 716 samples collected in the Cave Hills. Of these samples, 556 were also chemically analyzed for percent ash (A) and percent uranium in ash (UA). Inasmuch as the validity of several lines of reasoning and conclusions presented in the succeeding pages depends on the state of equivalent-uranium–uranium disequilibrium, it was desirable to eliminate from consideration most of those samples whose true state of equilibrium might be in doubt and to minimize the amount of apparent disequilibrium in the samples.

The percent expectable error in analyzing for equivalent uranium and uranium in the sample by radiometric and chemical methods is shown in table 5. The limits of error shown in figures 19–23 and 25 were constructed from table 5 by plotting maximum equivalent uranium versus minimum uranium and maximum uranium versus minimum equivalent uranium for a series of values ranging from 0.0003 percent through 10 percent and connecting the points thus obtained with smooth curves.

Thus, the plot of a sample, which appears to be in disequilibrium in favor of uranium and whose equivalent-uranium and uranium contents are reported to be 0.009 and 0.012 percent, respectively, is assumed to be in balance (sample 43, fig. 25*B*). Sample 7 has equivalent uranium and uranium contents of 0.008 and 0.15 percent, respectively (fig. 25*B*). It has an apparent excess of uranium of 0.007 percent. However, the excess uranium is assumed to be only 0.004 percent because that is the amount that would have to be deducted from the reported uranium content (0.15) to bring the plot of this sample to the edge of the "in balance area."

A similar procedure is followed in determining the equilibrium state of samples that have an apparent excess of equivalent uranium. The manner in which the equilibrium state was determined in each sample, as well as the percent disequilibrium and the average excess of equivalent uranium or uranium found in the sample groups, is illustrated in figure 19.

TABLE 5.—*Percent and limits of expectable error in radiometric and chemical analyses for eauivalent uranium and uranium in samples*

[Error estimated by J. N. Rosholt, Jr., and W. W. Niles, U.S. Geol. Survey lab., Denver, Colo.]

Equivalent uranium (eU)				Uranium (U)			
Error (percent)	eU (percent)	Maximum [1]	Minimum [1]	Error (percent)	U (percent)	Maximum [1]	Minimum [1]
100	0.0003– 0.002	0.0006– 0.004	0.00015–0.0005	100	0.0003	0.0006	0.00015
50	.003 – .004	.0045– .006	.0015 – .002	50	.0005– 0.00075	.00075– 0.00113	.00025–0.00035
30	.005 – .007	.0065– .009	.0035 – .005	20	.001 – .004	.0012 – .0048	.0008 – .0032
20	.008 – .010	.0096– .012	.0064 – .008	15	.005 – .007	.0058 – .008	.0042 – .006
15	.015	.017	.013	10	.008 – .015	.0088 – .0165	.0072 – .0135
12	.02 – .04	.0224– .045	.0176 – .035	5	.02 – .2	.021 – .21	.019 – .19
10	.05 – .2	.055 – .22	.045 – .18	3	.3 – 1.0	.31 – 1.03	.29 – .97
7	.3 – 1.0	.32 – 1.07	.28 – .93	2	2.0 –10.0	2.04 –10.2	1.96 –9.8
10	2.0 –10.0	2.2 –11.0	1.8 –9.0				

[1] Used in constructing limits of analytical error shown in figures 19–23 and 25.

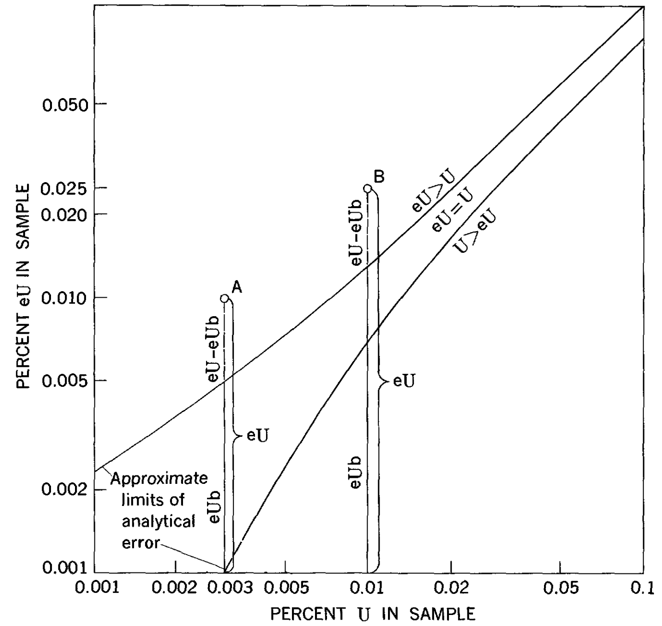
RADIOACTIVITY-EQUILIBRIUM STATUS OF SAMPLES FROM DIFFERENT STRATIGRAPHIC ZONES

Radioactivity equilibrium and disequilibrium, as well as the kind and intensity of disequilibrium, of samples, are closely related to the stratigraphic position of the beds. Samples in radioactivity equilibrium show a decreasing intensity of mineralization stratigraphically downward. Samples with the greatest excess equivalent-uranium content are stratigraphically high; those with the greatest excess uranium content are stratigraphically lower. The general direction of uranium transfer was from stratigraphically high source rocks to stratigraphically lower host rocks. As a consequence, the equilibrium status of sample groups is discussed in descending stratigraphic order.

Although the uranium content and equilibrium status of sample groups are in general dependent upon stratigraphic position, they are even more closely dependent upon proximity to aquifers. This is true not only of sample groups from host rocks that closely underlie and overlie the principal aquifer in the area, the D- and E-bed sandstones, but it is true also of sample groups from host rocks in the vicinity of other porous beds such as the sandstone dikes and the sandstone bodies in coal bed E of the central South Riley Pass district (fig. 13). This association suggests that the initial uranium mineralization, as well as the subsequent leaching and redeposition of uranium in host rocks was accomplished by circulating ground water.

Graphic illustrations were compiled as a means of studying the equilibrium status of all the sampled groups, but only the diagrams that showed unusual equivalent-uranium–uranium relations in sample groups were included in the text.

Analyses of eight samples from the Chadron Formation of the Cave Hills area show that all the samples



eU, Equivalent uranium in sample.
eUb, Equivalent uranium in balance with uranium in sample.
eU−eUb, Excess eU in sample.
⊙ A, Plot of sample A containing 0.01 percent eU and 0.003 percent U.
⊙ B, Plot of sample B containing 0.025 percent eU and 0.01 percent U.
Procedure used to determine percent disequilibrium and excess eU in sample group:

Sample	eU	eUb	eU−eUb
A	0.01	0.005	0.005
B	.025	.013	.012
	.035	.018	.017

Percent disequilibrium in sample group AB:

$$\frac{\text{Total eU}-\text{eUb}}{\text{Total eUb}}$$

$$\frac{0.017}{0.018}$$

0.94×100

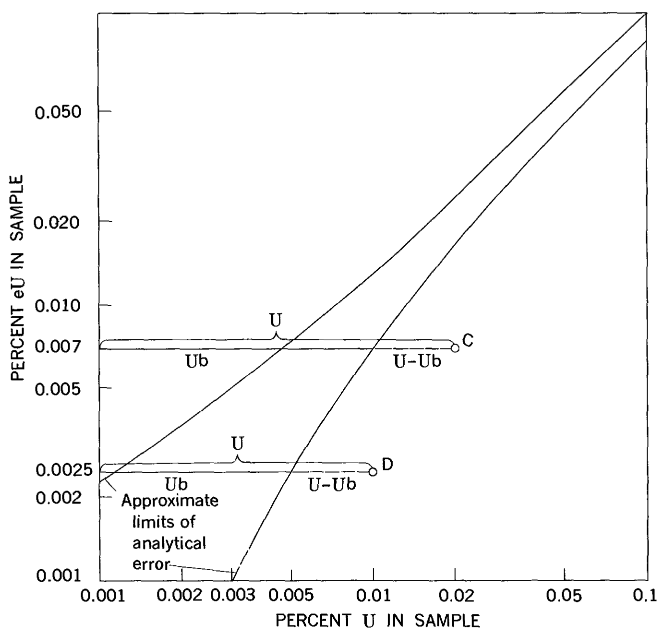
94 percent

Average excess eU in sample group AB:

$$\frac{\text{Total eU}-\text{eUb}}{\text{Total number of samples}}$$

$$\frac{0.017}{2}$$

0.0085



U, Uranium in sample.
Ub, Uranium in balance with equivalent uranium in sample.
U−Ub, Excess uranium in sample.
⊙C, Plot of sample C containing 0.007 percent eU and 0.02 percent U.
⊙D, Plot of sample D containing 0.0025 percent eU and 0.01 percent U.
Procedure used to determine percent disequilibrium and excess U in sample group:

Sample	U	Ub	U−Ub
C	0.02	0.01	0.01
D	.01	.005	.005
	.03	.015	.015

Percent disequilibrium in sample group CD:

$$\frac{\text{Total U}-\text{Ub}}{\text{Total Ub}}$$

$$\frac{0.015}{0.015}$$

1×100

100 percent

Average excess U in sample group CD:

$$\frac{\text{Total U}-\text{Ub}}{\text{Total number of samples}}$$

$$\frac{0.015}{2}$$

0.0075

FIGURE 19.—Procedures used to determine percent disequilibrium and average excess equivalent uranium (eU) or uranium (U) in sample groups.

are essentially in balance but that there is a slight suggestion of imbalance in favor of equivalent uranium. Each of these samples contains 0.001 percent uranium. It has been shown by analyses of seven samples from the Cedar Canyon deposits in the Slim Buttes (Gill and Moore, 1955, p. 259) that the equivalent-uranium content ranges from 0.036 to 0.14 percent and averages 0.076 percent, whereas the uranium content ranges from 0.001 to 0.23 percent and averages 0.1 percent. All these samples are in disequilibrium. Five of the seven samples contain an excess of uranium; the other two, including the sample with the lowest uranium content (0.001 percent), contain an excess of equivalent uranium. The general equivalent-uranium–uranium relations indicate that these samples were enriched in uranium and then locally leached of uranium. These samples contrast with samples from the Chadron Formation in the Cave Hills both in uranium content and in radioactivity-equilibrium status. Samples from the Chadron Formation in the Slim Buttes, other than those

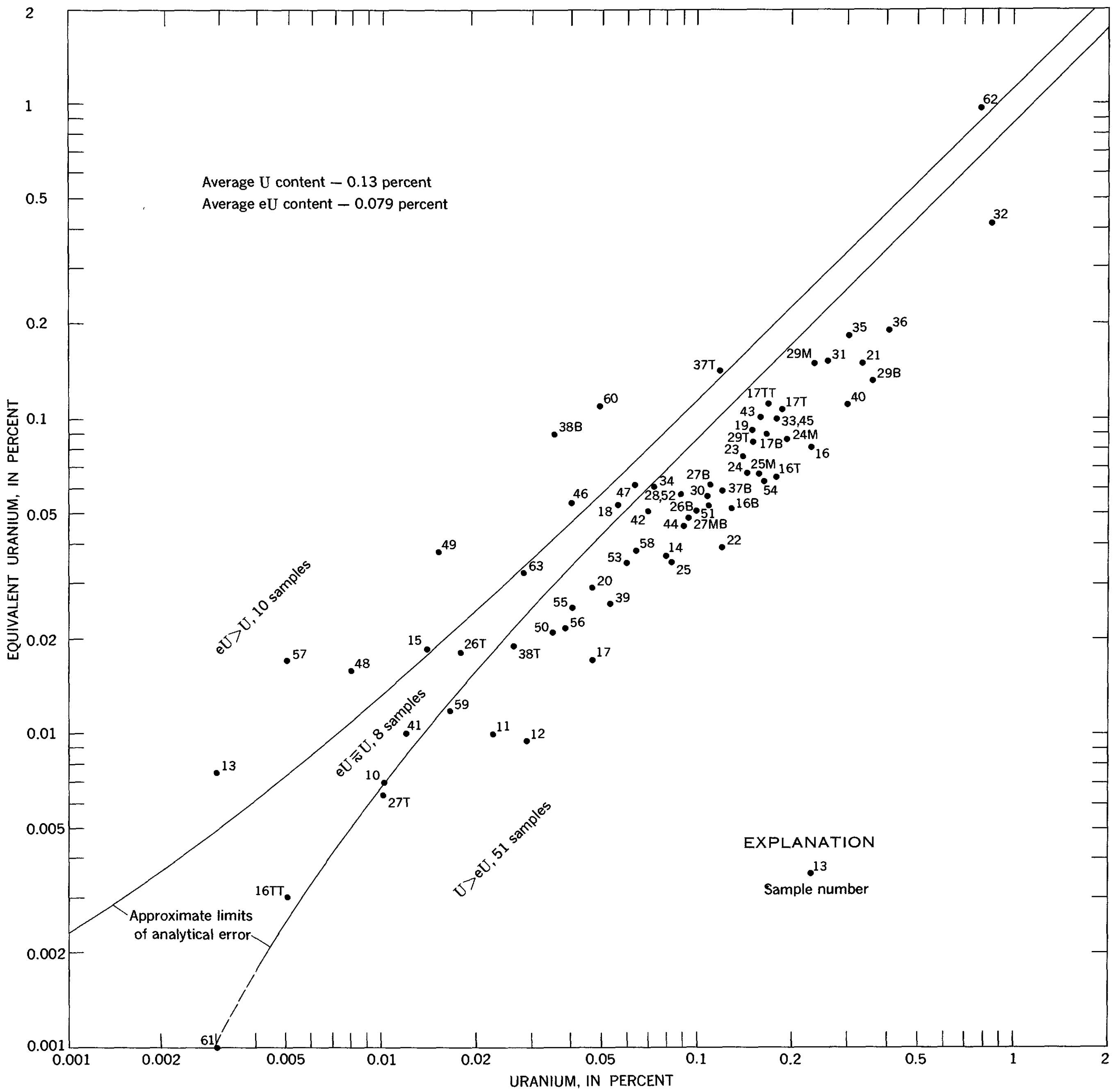


FIGURE 20.—Equivalent-uranium–uranium relations in 69 samples from coal bed E, North Riley Pass district and vicinity, Cave Hills, Harding County, S. Dak. (See table 7 for sample data.)

from the Cedar Canyon deposits, contain small quantities of uranium (0.0003 percent or less). This indicates either that they have been subjected to more leaching than have the samples from the Cave Hills or that they originally contained less uranium. The latter possibility is the more likely and suggests that the outliers in the Cave Hills are remnants of slightly enriched parts of the Chadron analogous to the carnotite deposits in the Slim Buttes.

The equilibrium relations in coal zone F are not unusual, but those in coal bed E in the Traverse Ranch and Riley Pass districts (figs. 20–23) show that a large proportion of the samples contain an excess of uranium over equivalent uranium.

The equilibrium relations of samples from coal bed E in the Traverse Ranch and Riley Pass districts are summarized in figure 24. As shown in column 4 of

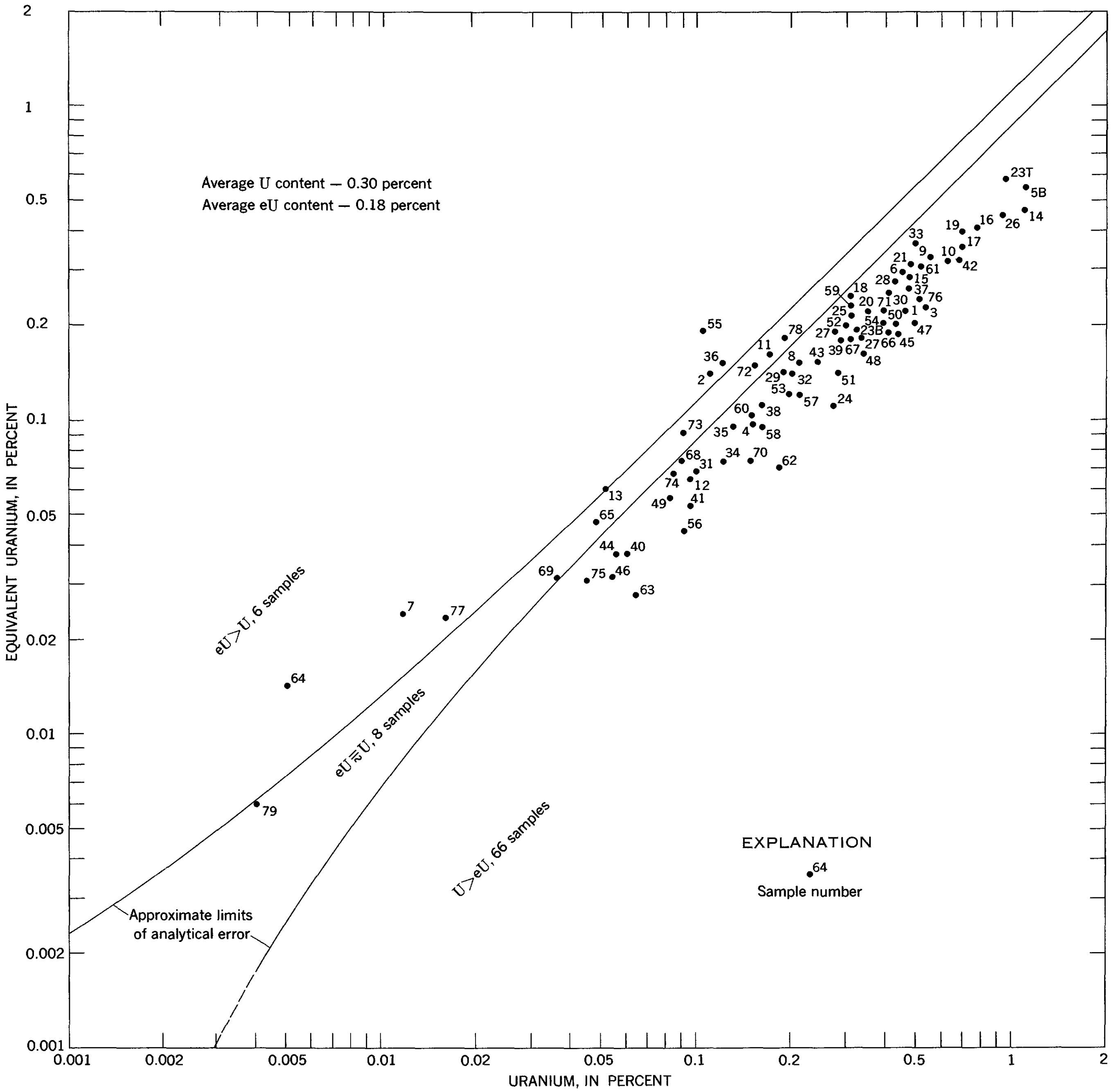


Figure 21.—Equivalent-uranium–uranium relations in 80 samples from coal bed E, western part of the South Riley Pass district, Cave Hills, Harding County, S. Dak. (See fig. 12 and table 6 for sample data.)

figure 24, only in the central and eastern parts of the South Riley Pass district are most of the rocks sampled in balance. In the other three areas most of the samples are in disequilibrium; in the North Riley Pass district and in the western part of the South Riley Pass district, 70–80 percent of the samples contain an excess amount of uranium. This indicates that the equilibrium status of rocks in the central and eastern parts of the South Riley Pass district has been affected only slightly, whereas in the other three areas the radioactivity disequilibrium has been affected greatly by the groundwater movement.

The fifth and sixth columns of figure 20 show only the samples that are in disequilibrium. Column 5 indicates the intensity or efficacy of the processes that resulted in the disequilibrium of the rocks sampled, and column 6 shows the actual amounts of excess equivalent uranium or uranium in the rocks sampled regardless of

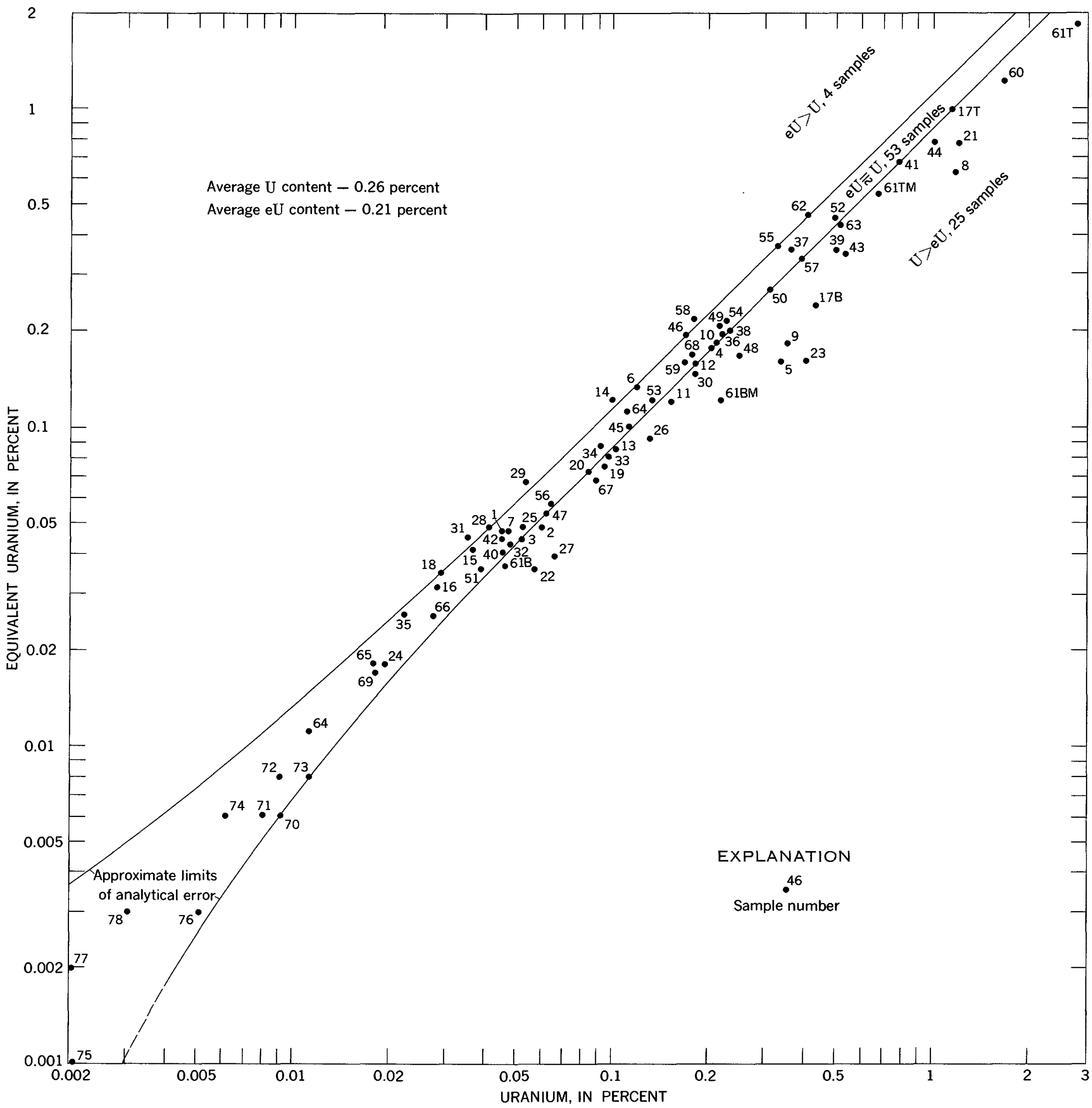


FIGURE 22.—Equivalent-uranium–uranium relations in 82 samples from coal bed E, central part of the South Riley Pass district, Cave Hills, Harding County, S. Dak. (See fig. 13 and table 6 for sample data.)

the degree of disequilibrium in each area of sampled rock.

Study of the data in columns 5 and 6 suggests that the degree of mineralization, or of leaching, is not consistently related to the total quantities of uranium or equivalent uranium involved. For example, the samples containing an excess of uranium in the North Riley Pass district indicate more than four times as much disequilibrium as those in the eastern part of the South Riley Pass district (75 percent compared with 17 per cent, col. 5, fig. 24). Yet the average excess uranium in samples from the South Riley Pass district exceeds that

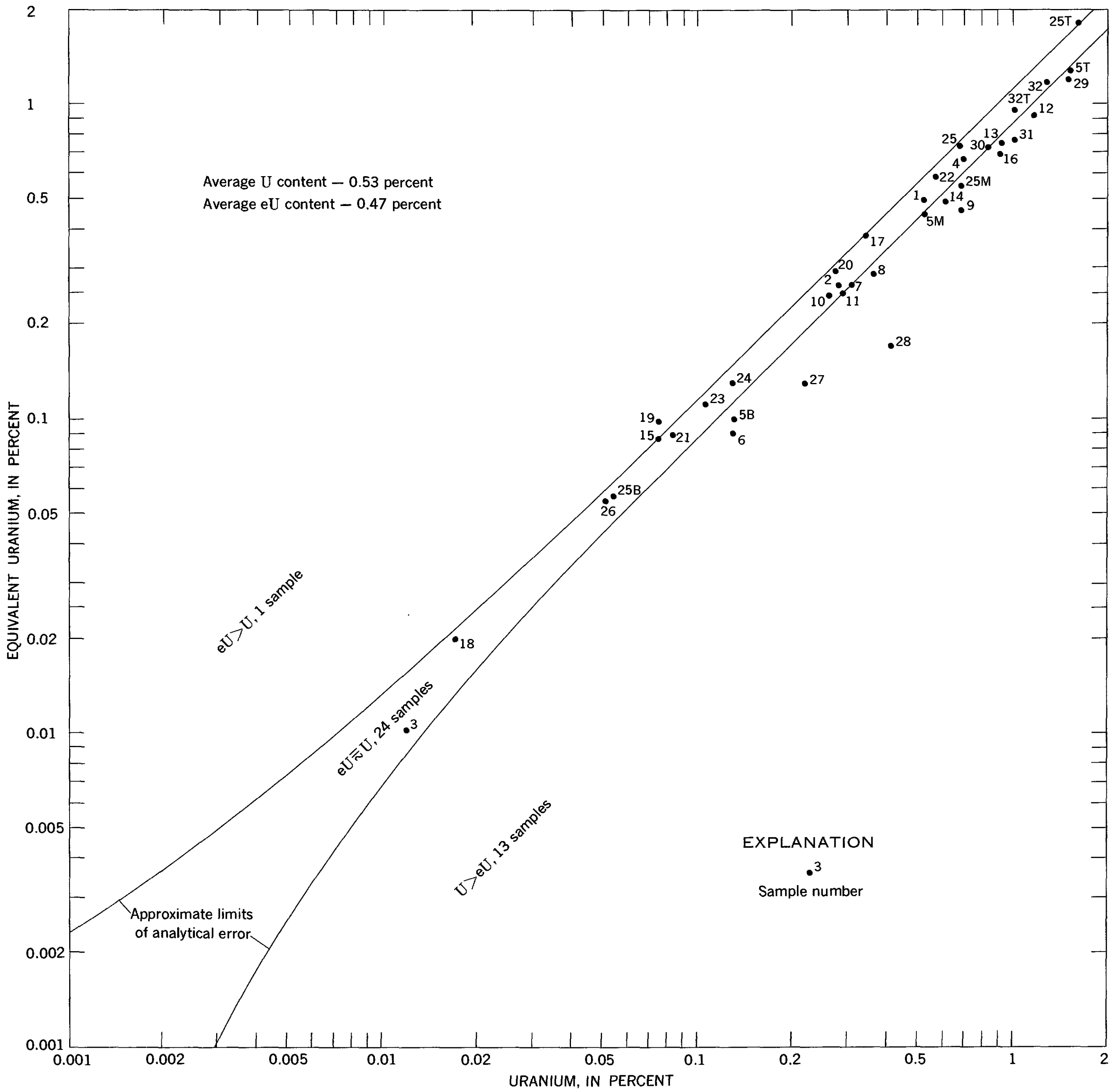


FIGURE 23.—Equivalent-uranium–uranium relations in 38 samples from coal bed E, eastern part of the South Riley Pass district, Cave Hills, Harding County, S. Dak. (See fig. 14 and table 6 for sample data.)

in samples from the North Riley Pass district (0.12 percent compared with 0.062 percent uranium, col. 6, fig. 24).

In each district considered in columns 5 and 6 (fig. 24), a larger percentage of uranium was added than was carried away; thus, the radioactivity-equilibrium status of these samples is not simply the result of the uranium being shifted from one spot to another. More probably it indicates that some of the uranium was contributed to these beds from an outside source and that the uranium was enriched relatively recently.

Equilibrium relations in samples from the Carbonate coal zone are almost normal. In contrast, most of the samples from the carbonaceous siltstone in this zone at

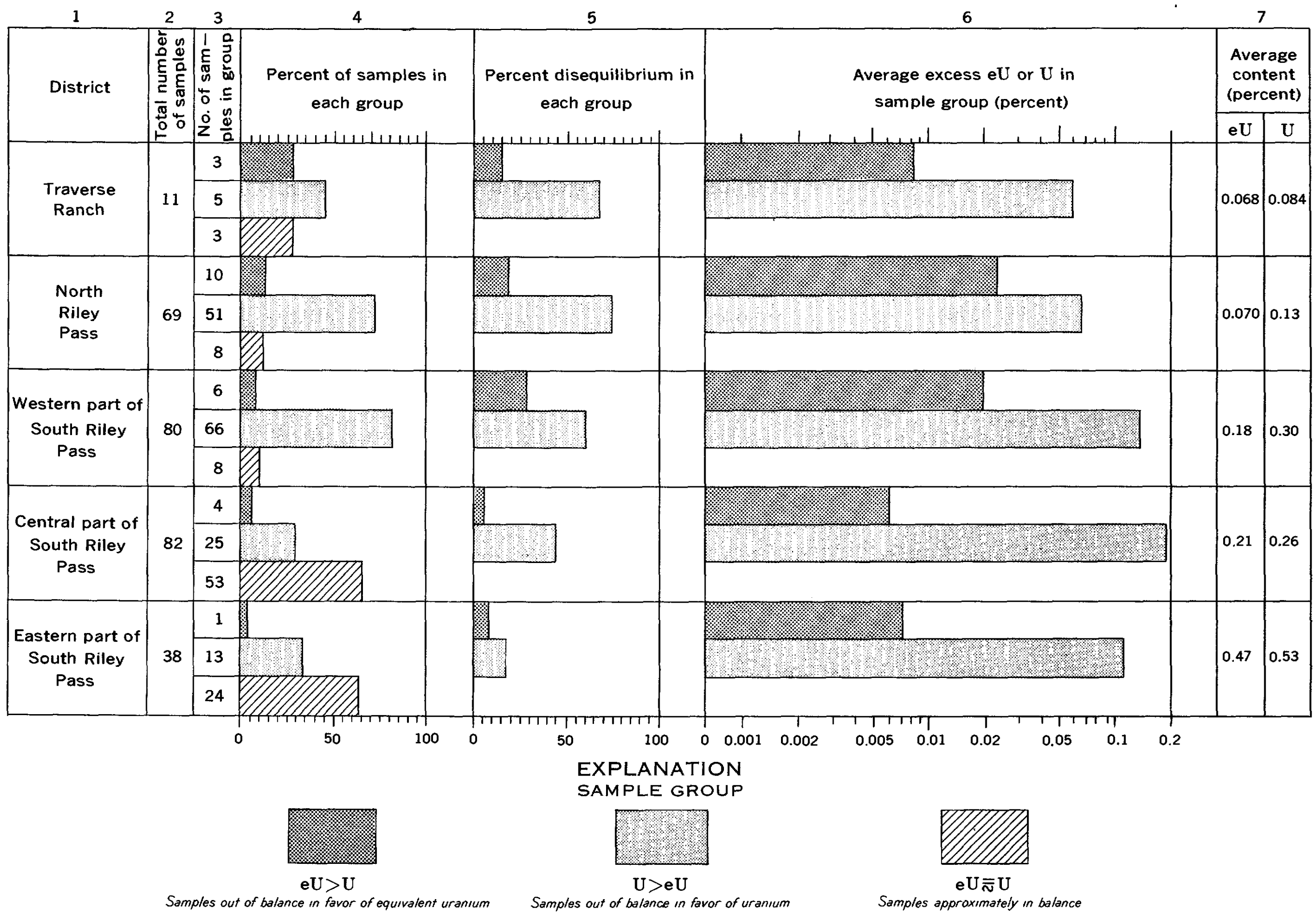


Figure 24.—Equivalent-uranium–uranium relations in coal bed E; summarized from data shown in figures 20–23, and in tables 6 and 7.

the Carbonate prospect show considerable disequilibrium. In the north pit, 85 percent of the samples are either in balance or contain an excess of uranium; in the south pit, about 80 feet away (see pl. 3*C*), 98 percent of the samples are either in balance or contain an excess of equivalent uranium (figs. 25, 26).

The disequilibrium relations shown in figures 25 and 26 are interpreted as follows: At some time after the sandstone dikes were intruded into the Carbonate zone (pl. 3*A*, fig. 16 middle and lower), uranium-bearing ground water entered the host rock at the Carbonate prospect through the sandstone dikes; the host rock probably was mineralized only in the vicinity of the sandstone dikes because little if any uranium-bearing water, whether flowing through aquifers above or below the host rock, could enter the relatively impermeable host rock without a means of access such as the dikes. The permeability characteristics of the overlying sandstone beds in the Tongue River Member and of the floor rock with its dikelike extensions probably are similar to those of the samples from the E-bed sandstone that underlines coal bed E at the U.S. Geological Survey drill hole (fig. 6). As discussed under the heading "Stratigraphy," the lateral permeability in these samples is greater than the vertical permeability; thus features such as sandstone dikes would be the most probable conduits through which ground water might enter beds such as the carbonaceous siltstone.

Uranium was probably concentrated in the host rocks during several periods of time. These periods possibly include the time of erosion of the Oligocene rocks and a later interval of erosion of any Miocene or Pliocene rocks which perhaps may have once overlain the Oligocene. Sufficient time elapsed after each period of mineralization for the uranium to achieve equilibrium with its daughter products. Samples in which the uranium is approximately equal to the equivalent uranium probably represent earlier periods of mineralization. The rocks represented by these samples have not been affected by subsequent periods of enrichment, nor by weathering and leaching. The excess uranium in the rocks sampled from the Carbonate prospect was probably deposited within about the last 250,000 years.

If an examination of the Carbonate prospect could have been made prior to the last period of equilibrium disturbance, the south pit probably would have shown a higher uranium content than the north pit, principally because it contained more dikes and therefore more entrances for uranium-bearing water.

The equivalent-uranium content may be taken as a measure of the original uranium content of the south pit immediately following enrichment; that its equivalent-uranium content is greater than the uranium content of the north pit would tend to support the inference that the original uranium content of the south pit was greater than the original uranium content of the north pit. Subsequent dissection by erosion caused the level of the water table to drop. Eventually the host rocks at the Carbonate prospect were in the zone of weathering and subsequent leaching of uranium above the water table. Because the south pit had more sandstone dikes, the uranium deposits there were more exposed to weathering and leaching than were the deposits in the north pit.

The distribution pattern of uranium in the south pit as shown in the section on plate 3*A* tends to support the suggestion that leaching has been greatest in the vicinity of the sandstone dikes. The long arcuate dike near the middle of the pit parallels a band whose uranium content (0.05–0.1 percent) is lower than that of the host rock farther from this dike. The pinched effect in the isochemical contours as they cross the upper and lower parts of the dike at the left side of the south pit likewise suggests leaching. The discontinuous distribution of the richest parts of the host rock in the south pit, in general, also tends to suggest leaching.

The north pit, with fewer points for water entry, showed only scattered evidence of leaching. Most samples from the north pit are either in balance or out of balance in favor of uranium. Thus the north pit is probably more nearly representative of a typical deposit after the latest period of mineralization and before leaching. It presents an appearance probably much like that which the south pit would be expected to have shown prior to leaching of uranium.

Column 5 (percent disequilibrium) in the summary diagram of equivalent-uranium–uranium relations (fig. 26) shows a greater intensity of both enrichment and impoverishment of uranium in the south pit. Of the two processes, leaching far exceeds enrichment, perhaps because the period of leaching to which the pit was and is being subjected has been longer than the preceding period of mineralization.

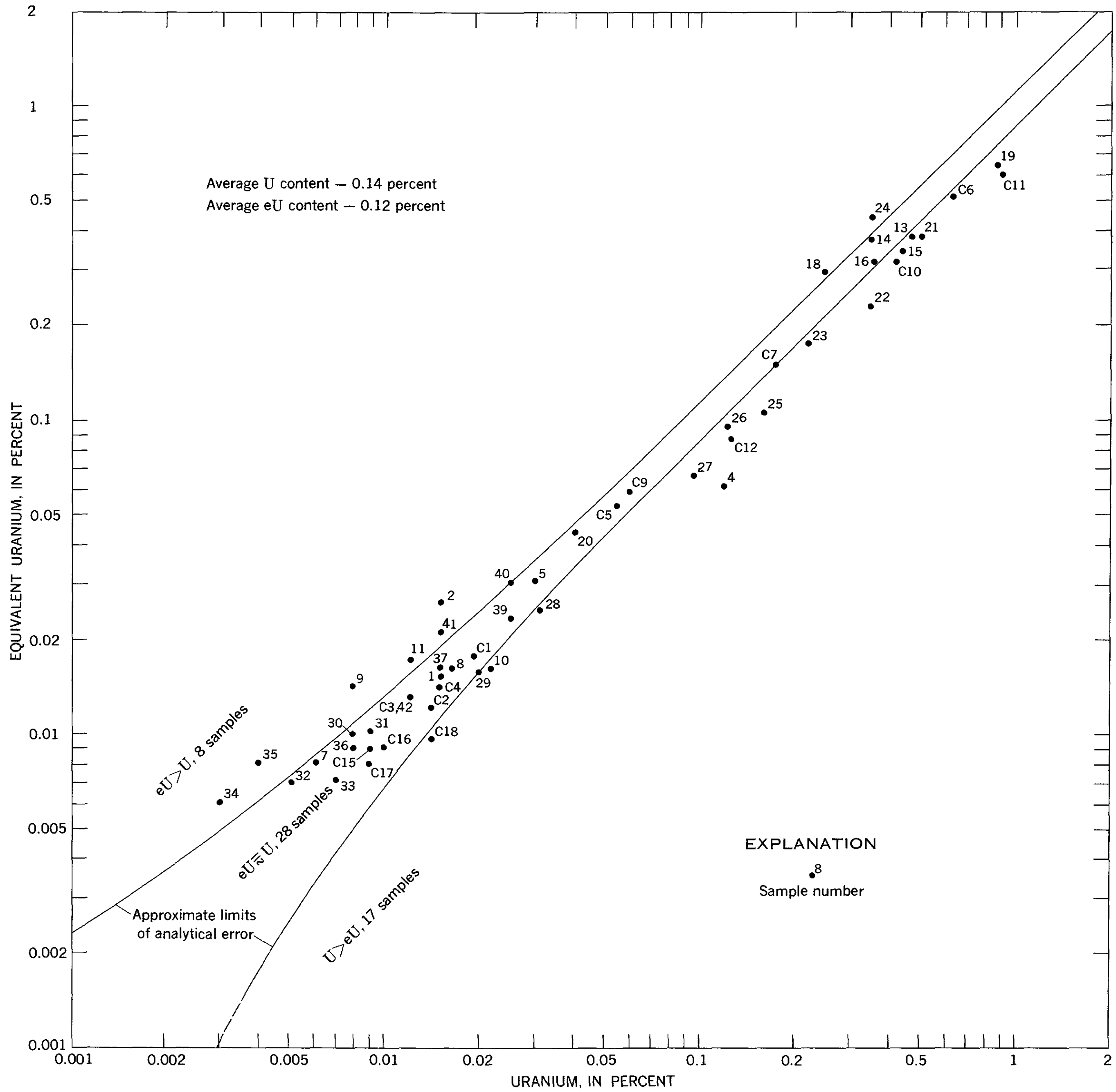
The average excess equivalent uranium or uranium in the samples from the north and south pits of the Carbonate prospect is indicative of the addition or subtraction of uranium (col. 6, fig. 26). The greater percentage of excess equivalent uranium in samples from the south pit in comparison with that in samples from the north pit indicates that leaching of uranium has been more extensive in the south pit than in the north pit. Conversely, the greater percentage of excess uranium in the samples from the north pit indicates that more uranium was added to the rocks in this locality than to the rocks represented by the samples from the south pit.

Although the percent disequilibrium of uranium is greater in the south pit than in the north pit (col. 5, fig. 26) and is indicative that the south pit was more intensely mineralized than the north pit, it is not clear as to why the amount of uranium added in the vicinity of the south pit was less than that in the north pit.

Evidence supporting the suggestion that leaching followed enrichment, during the disturbance of the equilibrium in the sampled rocks with the past half million years, is found in a group of samples taken from and alongside the large dike shown in the north-pit diagram (pl. 3*A*). Samples 3, 17, 18, and 38 (pl. 3*E* and fig. 25 left) are out of balance in favor of equivalent uranium. Samples (C5–C13) from the channels on either side of the dike as well as the grab samples (15, 16) are either in balance or contain an excess of uranium.

The original distribution of uranium in the vicinity of the south pit has been too greatly altered to allow any conclusions to be drawn concerning the order of enrichment and leaching. All but five of the samples in the left three-quarters of the south-pit diagram (to the left of a line drawn between sample localities 29 and 30) contain an excess of uranium (pl. 3*E* and fig. 25 right).

The equivalent-uranium–uranium relations in 60 samples from coal zone C (tables 6, 7) are nearly normal: 68 percent of the samples is in approximate equilibrium, 27 percent contains an excess of uranium, and 5 percent contains an excess of equivalent uranium. Sample 7T, from the upper part of coal bed C No. 1 in the Traverse Ranch district (table 6), exhibits an anomalously high imbalance in favor of equivalent uranium; whereas sample 7B, from the lower part of the bed, is in balance. In contrast, samples from an adjacent locality (8T and 8B, table 6) show the reverse—the bottom of the bed contains the excess equivalent uranium. In the samples containing an excess of equivalent uranium, 7T and 8B, the ash contents are 48 and 49 percent, respectively; whereas in the samples that are more nearly in balance, 7B and 8T, the ash contents are 34 and 37 percent, respectively. It is suggested that the more impure (higher ash content) parts of the bed were more permeable and conducive to surface and ground-water movement and were leached to a greater extent than was the rest of the coal bed.

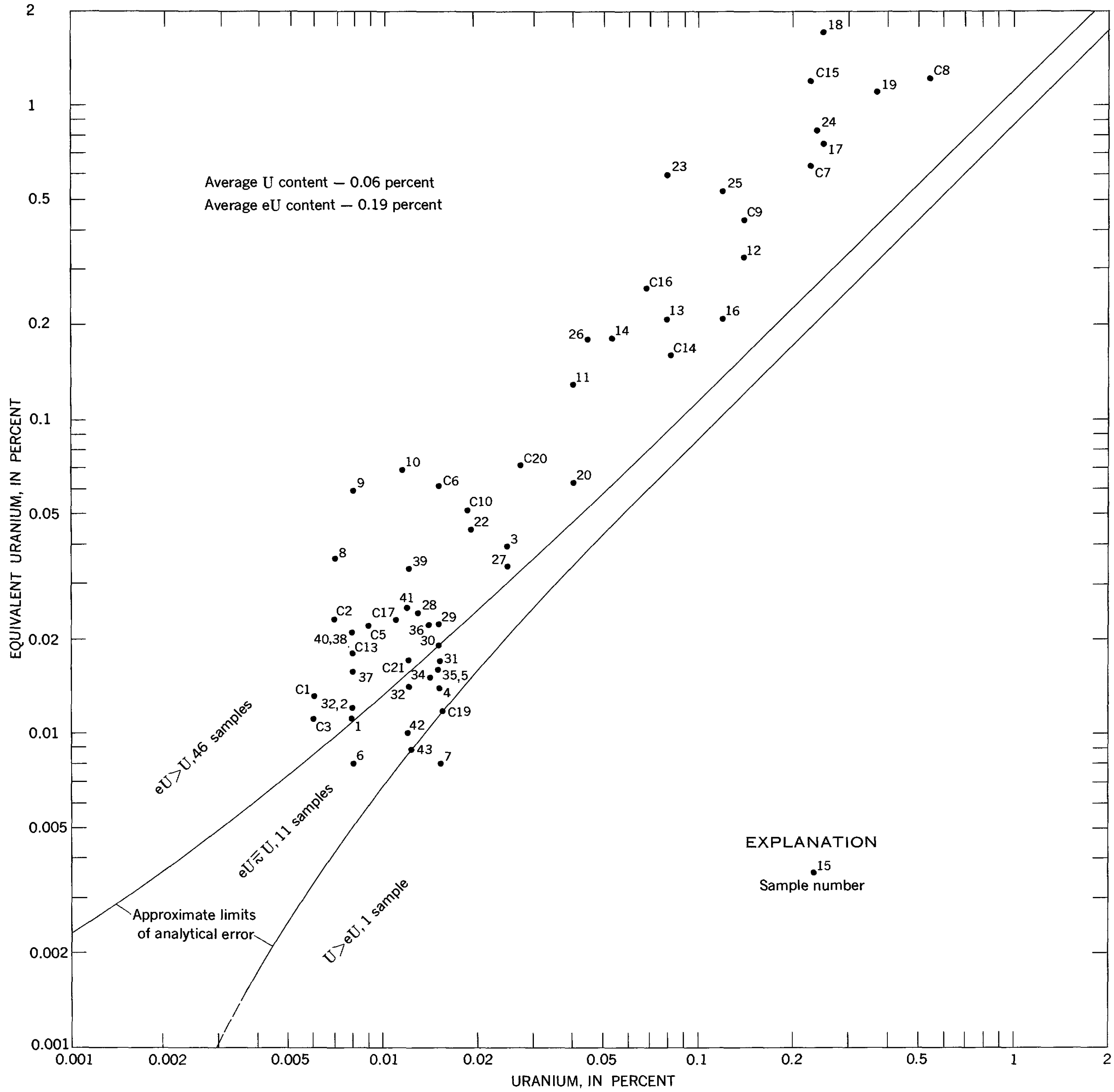


North pit (53 samples).

FIGURE 25.—EQUIVALENT-URANIUM–URANIUM RELATIONS IN CARBONACEOUS SILT

The radioactivity-equilibrium status in the four remaining stratigraphic units in this study is almost normal. Two samples from coal zone B, 7 samples from the Lonesome Pete ore zone, 6 samples from Lonesome Pete coal bed, and 10 samples from the lower coal beds contain an excess of uranium. The rest of the samples are in equilibrium with the exception of one sample from the Lonesome Pete ore zone which contains a small excess of equivalent uranium. These equilibrium conditions suggest that since the earlier periods of mineralization these units have been subjected to some additional uranium enrichment but to practically no weathering and leaching of uranium.

The equivalent-uranium–uranium relations in samples from the Cave Hills area are summarized in figure 27. Radioactivity equilibrium of the Chadron apparently



South pit (58 samples). (See table 8 and pl. 3*E* for sample data.)

FROM THE CARBONACEOUS PROSPECT, SOUTH CAVE HILLS, HARDING COUNTY, S. DAK.

has not been disturbed for the last 250,000 years. Chadron outliers that are perched on the butte tops are subject to leaching only by rainfall, and apparently the rainfall has not been great enough to upset the radioactivity-equilibrium relations in this formation.

Within the Fort Union Formation the most striking features shown in figure 27 are the relatively intense or more recent disturbance of equilibrium and the generally large average quantities of equivalent uranium and uranium involved in the leaching and enrichment of coal bed E, the Carbonate coal and ore zones, and coal zone C. The stratigraphically high coal zone F and all the units below coal zone C, with the exception of one sample from the Lonesome Pete ore zone, were unaffected by leaching.

The four leached stratigraphic units underlie and

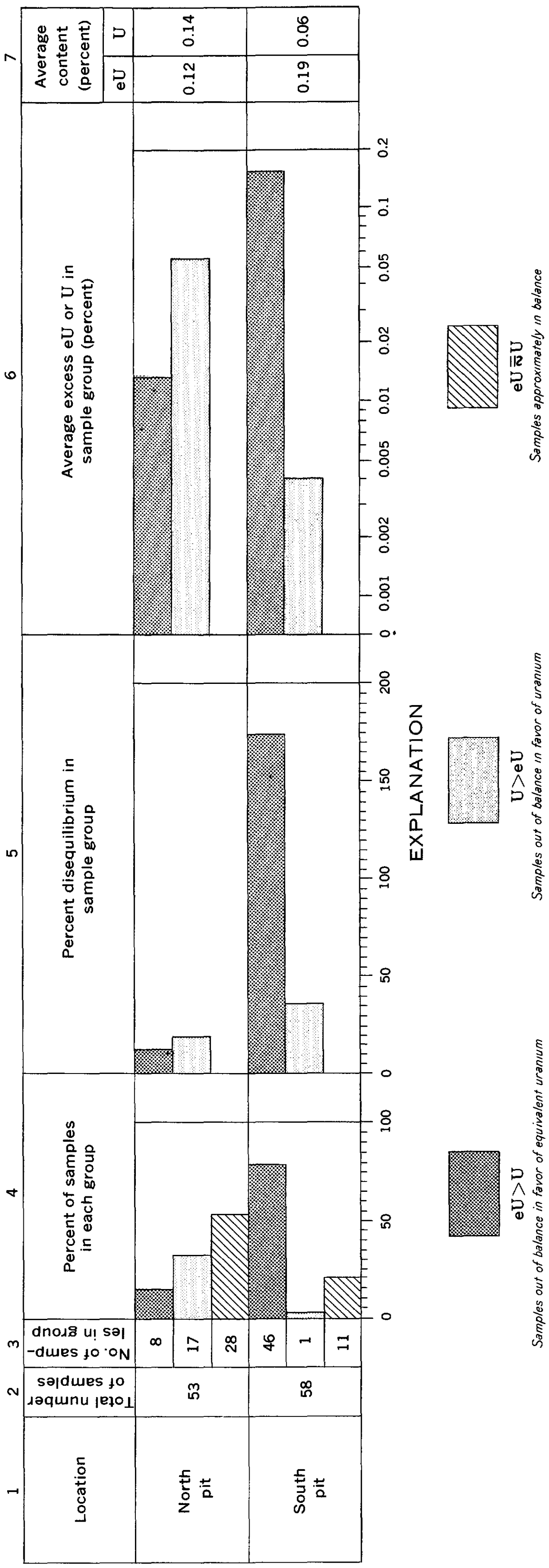


FIGURE 26.—Equivalent-uranium–uranium relations in the Carbonate prospect; summarized from data shown in figure 25.

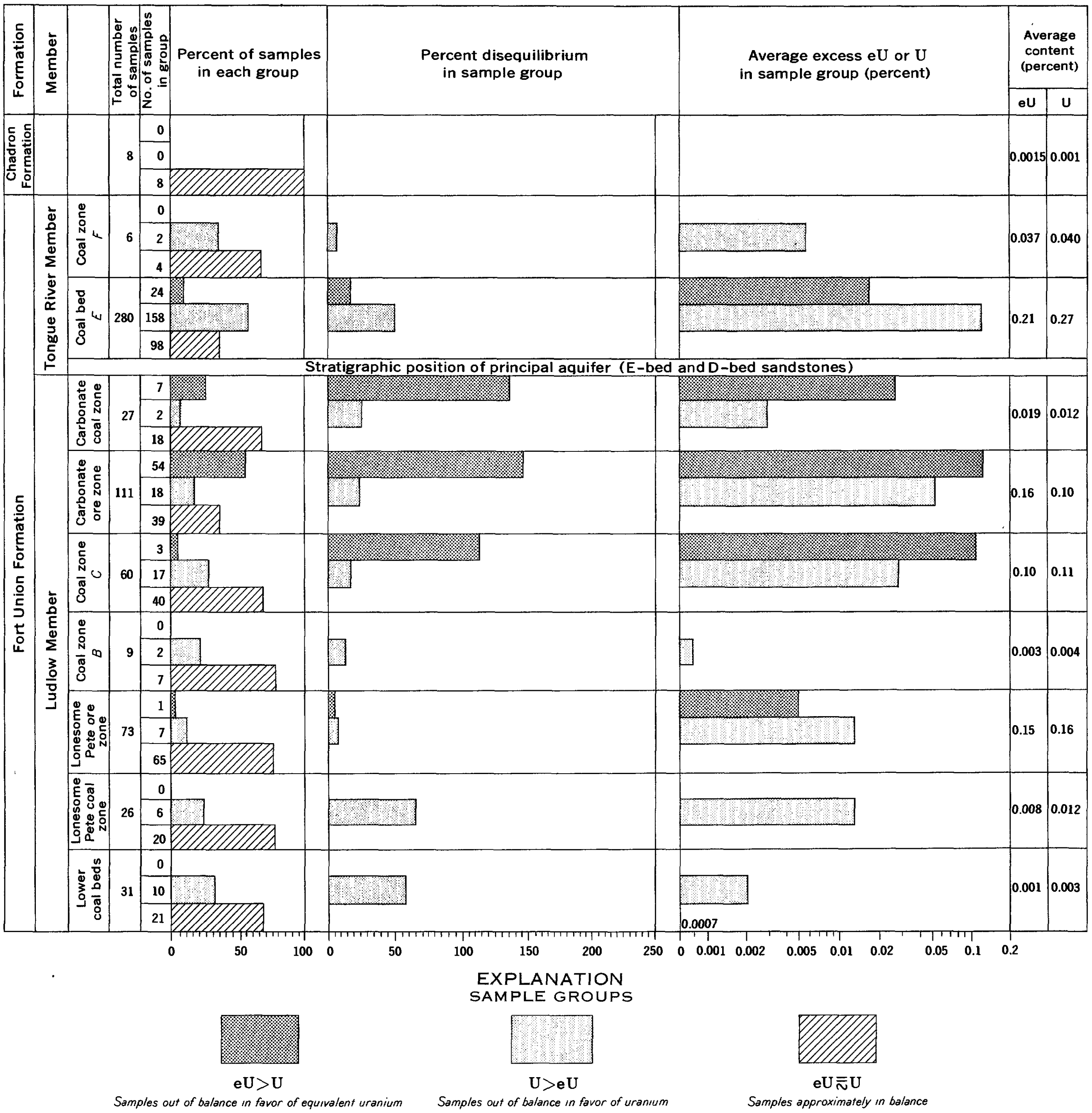


FIGURE 27.—Equivalent-uranium–uranium relations in the Chadron and Fort Union Formations; summarized from data shown in tables 6–10.

overlie the thick homogeneous sandstone sequence at the base of the Tongue River Member of the Fort Union. The sandstone is the principal aquifer in the area, and the leaching and enrichment of adjacent units are directly related to it. Coal zone F, like the Chadron outliers, has not been affected by the aquifer. However, locally coal zone F is overlain by younger rocks of the Tongue River and conceivably could have been enriched with uranium leached from them.

The intense leaching in the units above and below the aquifer and the relatively intense enrichment in the two stratigraphically lowest units suggest that part of the uranium removed from the higher zones eventually was redeposited in the lower beds. However, the descending intensity of enrichment from coal bed E down through the Lonesome Pete ore zone probably is not due solely to redeposition. If only "balanced" samples are considered, the downward-decreasing intensity of mineralization is still the same. This suggests that an early period of enrichment probably occurred when the aquifer was continuous throughout the area. The subsequent leaching and redeposition, however, could have happened either while the aquifer was still intact or when the valleys dissecting the aquifer were shallow and filled with permeable sediments that formed a closed circulatory system between valley fill and the aquifer. In either case, disturbance of radioactivity equilibrium could not have occurred earlier than 250,000 years ago. The gravel remnant on McKensie Butte mentioned under "Stratigraphy" might have been part of the hypothetical alluvial fill, and it may further indicate that the topographic level of the fill was high enough to have buried most of the aquifer remnants.

White (1958, table 1, p. 33, and p. 67–68) found radioactive barite closely associated with uranium minerals at several localities in the South Riley Pass district. "One flat analcite lens was found to be coated by a layer of the uranium mineral (sodium-autunite) which in turn was coated by a thin layer of radioactive barite." He concluded "the figure for the maximum age of the radioactive barite (15,000 years) together with the observations on the variable radioactivity of the uranium minerals and their very close association with the barite suggest that the uranium minerals have formed recently." The foregoing indicates that the formation of visible uranium minerals followed by deposition of radioactive barite are two of the most recent geochemical events in the Cave Hills area.

ORIGIN OF THE URANIUM DEPOSITS AND SOURCE OF THE URANIUM

There is little doubt that uranium mineralization was effected by circulating uranium-bearing ground water after the Paleocene host rocks were coalified or lithified and that subsequent leaching of the host rocks and redeposition of uranium likewise resulted from circulating ground water. The principal reasons for these beliefs are summarized below:

1. Uranium content of host rocks generally decreases downward, which suggests descending mineralizing solutions.
2. Uranium content generally is greatest in host rocks adjacent to aquifers and is least in host rocks that are farthest from the aquifers.
3. Uranium is commonly localized in areal extent and in stratigraphic range.
4. Localization of uranium and degree of radioactivity disequilibrium is controlled partly by structure but mostly by proximity to aquifers.
5. Host rocks adjacent to stratigraphically high aquifers show both excess uranium and excess equivalent uranium (enriched and leached); those adjacent to stratigraphically low aquifers show only excess uranium (enriched).

Analcitization and initial uranium mineralization seem to have occurred at about the same time, but some of the analcite probably was formed slightly earlier than the uranium occurrences with which it is now associated. This is suggested by the fact that some coal samples that have abundant analcite spherulites contain as little as 0.002 percent uranium. Chemical analyses of a sample of Lonesome Pete phosphatic claystone indicate that both the analcite spherulites and the matrix from which they were supersonically separated contained 0.04 percent uranium. The analcite spherulites may have formed at the time of deposition of the uranium, or they may have formed preceding mineralization; but it is unlikely that they formed after mineralization.

Dating of the formation of the analcite and of the accompanying uranium mineralization is possible from observations noted by Denson and Gill in areas adjacent to the Cave Hills area (Denson and Gill, 1965; Gill, 1962). Denson and Gill noted that throughout large areas in South Dakota, North Dakota, and adjacent parts of Montana rocks beneath the pre-Oligocene erosion surface are abundantly analcitized where directly overlain by the Arikaree Formation but are rarely analcitized where directly overlain by the Chadron Formation. Bedded analcite occurs at the contact of the Arikaree and the underlying Brule Formation (Oligocene) at the level of the perched water table in the Slim Buttes, sec. 29, T. 17 N., R. 8 E. Furthermore, analcite was abundant in the fault planes bounding fossil landslide blocks of the Brule Formation (Oligocene) in the Finger Buttes, Carter County, Mont., sec. 32, T. 5 S., R. 60 E. These landslide blocks are unconformably overlain by the Arikaree Formation. The landslides, therefore, occurred after the Brule was deposited and before deposition of the Arikaree, and analcitization took place after the landsliding.

If one considers all the foregoing evidence, it is highly probable that analcitization of the rocks was accomplished by ground water, that the Arikaree Formation was the principal source of the analcite found in older rocks, and that the analcitization of these rocks occurred after the deposition of the Arikaree Formation—probably after consolidation, uplift, and erosion of that formation in late Miocene and possibly early Pliocene time.

A coincidence in stratigraphic distribution of analcite and uranium and the probability that the Arikaree Formation was the principal source of analcite suggest that most of the uranium was also derived from that formation in Miocene or post-Miocene time.

According to J. R. Gill (oral commun., 1960), at many places in the Northern Great Plains where the Chadron Formation is absent and the Arikaree Formation of Miocene age rests directly on the Fort Union Formation, uranium mineralization in the Fort Union is generally greater than where the Chadron Formation is present. The lithology and permeability of the Brule Formation of middle and late Oligocene age resemble those of the Arikaree Formation. Presumably, uranium mineralization in host rocks directly overlain by the Brule should also be generally greater than where the Chadron Formation is present, but this suggestion has not been tested by field observations.

In the Slim Buttes and in the White River Badlands of South Dakota, the Chadron Formation also contains a few sporadic uranium occurrences (Moore and Levish, 1955, p. 2, 4) between impermeable beds, indicating that it was also a potential source for uranium. Ground waters from the Chadron, Brule, and Arikaree Formations contain about the same amounts of uranium—8, 8.5, and 10 ppb—as well as an abundance of sodium and other elements needed to form analcite (J. R. Gill, written commun., 1960).

The widespread occurrence of impervious bentonitic claystone and bentonite beds in the Chadron Formation (some of the bentonite beds are as much as 25 ft. thick (Gill and Moore, 1955, p. 253)) suggest that ground water containing uranium released by devitrification of volcanic material would have difficulty percolating downward into the underlying host rocks of the Fort Union Formation. As a result of the differences in the permeability of these two sequences, the top of the Chadron Formation supports a perched water table and water flows from springs along the contact with the overlying Arikaree Formation throughout most of the Slim Buttes district. Carnotite deposits also occur near the Chadron-Arikaree contact, and "* * * abnormal radioactivity readings have been obtained at the contact of the White River group and the Arikaree formation throughout the Slim Buttes" (Gill and Moore, 1955, p. 259).

Host rocks overlain by the Arikaree Formation generally are more highly mineralized than those overlain by the Chadron Formation because the Arikaree Formation is more permeable; this conclusion not only constitutes a convincing explanation as to why Miocene rocks contributed more uranium than did the Oligocene rocks but also serves to strengthen the original suggestion (inferred from the stratigraphic association of uranium and analcite) that the Miocene rocks did indeed contribute more uranium than the Oligocene rocks.

The foregoing observations suggest methods of prospecting for uranium. Prospecting for uranium deposits in older host rocks such as coal beds of Paleocene or Eocene age by searching in areas that are now directly overlain by permeable source rocks such as the Brule and Arikaree Formations should be more rewarding than searching in areas that are now directly overlain by impermeable source rocks such as the Chadron Formation. Furthermore, in areas where permeable source rocks occur, uranium is likely to be localized at the contact of the source rocks with the host rocks if the host rocks are impermeable, or it is likely to be distributed through the upper part of the host-rock sequence if the sequence is permeable (as in the Cave Hills). Host rocks are not likely to be highly mineralized where both impermeable and permeable source rocks overlie them in that order, but uranium deposits may occur at the contact of the impermeable and permeable source rocks, as exemplified by the carnotite deposits in Cedar Canyon, Slim Buttes.

The Cave Hills area is a small part of a larger region—including adjacent parts of Montana, Wyoming, North Dakota, and South Dakota—whose numerous uranium-in-coal occurrences have been under investigation by N. M. Denson and others since 1950. In 1950, Denson, Bachman, and Zeller (1959, p. 30) proposed that the uranium in host rocks of this region "is epigenetic in origin, being derived from unconformably overlying tuffaceous source rocks and carried by ground water percolating downward or moving laterally along aquifers near the lignite beds and extracted by the lignite after coalification."

The present investigation substantiates and amplifies in detail the conclusions of the earlier regional study by Denson, Bachman, and Zeller. Syngenetic and diagenetic hypotheses that have been proposed to explain the origin of these uranium occurrences (Wyant and Beroni, 1950, p. 18; Beroni and Bauer, 1952, p. 39; Gruner, 1956, p. 515; and others) seem to be inadequate and untenable.

The probable geologic history of the deposition and concentration of the uranium and the history of other pertinent geologic events in the Cave Hills area are summarized as follows:

1. Deposition of potential host rocks and aquifers of the Fort Union Formation in Paleocene time.
2. Deposition of rocks of Eocene age.
3. Folding, jointing, regional uplift, and erosion near

the end of Eocene time. Exposed and near-surface parts of the Fort Union Formation probably were oxidized at this time.

4. Deposition of source rocks (the Chadron Formation) of Oligocene age that buried and preserved topographic features resulting from erosion during stage 3.
5. Leaching of some uranium from the Chadron Formation by ground water and deposition of it in underlying host rocks. Mineralization ceased with, or was retarded by, the formation of impervious bentonite and bentonitic claystone beds.
6. Deposition of Brule Formation of Oligocene age.
7. Regional uplift and erosion; landsliding in late Oligocene or early Miocene time (post-Brule, pre-Arikaree). Most of the Brule and much of the Chadron Formations were stripped from the area. Some uranium mineralization occurred locally.
8. Deposition of the Arikaree Formation of Miocene age. More intense mineralization of underlying Fort Union host rocks began and continued throughout Miocene time wherever the Arikaree Formation rested directly on the host rocks.
9. Regional uplift and erosion. All the Miocene sequence was stripped from the Cave Hills area, concluding the principal period of mineralization in this area.
10. Deposition of slightly uraniferous rocks of Pliocene age. Uranium mineralization of host rocks may have continued but at a greatly diminished rate.
11. Regional uplift and erosion at or near the end of Pliocene time resulting in the exhumation of topographic features buried by deposition during stage 4.
12. Minor deposition alternating with major erosion throughout Quaternary time. Little if any uranium was transferred from source rocks still remaining in the area. Locally, part of the uranium was leached from the host rocks and was redeposited structurally lower in the same bed or in other stratigraphically lower host rocks. Leaching caused a deficiency of uranium in host rocks, and redeposition caused an excess of uranium. The presence of visible uranium minerals was the result of redeposition of uranium. Highly radioactive but uranium-deficient deposits such as radioactive barite were formed during this time as the result of extreme leaching of weathered host rocks and redeposition of the residual uranium daughter products.

ANALYTICAL DATA

TABLE 6.—*Uranium content of coal samples, Cave Hills area, S. Dak.*

[Values in percent. Uranium content calculated from uranium content of ash. Samples are of complete coal bed except as indicated by letters included in locality number (T, top; M, middle; B, bottom; TM, top of middle; and so forth). Chemical analyses by Glen Edgington, Joseph Budinsky, Grafton Daniels, and Roosevelt Moore; radioactivity analyses by B. A. McCall, U.S. Geol. Survey lab., Washington, D.C.]

Map locality No.	Laboratory No.	Thickness (feet)	Ash	U in ash	U in sample	eU in sample
COAL BED E						
Western part of the South Riley Pass district						
1	146027	0.5	63	0.73	0.46	0.22
2	146028	.4	69	.16	.11	.14
3	146029	.7	56	.95	.53	.23
4	146025	.3	81	.19	.15	.098
5B	145777	.4	59	1.9	1.1	.55
6	146026	1.0	44	1.0	.46	.29
7	145785	.6	77	.016	.012	.024
8	146020	.4	74	.28	.21	.15
9	146021	.3	55	1.0	.55	.33
10	146022	.5	64	.99	.63	.32
11	146023	.5	70	.24	.17	.16
12	146024	.5	80	.12	.095	.066
13	146018	.5	79	.064	.050	.060
14	145776	1.0	46	2.4	1.1	.46
15	146019	.8	68	.7	.47	.28
16	145783	.9	55	1.4	.78	.41
17	145794	.7	57	1.2	.70	.35
18	145784	.9	63	.50	.31	.24
19	146014	1.0	59	1.2	.70	.39
20	146015	.8	54	.65	.35	.22
21	146016	1.1	52	.94	.49	.31
22	146017	.7	61	.54	.33	.18
23T	146042	.4	53	1.8	.96	.59
23B	146043	.6	62	.52	.32	.19
24	145775	1.3	38	.72	.27	.11
25	146013	1.1	45	.70	.31	.21
26	145782	.7	51	1.9	.94	.44
27	146011	1.1	36	.77	.28	.19
28	146012	.4	68	.63	.43	.27
29	145790	1.1	51	.37	.19	.14
30	145774	1.4	45	.91	.41	.25
31	145781	.5	70	.14	.98	.059
32	146007	1.0	80	.26	.20	.14
33	146008	1.0	50	1.0	.50	.36
34	146009	1.0	43	.30	.12	.075
35	146010	.6	69	.19	.13	.095
36	146004	.7	80	.15	.12	.15
37	145789	.8	53	.88	.47	.26
38	146005	.85	55	.31	.16	.11
39	145773	1.0	63	.46	.29	.18
40	146006	.6	58	.10	.058	.038
41	145780	.4	73	.13	.094	.053
42	145996	.5	72	.96	.68	.34
43	145997	.9	63	.39	.24	.15
44	145998	.9	45	.12	.053	.038
45	145999	1.0	44	.96	.42	.29
46	146000	.7	63	.085	.053	.032
47	146001	.3	69	.71	.49	.20
48	146002	.6	59	.58	.34	.16
49	146003	.3	74	.11	.081	.057
50	145788	.5	73	.59	.43	.20
51	145993	.9	63	.45	.28	.14
52	145772	.9	48	.63	.30	.20
53	145994	.5	76	.27	.20	.12
54	145779	.7	54	.72	.39	.20
55	145995	.8	70	.16	.11	.19
56	145787	1.0	53	.17	.090	.045
57	145987	.4	64	.33	.21	.12
58	145988	.9	62	.27	.16	.094
59	145989	.7	66	.48	.31	.23
60	145991	.6	54	.29	.15	.10
61	145990	1.1	66	.78	.51	.31
62	145778	1.2	39	.46	.18	.072
63	145786	.9	38	.17	.064	.028
64	145992	.4	85	.007	.005	.014
65	145793	.4	70	.068	.048	.048
66	146037	.8	71	.57	.41	.20
67	146038	.9	71	.44	.31	.18
68	146039	.9	50	.18	.090	.075
69	146040	.8	56	.063	.035	.033
70	146041	.9	41	.35	.15	.075
71	146034	.7	66	.59	.39	.22
72	146035	.7	66	.23	.15	.15
73	145792	.5	65	.14	.09	.092
74	146036	.4	77	.11	.084	.068
75	146030	1.1	49	.094	.045	.031
76	146031	.7	53	.98	.51	.24
77	146032	.6	69	.024	.016	.024
78	146033	.5	75	.26	.19	.18
79	145791	.5	77	.005	.004	.006
Central part of the South Riley Pass district						
1	146549	0.8	73	0.060	0.044	0.046
2	146548	.6	60	.10	.060	.049

TABLE 6.—*Uranium content of coal samples, Cave Hills area, S. Dak.*—Continued

Map locality No.	Laboratory No.	Thickness (feet)	Ash	U in ash	U in sample	eU in sample
COAL BED E—Continued						
Central part of the South Riley Pass district—Continued						
3	146547	0.4	84	0.060	0.051	0.045
4	146546	.7	66	.30	.20	.18
5	146545	.8	49	.68	.34	.16
6	146544	.6	74	.16	.12	.13
7	146543	.7	64	.072	.046	.046
8	146542	1.4	57	2.1	1.2	.63
9	146541	1.4	52	.68	.35	.19
10	146540	1.1	37	.56	.20	.18
11	146539	1.1	48	.32	.15	.12
12	146538	.7	46	.40	.18	.16
13	146537	.7	37	.28	.10	.084
14	146550	.7	74	.14	.10	.12
15	146536	.7	74	.048	.036	.042
16	146535	.5	79	.036	.028	.032
17T	237052	.6	43	[1] 2.7	1.17	[2] .99
17B	237053	.8	45	[1] .95	.43	[2] .24
18	146534	.2	78	.036	.028	.035
19	146533	.5	75	.13	.097	.076
20	146532	.6	70	.12	.083	.071
21	146531	1.0	68	1.8	1.2	.78
22	146530	.4	57	.10	.057	.036
23	146529	.8	34	1.2	.40	.16
24	146528	.3	56	.034	.019	.018
25	146527	.95	79	.066	.052	.048
26	146526	.6	57	.23	.13	.093
27	146525	.4	78	.084	.065	.039
28	146524	.9	74	.056	.041	.048
29	146523	1.0	76	.070	.053	.067
30	146522	1.0	49	.37	.18	.15
31	146521	.7	62	.056	.035	.045
32	146520	.7	77	.060	.046	.046
33	146519	.8	45	.22	.098	.082
34	146518	.75	46	.20	.092	.087
35	146517	.6	74	.030	.022	.026
36	146516	.9	33	.62	.21	.19
37	146515	.7	41	.88	.36	.35
38	146514	.7	38	.60	.23	.20
39	146513	1.1	60	.84	.50	.36
40	146512	.6	57	.080	.045	.041
41	146555	1.0	55	1.4	.77	.69
42	146552	1.0	44	.78	.45	.45
43	146551	1.0	58	.90	.52	.35
44	146554	1.0	51	2.0	1.0	.79
45	146511	.6	73	.15	.11	.10
46	146510	1.0	61	.28	.17	.19
47	146509	.7	63	.10	.063	.054
48	146553	.8	60	.42	.25	.17
49	146508	1.0	59	.38	.22	.21
50	146823	.8	53	.57	.30	.27
51	146822	.4	86	.044	.038	.036
52	146821	.9	71	.70	.50	.45
53	146507	1.0	63	.70	.13	.12
54	146505	.7	45	.50	.22	.21
55	146506	1.1	40	.80	.33	.36
56	146504	.5	69	.092	.063	.056
57	146503	1.5	64	.60	.38	.34
58	146502	1.2	70	.26	.18	.21
59	146501	1.1	72	.24	.17	.16
60	238546	(3)	------	------	[1] 1.63	[2] 1.2
61T	237048	.3	52	[1] 5.3	2.76	[2] 1.8
61TM	237049	.3	35	[1] 1.9	.67	[2] .54
61BM	237050	.25	32	[1] .69	.22	[2] .12
61B	237051	.25	37	[1] .12	.046	[2] .037
62	146500	1.0	52	.80	.42	.46
63	146499	.95	51	1.0	.51	.44
64	146498	.2	69	.016	.011	.011
65	146497	.6	57	.032	.018	.018
66	146496	.9	52	.052	.027	.026
67	146493	.9	43	.20	.087	.069
68	146495	1.0	56	.30	.17	.16
69	146494	.6	80	.022	.018	.017
70	146492	.5	55	.018	.009	.006
71	146491	.3	38	.020	.008	.006
72	146490	.6	38	.024	.009	.008
73	146489	.6	48	.022	.011	.008
74	146488	.5	60	.010	.006	.006
75	146487	.4	48	.004	.002	.001
76	146486	.4	58	.008	.005	.003
77	146485	.4	59	.004	.002	.002
78	146484	.7	43	.008	.003	.003
Eastern part of the South Riley Pass district						
1	237174	1.5	32	1.6	0.52	0.48
2	237175	1.6	31	.92	.28	.26
3	237176	.8	31	.040	.012	.010
4	237177	1.3	49	1.4	.69	.69
5T	237178	.5	44	3.4	1.5	1.3

See footnotes at end of table.

TABLE 6.—*Uranium content of coal samples, Cave Hills area, S. Dak.*—Continued

Map locality No.	Laboratory No.	Thickness (feet)	Ash	U in ash	U in sample	eU in sample
COAL BED E—Continued						
Eastern part of the South Riley Pass district—Continued						
5M	237179	0.5	33	1.6	0.52	0.46
5B	237180	.5	36	.36	.13	.10
6	237181	.9	40	.32	.13	.092
7	237182	1.3	59	.50	.30	.27
8	237183	1.4	42	.85	.36	.29
9	237184	1.0	46	1.5	.69	.46
10	237185	1.4	34	.80	.27	.25
11	237186	1.3	28	1.0	.28	.20
12	237187	1.4	42	2.7	1.13	.94
13	237188	1.4	38	2.4	.91	.76
14	237189	1.4	38	1.6	.61	.49
15	237190	.6	63	.12	.075	.086
16	237191	1.3	58	1.6	.93	.73
17	237192	1.0	45	.75	.34	.37
18	237193	.4	54	.031	.017	.02
19	237194	.6	59	.13	.076	.094
20	237195	1.2	56	.50	.28	.29
21	237196	1.1	47	.18	.084	.087
22	237197	.9	59	.96	.57	.58
23	237199	.5	69	.16	.11	.11
24	237200	1.2	48	.26	.13	.13
25	237201	1.3	45	1.5	.68	.70
25T	237202	.4	58	2.8	1.6	1.8
25M	237202	.4	36	1.9	.69	.55
25B	237204	.5	42	.13	.054	.056
26	237205	1.0	59	.088	.052	.055
27	237206	.9	48	.46	.22	.13
28	237207	.7	53	.78	.41	.17
29	237208	1.0	50	3.0	1.5	1.2
30	237209	1.1	45	1.8	.81	.74
31	237210	1.2	51	2.0	1.0	.78
32	237212	1.4	29	4.6	1.3	1.2
32T	237211	.3	42	2.4	1.0	.95
COAL BED C NO. 1						
Traverse Ranch district						
1	149438	1.0	38	0.021	0.008	0.007
2T	149439	.7	57	.009	.005	.007
2B	149440	2.0	43	.028	.012	.010
3	149441	2.0	30	.095	.030	.018
4	149442	3.3	20	.021	.004	.003
5T	149443	.4	59	.008	.005	.011
5TM	149444	.4	54	.04	.021	.012
5BM	149445	1.0	34	.065	.022	.010
5B	149446	2.0	14	.029	.003	.002
6T	149344	2.0	22	.095	.021	.019
6B	149345	2.0	26	.05	.014	.012
7T	14943	1.5	48	.01	.002	.072
7B	149437	1.5	34	.015	.005	.007
8T	149434	1.5	37	.024	.009	.012
8B	149435	1.5	49	.51	.25	.55
9	149433	2.7	42	.017	.007	.008
10	149432	1.7	55	.11	.060	.057
11T	149430	1.4	43	.09	.037	.021
11B	149431	1.4	26	.046	.012	.011
12	149429	2.0	49	.08	.040	.036
13	149428	2.0	37	.06	.022	.023
14	149427	2.0	38	.36	.14	.070
15	149426	.7	44	.36	.16	.11
16	149350	.8	43	.19	.080	.076
17	149349	3.6	33	.09	.029	.028
18	149348	3.6	31	.23	.070	.063
18T	149347	.6	54	4.63	2.5	2.0
19	149346	3.5	41	.03	.013	.013

[1] Analysis by J. S. Wahlberg and R. P. Cox, U.S. Geological Survey Laboratory, Denver, Colo.
[2] Analysis by C. G. Angelo, U.S. Geological Survey Laboratory, Denver, Colo.
[3] Grab sample.

TABLE 7.—*Uranium content of miscellaneous coal samples mainly from localities peripheral to principal deposits*

[Values in percent. Uranium content calculated from uranium content of ash. Samples are of complete coal bed except as indicated by letters included in locality number (T, top; M, middle; B, bottom; TM, top of middle; and so forth) or by footnotes. Chemical analyses by Grafton Daniels, Roosevelt Moore, A. R. Sweeney, Irving May, Maryse Delevaux, and Carmen Johnson; radioactivity analyses by B. A. McCall, U.S. Geol. Survey lab., Washington, D.C.; except as otherwise noted]

Sample No.	Laboratory No.	Location			Thickness (feet)	Ash	U in ash	U in sample	eU in sample
		Sec.	T.N.	R.E.					
COAL ZONE F									
Riley Pass district and vicinity									
1	145297	NW¼NE¼SE¼ 22	22	5	0.3	39	0.55	0.22	0.18
2	237240	SW¼SW¼NE¼ 22	22	5	.2	85	.032	.027	.032
3T	148787	SW¼NE¼NE¼ 35	22	5	1.0	66	.006	.004	.001
3B	148788	SW¼NE¼NE¼ 35	22	5	1.2	76	.003	.002	.002
4T	148819	NW¼NW¼NW¼ 36	22	5	3.0	36	.007	.002	.002
4B	148820	NW¼NW¼NW¼ 36	22	5	1.0	55	.009	.005	.003
COAL BED E									
Traverse Ranch district and vicinity									
5	145574	SW¼NE¼ 15	22	5	0.6	61	0.006	0.004	0.009
6T	237407	SW¼NW¼NW¼ 21	22	5	.6	67	.010	.007	.016
6TM	237408	SW¼NW¼NW¼ 21	22	5	1.0	13	.15	.019	.015
6BM	237409	SW¼NW¼NW¼ 21	22	5	1.0	11	.045	.005	.004
6B	237410	SW¼NW¼NW¼ 21	22	5	1.0	12	.034	.004	.005
7T	237414	SW¼NW¼NW¼ 21	22	5	1.0	37	.24	.089	.088
7M	237415	SW¼NW¼NW¼ 21	22	5	1.0	36	.33	.12	.15
7TM	237416	SW¼NW¼NW¼ 21	22	5	.1	26	.92	.24	.22
7B	237417	SW¼NW¼NW¼ 21	22	5	1.0	66	.038	.025	.021
8	242427	SW¼NW¼NW¼ 21	22	5	(1)			[2] .011	[2] .006
9	242428	SW¼NW¼NW¼ 21	22	5	(1)			[2] .41	[2] .21
North Riley Pass district and vicinity									
10	145287	SW¼SW¼NE¼ 22	22	5	1.6	40	0.025	0.010	0.007
11	145288	SW¼SW¼NE¼ 22	22	5	1.2	43	.052	.023	.010
12	145289	SW¼SW¼NE¼ 22	22	5	1.7	27	.12	.029	.009
13	145290	SE¼SW¼NE¼ 22	22	5	1.5	30	.010	.003	.008
14	145291	NE¼NW¼SE¼ 22	22	5	1.0	56	.15	.082	.037
15	145292	NW¼NE¼SE¼ 22	22	5	.9	64	.022	.014	.019

See footnotes at end of table.

TABLE 7.—*Uranium content of miscellaneous coal samples mainly from localities peripheral to principal deposits*—Continued

Sample No.	Laboratory No.	Location			Thickness (feet)	Ash	U in ash	U in sample	eU in sample
		Sec.	T.N.	R.E.					
COAL BED E—Continued									
North Riley Pass district and vicinity—Continued									
16 [3]	145295	NW¼NE¼SE¼ 22	22	5	0.1	26	0.89	0.24	0.080
16T	145293	NW¼NE¼SE¼ 22	22	5	.8	28	.64	.18	.067
16TT	145296	NW¼NE¼SE¼ 22	22	5	.3	79	.006	.005	.003
16B	145294	NW¼NE¼SE¼ 22	22	5	.8	16	.84	.13	.053
17 [4]	145301	NE¼NE¼SE¼ 22	22	5	.1	83	.057	.047	.017
17TT	145300	NE¼NE¼SE¼ 22	22	5	.6	55	.31	.17	.11
17T	145298	NE¼NE¼SE¼ 22	22	5	1.0	33	.57	.19	.11
17B	145299	NE¼NE¼SE¼ 22	22	5	1.0	19	.86	.17	.091
18	145575	NW¼SE¼SE¼ 22	22	5	.9	45	.12	.056	.053
19	145569	SE¼SE¼ 22	22	5	1.0	41	.38	.15	.091
20	145570	SE¼SE¼ 22	22	5	1.0	22	.21	.047	.029
21	145571	SE¼SE¼ 22	22	5	1.8	21	1.6	.34	.15
22	145572	SE¼SE¼ 22	22	5	1.7	36	.32	.12	.039
23	145573	SE¼SE¼ 22	22	5	1.6	31	.46	.14	.076
24	145302	NW¼NW¼SW¼ 23	22	5	1.9	44	.33	.15	.068
24M	145303	NW¼NW¼SW¼ 23	22	5	.3	27	.72	.19	.088
25	145304	NW¼NW¼SW¼ 23	22	5	2.2	23	.35	.082	.036
25M	145305	NW¼NW¼SW¼ 23	22	5	.8	20	.86	.16	.066
26T	145306	NW¼NW¼SW¼ 23	22	5	.5	62	.029	.018	.018
26B	145307	NW¼NW¼SW¼ 23	22	5	.7	49	.20	.10	.051
27T	145310	NW¼NW¼SW¼ 23	22	5	.6	60	.017	.010	.007
27B	145308	NW¼NW¼SW¼ 23	22	5	1.7	22	.54	.12	.061
27MB	145309	NW¼NW¼SW¼ 23	22	5	.7	20	.46	.095	.049
28	145311	SW¼NW¼SW¼ 23	22	5	1.7	30	.33	.10	.061
29T	145566	SW¼NW¼SW¼ 23	22	5	.85	24	.62	.15	.086
29B	145567	SW¼NW¼SW¼ 23	22	5	.85	23	1.6	.36	.13
29M [5]	145568	SW¼NW¼SW¼ 23	22	5	.6	19	1.2	.24	.15
30	145565	SE¼NE¼SE¼ 23	22	5	1.3	24	.44	.11	.057
31	145594	NW¼SW¼NW¼ 26	22	5	1.2	36	.88	.26	.15
32	145593	NW¼SW¼NW¼ 26	22	5	1.0	36	2.36	.85	.41
33	145695	NW¼SW¼NW¼ 26	22	5	1.0	40	.45	.18	.10
34	145592	NE¼SE¼NE¼ 27	22	5	1.4	36	.20	.073	.062
35	145591	NE¼SE¼NE¼ 27	22	5	1.4	34	.91	.31	.18
36	145590	NE¼SE¼NE¼ 27	22	5	1.1	28	1.43	.41	.19
37T	145588	NE¼SE¼NE¼ 27	22	5	.8	35	.34	.12	.14
37B	145589	NE¼SE¼NE¼ 27	22	5	.8	22	.56	.12	.059
38T	145586	SE¼NE¼NE¼ 27	22	5	.75	34	.076	.026	.019
38B	145587	SE¼NE¼NE¼ 27	22	5	.75	20	.17	.035	.089
39	145696	SE¼NE¼NE¼ 27	22	5	1.0	36	.15	.053	.026
40	145697	SE¼NE¼NE¼ 27	22	5	.5	45	.66	.30	.11
41	145698	SE¼NE¼NE¼ 27	22	5	.9	60	.02	.012	.010
42	145699	SE¼NE¼NE¼ 27	22	5	1.5	21	.33	.070	.051
43	145700	SE¼NE¼NE¼ 27	22	5	1.2	32	.50	.16	.10
44	145701	SE¼NE¼NE¼ 27	22	5	1.4	23	.39	.092	.047
45	145702	SE¼NE¼NE¼ 27	22	5	.6	37	.48	.18	.10
46	145703	NW¼NE¼NE¼ 27	22	5	.7	44	.091	.040	.054
47	145704	NW¼NE¼NE¼ 27	22	5	1.0	37	.17	.064	.062
48	145577	SW¼NE¼NE¼ 27	22	5	1.2	36	.021	.008	.016
49	145578	SW¼NE¼NE¼ 27	22	5	1.2	24	.062	.015	.038
50	145579	SW¼NE¼NE¼ 27	22	5	1.1	24	.15	.036	.023
51	145580	SW¼NE¼NE¼ 27	22	5	1.2	29	.38	.11	.053
52	145581	SW¼NE¼NE¼ 27	22	5	1.4	21	.48	.10	.061
53	145582	SW¼NE¼NE¼ 27	22	5	.3	27	.22	.060	.035
54	145583	NW¼SE¼NE¼ 27	22	5	1.0	33	.50	.17	.064
55	145584	NW¼SE¼NE¼ 27	22	5	1.4	26	.15	.040	.025
56	145585	NE¼SW¼NE¼ 27	22	5	1.1	40	.095	.038	.022
57	145705	NE¼SW¼NE¼ 27	22	5	1.3	49	.011	.005	.017
58	145706	NE¼SW¼NE¼ 27	22	5	1.4	27	.27	.064	.038
59	145707	NE¼SW¼NE¼ 27	22	5	1.2	28	.043	.016	.012
60	145708	NW¼SW¼NE¼ 27	22	5	1.1	36	.14	.049	.11
61	148784	NW¼NW¼SW¼ 28	22	5	.1	94	.003	.003	.001
62	145710	SE¼NE¼NW¼ 35	22	5	1.2	42	1.9	.80	.97
63	148821	NW¼NW¼NW¼ 36	22	5	.9	37	.076	.028	.033
CARBONATE COAL ZONE									
64T	148782	NW¼NW¼SW¼ 28	22	5	0.9	33	0.063	0.021	0.013
64B	148783	NW¼NW¼SW¼ 28	22	5	.8	24	.022	.005	.003
65M [6]	237084	NE¼NE¼NW¼ 32	21	5	.6	85	.066	.056	.24
66T [7]	237154	NE¼NE¼NW¼ 32	21	5	.7	45	.012	.005	.004
66B [7]	237155	NE¼NE¼NW¼ 32	21	5	.5	54	.035	.019	.016
67T [8]	237156	NE¼NE¼NW¼ 32	21	5	.7	70	.004	.003	.002
68	149366	SW¼SW¼SE¼ 21	20	4	[1]	92	.002	.002	.002
COAL ZONE C									
69T [9]	148789	SE¼SE¼SW¼ 12	21	5	1.1	16	0.019	0.003	<.001
69B [9]	148790	SE¼SE¼SW¼ 12	21	5	1.1	30	.005	.001	<.001
70	149343	NE¼NW¼NW¼ 14	22	5	[1]	22	.066	.015	.011
71T	149340	20	22	5	1.1	15	.14	.020	.018
71M	149341	20	22	5	1.4	21	.02	.004	.003
71B	149342	20	22	5	.8	25	.03	.007	.003
72	149451	NW¼SE¼SE¼ 29	22	5	.4	21	.028	.006	.005
73	149452	NW¼SE¼SE¼ 29	22	5	.8	37	.049	.019	.012
74	149448	SE¼SE¼SE¼ 29	22	5	1.0	23	.09	.021	.013
75	149449	SE¼SE¼SE¼ 29	22	5	1.0	32	.021	.007	.009

See footnotes at end of table.

TABLE 7.—*Uranium content of miscellaneous coal samples mainly from localities peripheral to principal deposits*—Continued

Sample No.	Laboratory No.	Location			Thickness (feet)	Ash	U in ash	U in sample	eU in sample
		Sec.	T.N.	R.E.					
		COAL ZONE C—Continued							
76	149450	SE¼SE¼SE¼ 29	22	5	1.0	28	0.025	0.007	0.007
77	149447	SE¼NE¼NE¼ 32	22	5	1.0	39	.09	.035	.033
78[10]	145771	NE¼NE¼NW¼ 35	22	5	2.3	18	.71	.013	.008
79	149358	SW¼NW¼SE¼ 2	21	5	1.3	35	.06	.021	.017
80	149359	SW¼NW¼SE¼ 2	21	5	1.4	26	.05	.013	.011
81	149351	SE¼NW¼SE¼ 2	21	5	1.6	35	.05	.019	.017
82	149353	SE¼NW¼SE¼ 2	21	5	1.2	32	.10	.032	.030
82a	149352	SE¼NW¼SE¼ 2	21	5	(11)	32	2.0	.63	.68
83	149354	SE¼NW¼SE¼ 2	21	5	1.5	36	.36	.13	.11
84	149355	NE¼SW¼SE¼ 2	21	5	1.4	37	.04	.015	.013
85T	149356	NE¼SW¼SE¼ 2	21	5	1.0	34	.21	.070	.065
85B	149357	NE¼SW¼SE¼ 2	21	5	.4	30	6.3	1.9	1.7
86	149360	NE¼NE¼NE¼ 11	21	5	2.0	26	.026	.007	.006
87	149361	NE¼NW¼NW¼ 12	21	5	3.0	35	.04	.015	.011
87T	149362	NE¼NW¼NW¼ 12	21	5	.8	40	.05	.021	.016
88T [12]	149363	NW¼NE¼NW¼ 12	21	5	3.0	25	.03	.008	.006
89	237160	SE¼SE¼SW¼ 29	21	5	.8	70	.006	.004	.006
90T	237157	NE¼NE¼NW¼ 32	21	5	1.1	30	.069	.019	.018
90M	237158	NE¼NE¼NW¼ 32	21	5	1.2	24	.042	.010	.011
90B	237159	NE¼NE¼NW¼ 32	21	5	1.2	33	.065	.021	.018
91T [13]	237063	SW¼SW¼SW¼ 4	20	5	.4	70	.088	.060	.060
91B [13]	237064	SW¼SW¼SW¼ 4	20	5	.7	54	.085	.046	.033
		COAL ZONE B							
92T [9]	148791	SE¼SE¼SW¼ 12	21	5	1.9	15	0.004	0.001	<0.001
92M [9]	148792	SE¼SE¼SW¼ 12	21	5	1.9	26	.005	.001	<.001
92B [9]	148793	SE¼SE¼SW¼ 12	21	5	2.0	11	.003	<.001	<.001
92a [9]	148794	SE¼SE¼SW¼ 12	21	5	1.1	28	.005	.001	.001
93T	148785	SE¼NW¼SW¼ 28	22	5	.8	34	.014	.005	.001
93B	148786	SE¼NW¼SW¼ 28	22	5	.8	25	.006	.002	.002
94 [7]	237161	NE¼NE¼NW¼ 32	21	5	1.6	34	.020	.007	.004
95T [13]	237065	SW¼SW¼SW¼ 4	20	5	1.1	47	.026	.012	.013
95B [13]	237066	SW¼SW¼SW¼ 4	20	5	1.1	75	.003	.002	.002
		LONESOME PETE COAL ZONE							
96T [9]	148795	SE¼SE¼SW¼ 12	21	5	1.0	71	0.004	0.003	0.002
96B [9]	148796	SE¼SE¼SW¼ 12	21	5	.1	11	.011	.001	<.001
96a [9]	148997	SE¼SE¼SW¼ 12	21	5	.5	38	.003	.001	.002
97T [9]	148798	SE¼SE¼SW¼ 12	21	5	1.0	23	.003	.001	<.001
97B [9]	148799	SE¼SE¼SW¼ 12	21	5	1.0	17	.003	.001	<.001
98T [7]	237162	NE¼NE¼NW¼ 32	21	5	.4	29	.050	.014	.011
98B [7]	237163	NE¼NE¼NW¼ 32	21	5	1.2	36	.007	.003	.003
		LOWER COAL BEDS							
99 [9]	148800	SE¼SE¼SW¼ 12	21	5	1.0	42	0.004	0.002	0.002
100 [9]	148801	SE¼SE¼SW¼ 12	21	5	1.2	29	.008	.002	.001
101 [9]	148802	SE¼SE¼SW¼ 12	21	5	.9	35	.014	.005	.002
102T [9]	148803	SE¼SE¼SW¼ 12	21	5	1.8	22	.004	.001	.001
102B [9]	148804	SE¼SE¼SW¼ 12	21	5	2.0	15	.005	.001	.001
103T [9]	148805	SE¼SE¼SW¼ 12	21	5	1.5	40	.008	.003	<.001
103B [9]	148806	SE½SE¼SW¼ 12	21	5	1.5	24	.007	.002	<.001
104T [9]	148807	SE¼SE¼SW¼ 12	21	5	3.0	58	.009	.005	<.001
104B [9]	148808	SE¼SE¼SW¼ 12	21	5	1.0	22	.006	.001	.001
105 [9]	148809	SE¼SE¼SW¼ 12	21	5	.5	64	.008	.005	.001
106 [9]	148810	SE¼SE¼SW¼ 12	21	5	1.0	23	.008	.002	<.001
107 [9]	148812	SE¼SE¼SW¼ 12	21	5	1.0	31	.009	.003	.001
108 [9]	148813	SE¼SE¼SW¼ 12	21	5	.6	27	.010	.003	<.001
109 [9]	148814	SE¼SE¼SW¼ 12	21	5	.5	39	.009	.004	.001
110 [9]	148815	SE¼SE¼SW¼ 12	21	5	.8	70	.008	.006	.001
111 [9]	148816	SE¼SE¼SW¼ 12	21	5	.2	76	.007	.005	<.001
112T [9]	148817	SE¼SE¼SW¼ 12	21	5	1.9	32	.009	.003	.002
112B [9]	148818	SE¼SE¼SW¼ 12	21	5	1.9	54	.005	.003	.001
113 [7]	237164	NE¼NE¼NW¼ 32	21	5	1.1	46	.005	.002	.002
114 [7]	237165	NE¼NE¼NW¼ 32	21	5	.9	35	.002	.0007	<.001
115 [13]	237067	SW¼SW¼SW¼ 4	20	5	.9	27	.015	.004	.004
116T [13]	237068	SW¼SW¼SW¼ 4	20	5	.8	20	.018	.004	.003
116B [13]	237069	SW¼SW¼SW¼ 4	20	5	.9	24	.010	.002	.002
117 [13]	237070	SW¼SW¼SW¼ 4	20	5	1.4	41	.003	.001	.001
118T [13]	237071	SW¼SW¼SW¼ 4	20	5	.8	26	.001	.0003	<.001
118B [13]	237072	SW¼SW¼SW¼ 4	20	5	.9	21	.002	.0004	<.001
119T [13]	237073	SW¼SW¼SW¼ 4	20	5	1.7	27	.003	.0008	<.001
119B [13]	237074	SW¼SW¼SW¼ 4	20	5	1.2	19	.004	.0008	<.001
119a [13]	237074	SW¼SW¼SW¼ 4	20	5	1.2	[2] 18	[2] .003	.0005	[2] <.001
120 [13]	237075	SW¼SW¼SW¼ 4	20	5	.2	38	.009	.003	.002

[1] Grab sample. Uranium content determined from coal rather than ash.
[2] Chemical analyses by R. P. Cox, J. S. Wahlberg, E. C. Mallory, Jr., and Mary Finch; radioactivity analyses by C. G. Angelo, U.S. Geol. Survey lab., Denver, Colo.
[3] Rider 10 ft above sample 16T.
[4] Rider 10 ft above sample 17T.
[5] Middle, overlaps samples 29T and 29B.
[6] Locality 6, pl. 3, middle of 2.2-foot bed.
[7] Shown on columnar section 11, plate 2.
[8] Top of 1.2-ft bed.
[9] Shown on columnar section 8, pl. 2.
[10] Shown on columnar section 6, pl. 20.
[11] Grab sample from sample 82.
[12] Top of 4-foot bed.
[13] Shown on columnar section 15, pl. 2; sample 119a is a split of sample 119B.

TABLE 8.—*Uranium and trace-element content of carbonaceous siltstone and associated rocks, Carbonate prospect and vicinity*

[Values in percent. Uranium content of sample calculated from uranium content of ash except for unashed samples. Composite channel samples are of complete bed except as indicated by letters included in sample number (T, top; M, middle; B, bottom). Samples whose laboratory number begins with either 55- or 65- were analyzed in the U.S. Geol. Survey lab., Denver; chemical analyses by H. E. Crowe, C. E. Thompson, W. R. Weston, and W. J. Breed; radioactivity analyses by L. M. Lee and W. W. Niles. Samples whose laboratory number begins with either 1 or 2 were analyzed in the U.S. Geol. Survey lab., Washington, D.C.; chemical analyses by Roosevelt Moore, Grafton Daniels, and Joseph Budinsky; radioactivity analyses by B. A. McCall]

Sample No.	Laboratory No.	Lithology	Thickness (feet)	Ash	U in ash	U in sample	eU in sample	V	Mo	As	Fe	Cu	Se
		NORTH PIT											
		Grab samples											
1	55-5486	Upper siltstone				0.015	0.015	0.015	0.0006	0.005	1.9	0.004	0.002
2	55-5487	do				.015	.026	.030	.0006	.010	5.5	.004	.001
3	55-5488	Sandstone dike				.006	.010	.010	.0060	.30	9.2	.004	.001
4	55-5489	Upper siltstone				.120	.058	.010	.0015	.010	1.7	.004	.002
5	55-5490	do				.030	.029	.010	.0015	.005	1.8	.003	.001
6	55-5491	do				.008	.009	.015	.0008	.030	2.0	.003	.001
7	55-5492	do				.006	.008	.010	.0008	.030	2.4	.004	.003
8	146583	Carbonaceous siltstone				.016	.016						
9	55-5493	do				.008	.014	.010	.0004	.005	1.6	.005	.001
10	237105	do		82	0.025	.020	.016						
11	55-5494	do				.012	.017	.060	.0015	.010	5.7	.003	.002
12	237106	Sandstone dike		92	.023	.021	.023						
13	237107	Carbonaceous siltstone		78	.62	.48	.38						
14	55-5495	do				.350	.37	.015	.0008	.020	1.5	.003	.002
15	237108	do		79	.56	.44	.34						
16	55-5496	do				.350	.32	.050	.0030	.020	2.4	.004	.004
17	237109	Sandstone dike		94	.011	.010	.02						
18	55-5497	Carbonaceous siltstone				.250	.39	.060	.0160	.030	5.4	.005	.006
19	237110	do		66	1.4	.89	.64						
20	55-5498	do				.040	.044	.010	.0060	.020	2.0	.004	.002
21	237111	do		78	.64	.50	.38						
22	55-5499	do				.350	.23	.010	.0040	.030	1.6	.003	.001
23	237112	do		80	.27	.22	.18						
24	55-5500	do				.350	.44	.015	.0040	.030	1.4	.004	.002
25	237113	do		81	.20	.16	.11						
26	55-5501	do				.120	.095	.015	.0070	.020	2.1	.004	.001
27	237114	do		82	.12	.095	.065						
28	55-5502	do				.030	.025	.020	.0400	.020	9.5	.005	.002
29	237115	do		82	.023	.019	.016						
30	55-5503	do				.008	.010	.010	.0025	.010	1.7	.004	.005
31	237116	do		83	.011	.009	.010						
32	55-5504	do				.004	.007	.015	.0030	.020	2.2	.004	.0005
33	237117	do		82	.008	.007	.007						
34	55-5505	do				.003	.006	.015	.0070	.040	2.3	.004	.003
35	237118	do		82	.005	.004	.008						
36	55-5506	Lower siltstone				.008	.009	.015	.0004	.050	1.8	.004	.0007
37	55-5507	do				.015	.016	.050	.0015	.080	2.6	.005	.015
38	55-5508	Sandstone dike				.003	.008	.015	.0015	.010	2.3	.003	.001
39	55-5509	Lower siltstone				.025	.023	.050	.0040	.020	3.7	.005	.015
40	55-5510	do				.025	.030	.025	.0025	.010	2.3	.004	.005
41	55-5511	do				.015	.021	.025	.0040	.005	3.0	.005	.007
42	55-5512	do				.012	.013	.025	.0030	.020	4.5	.005	.005
		Channel samples											
C1	237090	Upper siltstone	0.7	91	0.021	0.019	0.017						
C2	237091	Carbonaceous siltstone	1.5	85	.016	.014	.012						
C3	237092	do	.5	80	.015	.012	.013						
C4	237093	Lower siltstone	.5	83	.018	.015	.014						
C5	237094	Upper siltstone	.6	91	.061	.055	.053						
C6	237095	Carbonaceous siltstone	1.0	75	.82	.62	.53						
C7	237096	Lower siltstone	.6	83	.21	.17	.15						
C8	237216	Sandstone roof	.2	94	.007	.007	.009						
C9	237097	Upper siltstone	.55	91	.065	.059	.059						
C10	237098	Carbonaceous siltstone	.4	85	.50	.42	.33						
C11	237099	do	.5	69	1.4	.91	.62						
C12	237100	Lower siltstone	.65	87	.15	.13	.086						
C13	237217	Sandstone floor	.2	99	.006	.006	.007						
C14	237215	Sandstone roof	.2	94	.004	.004	.006						
C15	237101	Upper siltstone	.7	91	.011	.009	.009						
C16	237102	Carbonaceous siltstone	.5	87	.011	.010	.009						
C17	237103	do	.5	81	.011	.009	.008						
C18	237104	Lower siltstone	.5	86	.016	.014	.010						
C19	237218	Sandstone floor	.2	97	.008	.008	.006						
		SOUTH PIT											
		Grab samples											
1	65-5433	Upper siltstone				0.008	0.011	0.020	0.0008	0.008	2.2	0.003	0.005
2	65-5434	do				.008	.012	.012	.0004	.004	2.1	.004	.001
3	65-5435	do				.025	.039	.012	.0008	.004	1.7	.004	.0001
4	65-5436	do				.015	.014	.012	.0008	.016	1.9	.003	.0001
5	65-5437	do				.015	.016	.008	.0004	.006	1.8	.004	.0001
6	65-5438	do				.008	.008	.008	.0002	.006	2.4	.004	.0001
7	65-5439	do				.015	.008	.012	.0015	.040	3.0	.004	.0001

TABLE 8.—*Uranium and trace-element content of carbonaceous siltstone and associated rocks, Carbonate prospect and vicinity*—Continued

Sample No.	Laboratory No.	Lithology	Thickness (feet)	Ash	U in ash	U in sample	eU in sample	V	Mo	As	Fe	Cu	Se
		SOUTH PIT—Continued											
		Grab samples—Continued											
8	237136	Carbonaceous siltstone		91	0.008	0.007	0.036						
9	65-5440	do				.008	059	0.080	0.0015	0.004	2.0	0.003	0.0001
10	237137	do		91	.013	.012	.072						
11	65-5441	do				.040	.13	.080	.0008	.006	1.7	.003	.0003
12	237138	do		88	.16	.14	.33						
13	65-5442	do				.080	.21	.020	.0040	.020	2.4	.003	.0001
14	237139	do		88	.060	.053	.18						
15	237214	Sandstone dike		93	.052	.049	.062						
16	65-5443	Carbonaceous siltstone				.120	.21	.150	.1600	.160	16.0	.003	.0001
17	237140	do		79	.32	.25	.75						
18	65-5444	do				.250	1.07	.025	.0300	.030	1.1	.004	.001
19	237141	do		75	.50	.37	1.1						
20	65-5445	do				.040	.063	.050	.1200	.120	6.0	.004	.003
21	237213	Sandstone dike		95	.059	.056	.060						
22	237142	Carbonaceous siltstone		92	.020	.019	.044						
23	65-5446	do				.080	.60	.015	.0200	.020	1.5	.004	.0001
24	237143	do		92	.26	.24	.83						
25	65-5447	do				.120	.53	.010	.0300	.030	1.5	.004	.0005
26	237144	do		90	.050	.045	.18						
27	65-5448	do				.025	.034	.035	.0300	.030	12.0	.004	.0001
28	237145	do		92	.014	.013	.024						
29	65-5449	do				.015	.022	.010	.0060	.006	2.3	.004	.0001
30	237146	do		91	.016	.015	.019						
31	65-5450	do				.015	.017	.010	.0060	.006	1.9	.004	.0001
32	237147	do		90	.013	.012	.014						
33	65-5451	do				.008	.012	.005	.0040	.004	2.0	.004	.0001
34	237148	do		90	.016	.014	.015						
35	65-5452	do				.015	.016	.010	.0100	.010	2.6	.004	.0005
36	237149	do		90	.016	.014	.022						
37	65-5453	Lower siltstone				.008	.016	.030	.0160	.016	2.3	.003	.0003
38	65-5454	do				.008	.021	.015	.0100	.010	1.3	.003	.007
39	65-5455	do				.012	.033	.025	.0100	.010	2.0	.004	.003
40	65-5456	do				.008	.021	.035	.0200	.020	2.5	.004	.003
41	65-5457	do				.012	.025	.025	.0200	.020	2.2	.004	.001
42	65-5458	do				.012	.010	.025	.0300	.030	2.8	.005	.007
43	65-5459	do				.012	.009	.025	.0800	.080	2.5	.004	.005
		Channel samples											
C1	237119	Carbonaceous siltstone	1.2	92	0.006	0.006	0.013						
C2	237120	do	.6	89	.008	.007	.023						
C3	237121	Lower siltstone	.4	92	.006	.006	.011						
C4	237150	Sandstone roof	.5	95	.008	.008	.008						
C5	237122	Upper siltstone	.5	93	.010	.009	.022						
C6	237123	do	.4	92	.017	.015	.061						
C7	237124	Carbonaceous siltstone	.4	84	.27	.23	.64						
C8	237125	do	.5	78	.70	.55	1.2						
C9	237126	do	.35	85	.16	.14	.43						
C10	237127	Lower siltstone	.35	92	.021	.019	.051						
C11	237128	Sandstone floor	.3	96	.011	.011	.014						
C12	237129	Sandstone roof	.3	95	.004	.004	.010						
C13	237130	Upper siltstone	.6	93	.009	.008	.018						
C14	237131	do	.4	91	.090	.082	.16						
C15	237132	Carbonaceous siltstone	.5	88	.28	.23	1.2						
C16	237133	do	.5	87	.080	.069	.26						
C17	237134	Lower siltstone	.5	93	.012	.011	.023						
C18	237135	Sandstone floor	.3	95	.027	.026	.017						
C19	237151	Upper siltstone	1.0	92	.016	.015	.012						
C20	237152	Carbonaceous siltstone	.6	90	.031	.028	.071						
C21	237153	Lower siltstone	.7	93	.013	.012	.017						
		LOCALITIES ADJACENT TO THE NORTH AND SOUTH PITS											
		Composite channel samples											
1	237076		2.2	84	0.008	0.007	0.008						
2	237077		1.8	84	.010	.008	.008						
3	237078		2.2	90	.009	.008	.008						
4T	237079		1	82	.006	.005	.008						
4M	237080		.7	89	.006	.005	.011						
4B	237081		.4	91	.006	.005	.009						
5	237082		2.2	91	.010	.009	.010						
6T	237083		1.1	93	.019	.018	.027						
6M [1]	237084		.6	85	.066	.056	.24						
6B	237085		.5	91	.018	.016	.023						
7	237086		2.1	91	.003	.003	.005						
8	237087		2.2	90	.006	.005	.006						
9	237088		2.3	91	.002	.005	.007						
10	237089		2.2	91	.002	.002	.005						

[1] Equals sample 65, table 7.

TABLE 9.—*Uranium and phosphorus content of phosphatic claystone and associated rocks, Lonesome Pete mine and vicinity*

[Values in percent. Uranium and phosphorus content of the ash of noncoal samples calculated from uranium and phosphate content of sample. Phosphorus content of unashed noncoal samples calculated from phosphate content of sample. Uranium content of coal samples calculated from uranium content of ash. Samples are of complete bed except as indicated by letters included in sample number (T, top; B, bottom) or on pl. 4-*D* and stratigraphic sections 12 and 13 (pl. 2). Chemical analyses of noncoal samples by Joseph Budinsky, Roosevelt Moore, and W. P. Tucker; chemical analyses of coal samples by Maryse Delevaux, Carmen Johnson, and Grafton Daniels; radioactivity analyses by B. A. McCall, U.S. Geol. Survey lab., Washington, D.C.]

Sample No.	Laboratory No.	Thickness (feet)	Ash	U in ash	U in sample	eU in sample	P. n ash	P in sample	P_2O_5 sample
				LONESOME PETE MINE					
				Noncoal samples (ore zone)					
1	146680	0.95	94	0.17	0.16	0.14	0.99	------	2.1
2	146681	.75	94	.29	.27	.24	1.9	------	4.1
3	146682	.4	94	.21	.20	.17	1.2	------	2.6
4	146683	.4	94	.32	.30	.29	2.6	------	5.6
5	146684	1.0	94	.016	.015	.016	.19	------	.4
6	146685	.95	93	.075	.070	.068	.51	------	1.1
7	146686	.75	94	.3	.28	.28	.51	------	1.1
8	146687	.5	94	.16	.15	.15	1.1	------	2.4
9T	146700	1.1	94	.013	.012	.014	.14	------	.3
9B	146701	1.0	93	.008	.007	.007	<.047	------	<.1
10	146688	.85	92	.23	.21	.19	2.2	------	4.7
11	146689	.75	93	.2	.18	.16	1.2	------	2.6
12	146690	.8	93	.19	.18	.15	1.2	------	2.6
13	146691	.85	92	.19	.17	.16	.90	------	1.9
14	146692	.7	92	.17	.16	.16	1.2	------	2.5
15	146693	.9	92	.038	.035	.033	.24	------	.5
16	146697	1.2	93	.032	.030	.032	.23	------	.5
17T	146695	1.2	92	.043	.040	.039	.33	------	.7
17B	146694	.8	92	.013	.012	.014	.09	------	.2
18	146696	.9	92	.11	.10	.097	.62	------	1.3
19	146721	.75	92	.44	.40	.36	3.6	------	7.5
20	146698	.6	92	.28	.26	.24	1.7	------	3.16
21	146699	.85	93	.17	.16	.14	.89	------	1.9
22	146702	.7	92	.087	.080	.078	.048	------	.1
23	146703	1.0	92	.16	.15	.14	.85	------	1.8
24	146704	1.1	92	.29	.27	.24	2.0	------	4.2
25	146705	.9	92	.21	.19	.19	1.2	------	2.6
26	146706	.9	92	.28	.26	.25	2.9	------	6.2
27	146707	.55	92	.21	.19	.17	1.1	------	2.3
28	146708	.6	92	.20	.18	.17	1.1	------	2.4
29	146709	1.0	92	.13	.12	.12	.85	------	1.8
30	146710	.8	92	.12	.11	.10	.52	------	1.1
31	146711	.25	92	.31	.28	.25	1.5	------	3.2
32	146713	.9	92	.054	.050	.047	.33	------	.7
33	146714	.85	92	.098	.090	.084	.62	------	1.3
34	146715	.75	92	.35	.32	.3	2.2	------	4.7
35	146716	.7	92	.27	.25	.23	1.6	------	3.3
36	146717	.4	92	.14	.13	.11	.81	------	1.7
37	146718	.9	92	.11	.10	.094	.57	------	1.2
38	146719	.8	92	.098	.090	.088	.47	------	1.0
39T	146752	.6	------	------	.01	.012	------	------	.20
39B	146712	.6	92	.087	.080	.075	.52	------	1.1
40	146720	1.0	93	.017	.016	.017	.19	------	.4
41	146722	.9	93	.029	.027	.030	.19	------	.4
42	146723	1.0	92	.20	.19	.17	1.4	------	2.8
43	146724	.7	93	.097	.090	.094	.61	------	1.3
44	146725	.8	92	.065	.060	.062	.43	------	.9
45	146726	.8	92	.16	.15	.15	1.1	------	2.3
46	146727	.8	92	.087	.080	.076	.61	------	1.3
47	146728	.2	93	.64	.60	.55	7.9	------	16.8
48	146729	.5	92	.27	.25	.22	1.7	------	3.5
49	146730	.68	------	------	.21	.19	------	------	3.4
50	146731	.7	------	------	.20	.17	------	------	3.1
51	146732	.6	------	------	.16	.14	------	------	2.6
52	146733	.7	------	------	.060	.055	------	------	1.2
53	146734	.45	------	------	.20	.20	------	------	5.6
54	146741	.8	------	------	.21	.18	------	------	3.7
54a [1]	146742	.2	------	------	.42	.39	------	------	8.2
55	146737	.9	------	------	.046	.044	------	------	.8
55a [1]	146738	.2	------	------	.34	.30	------	------	7.9
56	146739	.9	------	------	.17	.15	------	------	2.2
57	146740	.8	------	------	.20	.17	------	------	6.7
58	146735	.5	------	------	.21	.19	------	------	4.0
59	146736	.6	------	------	.12	.14	------	------	3.0

TABLE 9.—*Uranium and phosphorus content of phosphatic claystone and associated rocks, Lonesome Pete mine and vicinity*—Continued

Sample No.	Laboratory No.	Thickness (feet)	Ash	U in ash	U in sample	eU in sample	P in ash	P in sample	P_2O_5 sample
				Coal samples					
9T	237399	0.6	34.0	0.24	0.085	0.039	------	------	------
17T	237401	1.0	36.9	.094	.035	.017	------	------	------
17B	237402	1.0	21.5	.037	.008	.004	------	------	------
39T	237403	.3	39.7	.033	.013	.014	------	------	------
				VICINITY OF THE LONESOME PETE MINE					
				Noncoal samples					
1	146677	1.0	------	------	0.010	0.010	------	0.13	0.3
2	146678	.5	------	------	.011	.011	------	<.04	<.1
3	146679	1.3	------	------	.004	.005	------	.09	.2
4	146759	1.2	------	------	.003	.003	------	.04	.1
5	146760	1.2	------	------	.003	.003	------	.04	.1
6	146761	1.1	------	------	.002	.003	------	.04	.1
7	146762	.2	------	------	.009	.010	------	.09	.2
8	146763	.25	------	------	.27	.24	------	2.14	4.9
9	146764	.2	------	------	.010	.010	------	.09	.2
10	146765	1.0	------	------	.005	.005	------	.04	.1
11	146766	1.0	------	------	.005	.006	------	.04	.1
14	146767	.25	------	------	.002	.002	------	<.04	<.1
22	146768	.15	------	------	.001	.002	------	.04	.1
23	146769	.75	------	------	.001	.002	------	.04	.1
24	146770	.75	------	------	.002	.003	------	.04	.1
25	146771	1.0	------	------	.002	.002	------	.04	.1
26	146772	.25	------	------	.003	.004	------	.09	.2
27	146773	.35	------	------	.003	.003	------	.04	.1
28	146774	.4	------	------	.004	.006	------	.04	.1
29	146775	.3	------	------	.005	.004	------	.04	.1
30	242834	.35	------	------	.34	.28	------	1.81	4.15
31	242835	.25	------	------	.031	.031	------	.23	.52
32	146776	.3	------	------	.022	.024	------	.09	.2
33	146777	.5	------	------	.007	.009	------	.04	.1
34	146778	.5	------	------	.006	.006	------	.04	.1
39	146750	.6	------	------	.004	.006	------	.04	.1
40	146749	.4	------	------	.005	.007	------	.04	.1
41	146748	.2	------	------	.006	.005	------	.04	.1
42	146747	.25	------	------	.011	.013	------	.09	.2
43	146746	.3	------	------	.40	.41	------	3.57	8.2
44	146745	.3	------	------	.08	.079	------	.61	1.4
45	146744	.6	------	------	.009	.011	------	.09	.2
46	146743	.6	------	------	.009	.009	------	.09	.2
48	146753	.6	------	------	.003	.003	------	.04	.1
49	146754	.2	------	------	.005	.005	------	.09	.2
50	146755	.3	------	------	.017	.016	------	<.04	<.1
51	146756	.2	------	------	.061	.060	------	.09	.2
52	146757	.2	------	------	.024	.022	------	<.04	<.1
53	146758	.3	------	------	.011	.014	------	.09	.2
64 [2]	149364	1.0	------	------	.002	.003	------	------	------
				Coal samples					
12	237054	1.1	32	0.090	0.033	0.018	------	------	------
13	237055	1.1	26	.035	.009	.010	------	------	------
15	237056	1.1	35	.066	.023	.011	------	------	------
16	237057	1.0	19	.037	.007	.004	------	------	------
17	237058	1.0	27	.006	.002	.002	------	------	------
18	237059	1.0	19	.008	.001	.001	------	------	------
19	237060	1.0	37	.007	.003	.002	------	------	------
20	237061	1.0	50	.007	.004	.004	------	------	------
21	237062	1.0	47	.010	.005	.004	------	------	------
35	237400	.6	40	.043	.017	.015	------	------	------
47	237388	0.6	34	.045	.015	.015	------	------	------
54	237389	1.0	36	.033	.012	.012	------	------	------
55	237390	1.0	34	.027	.009	.009	------	------	------
56	237391	1.0	45	.006	.003	.002	------	------	------
57 [3]	237392	.8	38	.14	.053	.047	------	------	------
58 [3]	237393	1.0	34	.030	.010	.009	------	------	------
59 [3]	237394	1.1	32	.019	.006	.005	------	------	------
60 [3]	237395	1.1	25	.031	.008	.006	------	------	------
61 [3]	237396	1.3	37	.029	.011	.007	------	------	------
62 [3]	237397	1.3	33	.019	.006	.008	------	------	------
63 [3]	237398	1.3	30	.029	.009	.008	------	------	------
65 [3]	149365	2.0	14	.050	.007	.005	------	------	------

[1] Selected sample.
[2] See stratigraphic section 13, pl. 2.
[3] See stratigraphic section 12, pl. 2.

TABLE 10.—*Uranium content of sandstone, siltstone, and claystone samples from the Cave Hills area, Harding County, S. Dak.*

[Values in percent. Chemical analyses by Roosevelt Moore; radioactivity analyses by B. A. McCall, U.S. Geol. Survey lab., Washington, D.C.]

Sample No	Laboratory No.	Location			Sample description	Position in formation	U in sample	eU in sample
		Sec.	T.N.	R.E.				
				Chadron Formation (Oligocene)				
1	148770	NW¼SW¼NW¼ 28	22	5	Tuffaceous sandstone	8 ft above base	0.001	0.002
2	148769	NE¼SW¼NW¼ 28	22	5	Conglomerate	1.5 ft above base	.001	<.001
3	148766	SE¼NE¼SW¼ 21	22	5	Tuffaceous sandstone	1 ft above base	.001	.002
4	148763	NW¼NW¼ 5	20	5	do	35 ft above base	.001	.001
5	148761	NW¼NW¼ 5	20	5	do	10 ft above base	.001	.002
6	148762	NW¼NW¼ 5	20	5	do	2 ft above base	.001	.002
7	148765	SW¼NW¼ 32	21	5	Silicified claystone	5 ft above base	.001	.002
8	148764	SW¼NW¼ 32	21	5	do	4 ft above base	.001	<.001
				Tongue River Member of the Fort Union Formation (Paleocene)				
9	148767	SE¼NW¼SW¼ 21	22	5	Sandstone	Directly under Chadron Formation	.001	0.002
10	148768	NE¼SW¼NW¼ 28	22	5	do	do	.001	.002
11	148772	NW¼NW¼NW¼ 36	22	5	do	4 ft above coal zone (F)	.001	.001
12	148771	NW¼NW¼SW¼ 28	22	5	do	10 ft above coal bed E	.001	.002
13	148773	NW¼NW¼NW¼ 36	22	5	do	Directly under coal bed E	.001	.003
14	237239	SE¼NE¼SE¼ 23	22	5	Siltstone	Directly over coal bed E	.003	.002
15	237411	SE¼SW¼NW¼ 21	22	5	do	Directly under coal bed E	.003	.004
16	237246	SE¼SW¼SW¼ 26	22	5	Claystone	Directly over coal bed E	.025	.014
17	237244	SE¼SW¼SW¼ 26	22	5	Analcitic claystone	do	.050	.047
18	237241	NE¼SW¼NE¼ 27	22	5	Silty claystone	do	.003	.003
19	237234	NE¼SE¼NE¼ 27	22	5	Claystone	do	.010	.008
20	237242	SE¼NE¼NW¼ 35	22	5	Analcitic silty claystone	do	.30	.28
				Ludlow Member of Fort Union Formation (Paleocene)				
21	237236	NW¼NE¼NE¼ 22	22	5	Sandstone	Directly under Tongue River Member.	0.15	0.14
22	237237	NW¼NE¼NE¼ 22	22	5	do	Directly under sample 21	.080	.75

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