Factors that Localized Uranium Deposition in the Dakota Sandstone, Gallup and Ambrosia Lake Mining Districts, McKinley County, New Mexico

GEOLOGICAL SURVEY BULLETIN 1485

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By CHARLES T. PIERSON *and* MORRIS W. GREEN

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A contribution to the geology of uranium deposits in Cretaceous rocks in the central and western parts of the Grants mineral belt

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1980

UNITED STATES DEPARTMENT OF THE INTERIOR

CECIL D. ANDRUS, *Secretary*

GEOLOGICAL SURVEY

H. William Menard, *Director*

Library of Congress Cataloging in Publication Data

Pierson, Charles Thomas, 1918-
Factors that localized uranium deposition in the Dakota Sandstone,
Gallup, and Ambrosia Lake mining districts, McKinley County,
New Mexico.

(Geological Survey bulletin ; 1485)
Bibliography: p. 30-31.
Supt. of Docs. no. I 19.3:1485
1. Uranium ores–New Mexico–McKinley Co. 2. Geology, Stratigraphic–Cretaceous. I. Green, Morris W., joint author. II. Title. III. Series: United States. Geological Survey. Bulletin ; 1485.
QE75.B9 no. 1485 [TN490.U7] 557.3s 79-607188
[553.4'932'0978983]

For sale by the Superintendent of Documents, U. S. Government Printing Office
Washington, D. C. 20402

Stock number 024-001-03281-3

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FACTORS THAT LOCALIZED URANIUM DEPOSITION IN THE DAKOTA SANDSTONE, GALLUP AND AMBROSIA LAKE MINING DISTRICTS, McKINLEY COUNTY, NEW MEXICO

By CHARLES T. PIERSON and MORRIS W. GREEN

ABSTRACT

Geologic studies were made at all of the uranium mines and prospects in the Dakota Sandstone of Early(?) and Late Cretaceous age in the Gallup mining district, McKinley County, N. Mex. Mines in rocks of Dakota age of the adjacent Ambrosia Lake mining district were visited for comparative purposes.

Mines in the eastern part of the Gallup district and in the Ambrosia Lake district are on the Chaco slope of the southern San Juan Basin in strata that dip gently northward toward the central part of the basin. Mines in the western part of the Gallup district are along The Hogback (Nutria monocline) in strata that dip steeply westward into the Gallup sag.

Geologic factors that controlled formation of the uranium deposits in the Dakota Sandstone are (1) the presence of a source of uranium, believed to be uranium deposits of the underlying Morrison Formation of Late Jurassic age; (2) the accessibility to the Dakota of uranium-bearing solutions from the Morrison; (3) the presence in the Dakota of permeable sandstone beds overlain by impermeable carbonaceous shale beds; and (4) the occurrence within the permeable Dakota Sandstone beds of carbonaceous reducing material as bedding-plane laminae or as pockets of carbonaceous trash.

Most of the uranium deposits in the Dakota Sandstone are found in the lower part of the formation in marginal-marine distributary-channel sandstones. However, the Hogback No. 4 (Hyde) mine (Gallup district) is found in sandy paludal shale, and another deposit, the Silver Spur (Ambrosia Lake district), is found in what is interpreted to be a massive beach or barrier-island sandstone in the upper part of the Dakota.

The most favorable sedimentary depositional environments for the accumulation of uranium are the areas lateral to main distributary channels, where levee, splay, and some distributary-channel sandstones intertongue with gray carbonaceous shales and siltstones of the well-drained swamp environment. Black carbonaceous shale beds formed in the poorly drained swamps in the interfluve areas are not favorable host rocks for uranium.

The depositional energy levels of the various environments in which the sandstone and shale beds of the Dakota were deposited govern the relative favorability of the strata as uranium host rocks. In the report area, uranium commonly is in carbonaceous sandstone deposited in medium-energy channels. A prerequisite, however, is that the sandstone be overlain by impermeable shale beds.

Medium-energy fluvial conditions result in the deposition of sandstone beds having detrital carbonaceous material distributed in laminae or in trash pockets on bedding planes. The carbonaceous laminae and trash pockets provide the necessary reductant to precipitate uranium from solution. High-energy fluvial conditions result in the deposition of sandstones having little or no carbonaceous material. Low-energy swampy conditions result in carbonaceous shale deposits, which are generally barren of uranium because of their relative impermeability to migrating uranium-bearing solutions.

INTRODUCTION

LOCATION AND GEOLOGIC SETTING

Uranium in the Dakota Sandstone of Early(?) and Late Cretaceous age is found in five areas in the Gallup mining district (areas 1–5, fig. 1) and in one area in the Ambrosia Lake mining district (area 6, fig. 1). Both districts are in McKinley County, northwest New Mexico.

Occurrences of uranium in the Dakota Sandstone at the Diamond No. 2 (Largo No. 2), Becenti, Hogback No. 4 (Hyde), Church Rock, U, and Rats Nest mines, and at the Delter prospect in the Gallup district are discussed in this report and are shown by a geologic sketch map (fig. 2) of part of the Gallup district. Uranium mines in the Morrison Formation, such as the Foutz No. 1–3 mines and the Westwater No. 1 mine are also shown by figure 2. Uranium at the Church Rock mine is found in both the Dakota and the Morrison (Hilpert, 1969, p. 75).

The Febco (Small Stake), Silver Spur Nos. 1 and 5, and Junior mines (area 6, fig. 1) in the Ambrosia Lake mining district are also discussed, but they are not on the map in this report. Some or all of these mines are shown, however, on maps by Thaden, Santos, and Ostling (1966), Hilpert (1969, pl. 1), and Gay and Nestler (1968).

The geologic settings of the parts of the two mining districts in which the Dakota deposits are found are somewhat similar. Gently northeast-dipping beds of the Dakota uncomformably overlie strata of the Upper Jurassic Morrison Formation everywhere except in the area of The Hogback (Nutria monocline) (fig. 2). Throughout the area an erosional contact separates the Morrison from the Dakota.

There are two differences between the geologic settings of the mines in the two districts: (1) faulting is associated with the mines in the Ambrosia Lake district but is absent in the Gallup district; and (2) claystone beds of the Brushy Basin Shale Member of the Morrison Formation underlie the Dakota in the Ambrosia Lake district but are absent in the vicinity of the Dakota mines in the Gallup district, owing primarily to pre-Dakota erosion, or locally to a facies change of shale to sandstone.

Locations and brief descriptions of all of the mines in Dakota-age rocks referred to in the present report are given in table 4 of Hilpert

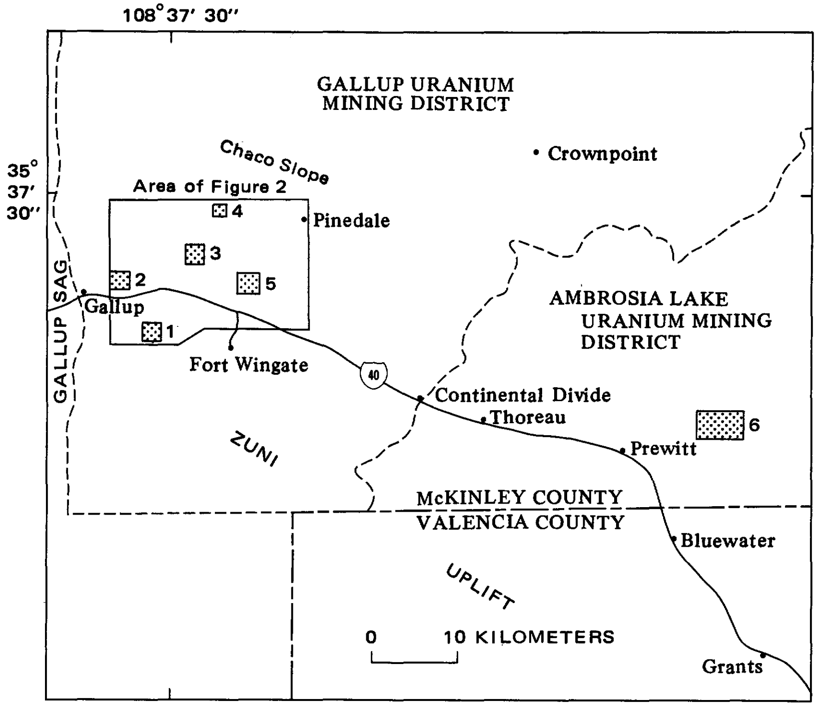
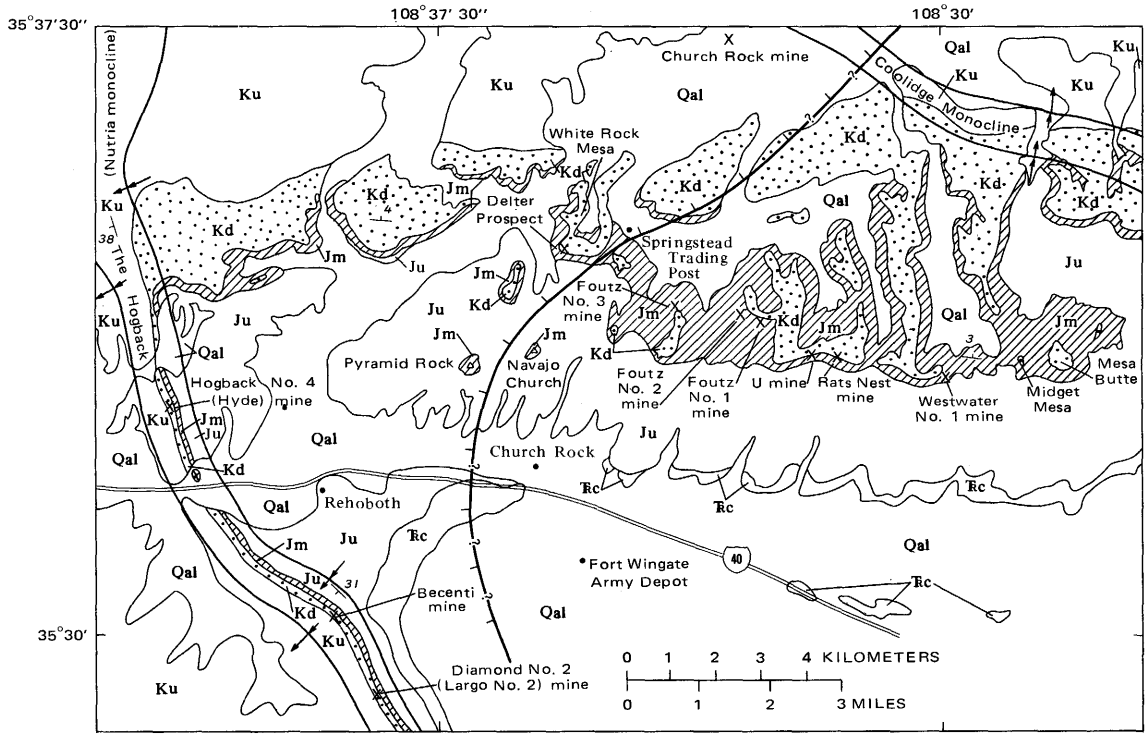


FIGURE 1.—Index map of parts of the Gallup and Ambrosia Lake mining districts, New Mexico, showing areas in which uranium mines or prospects are found in the Dakota Sandstone (stippled); 1, Diamond No. 2 (Largo No. 2) and Becenti mines; 2, Hogback No. 4 (Hyde) mine; 3, Delter prospect; 4, Church Rock mine; 5, U and Rats Nest mines; 6, Silver Spur No. 1, Silver Spur No. 5, Febco (Small Stake), Junior, Section 5, and Dakota (Pat) mines. Dashed line indicates boundary of the Gallup mining district; eastern edge follows the Continental Divide.

(1969). Most of the mine locations are shown by the geologic quadrangle maps of the Church Rock (Green and Jackson, 1975), Gallup East (Green and Jackson, 1976), Thoreau NE (Green and Pierson, 1971), and Goat Mountain (Thaden and others, 1966) quadrangles.

PREVIOUS GEOLOGIC STUDIES

The only published geologic studies of uranium deposits in the Dakota Sandstone of the Gallup-Ambrosia Lake area are found in reports by Mirsky (1953), Gabelman (1956), and the U.S. Atomic Energy Commission (1959). Hilpert (1969) summarized salient data for all of the uranium deposits of northwestern New Mexico, and Granger (1968) discussed the localization and control of the deposits in the southern San Juan Basin (Grants) mineral belt. Some of the data used in this report came from Reimer (1969).



35°37'30"
108°37' 30"
108°30'
35°30'
Church Rock mine
Coolidge Monocline
(Nutria monocline)
The Hogback
White Rock Mesa
Delter Prospect
Springstead Trading Post
Foutz No. 3 mine
Foutz No. 2 mine
Foutz No. 1 mine
U mine
Rats Nest mine
Westwater No. 1 mine
Midget Mesa
Mesa Butte
Pyramid Rock
Navajo Church
Hogback No. 4 (Hyde) mine
Church Rock
Rehoboth
Fort Wingate Army Depot
Becenti mine
Diamond No. 2 (Largo No. 2) mine
40
Ku
Kd
Jm
Ju
Qal
Ꞓc
38
31
0 1 2 3 4 KILOMETERS
0 1 2 3 MILES

EXPLANATION

Qal	ALLUVIUM, COLLUVIUM, AND EOLIAN DEPOSITS (HOLOCENE AND PLEISTOCENE)
Ku	POST–DAKOTA SEDIMENTARY ROCKS, UNDIFFERENTIATED (UPPER CRETACEOUS)–Menefee Formation, Crevasse Canyon Formation, Gallup Sandstone, and Mancos Shale
Kd	DAKOTA SANDSTONE (UPPER AND LOWER? CRETACEOUS)– Includes the Whitewater Arroyo Tongue of the Mancos Shale and the Twowells Tongue of the Dakota Sandstone
Jm	MORRISON FORMATION (UPPER JURASSIC) – Includes Brushy Basin Shale, Westwater Canyon Sandstone, and Recapture Shale Members
Ju	PRE-MORRISON SEDIMENTARY ROCKS, UNDIFFERENTIATED (MIDDLE JURASSIC)–Cow Springs Sandstone, Summerville Formation, Todilto Limestone, and Entrada Sandstone
₹c	CHINLE FORMATION (UPPER TRIASSIC)

CONTACT

MONOCLINAL FLEXURES–Showing upper and lower fold axes. Arrows indicate direction of dip, longer arrow indicates flatter dip

31 STRIKE AND DIP OF BEDS

? LIMIT OF BRUSHY BASIN SHALE MEMBER–Brushy Basin Member of the Morrison Formation has been removed on the hachured side by pre-Dakota erosion. Queried where data unavailable

△ URANIUM MINE OR PROSPECT–Mine symbol located in formation in which ore occurs (Dakota Sandstone or Morrison Formation). Ore in the Church Rock mine is found in both the Dakota and the Morrison

FIGURE 2.—Geologic sketch map of part of the Gallup mining district, McKinley County, N. Mex., showing locations of uranium mines and prospects. Photogeology by M. W. Green and C. T. Pierson, 1971.

PRESENT STUDY

Work done by the authors in 1974–75 includes radioactivity and stratigraphic measurements, field interpretations of the environments of deposition of the ore-bearing and adjacent strata, and deductions about the probable effects of stratigraphic variations on control of uranium deposition. Data from Reimer (1969) are included in the measured stratigraphic section for a uranium mine called the U mine (measured stratigraphic section 6).

ACKNOWLEDGMENTS

Acknowledgment is made to T. N. Parthasarathy, International Atomic Energy Agency Fellow from India, who, as part of his training with the U.S. Geological Survey, mapped and sampled the U mine in 1974 and made a petrographic study of selected samples.

STRATIGRAPHY AND ENVIRONMENTS OF DEPOSITION

Pre-Quaternary sedimentary rocks exposed in the area covered by figure 2 include, in ascending order, the Chinle Formation of Late Triassic age; the Entrada Sandstone, Todilto Limestone, Summerville Formation, and Cow Springs Sandstone of Middle Jurassic age; the Morrison Formation of Late Jurassic age; the Dakota Sandstone of Early(?) and Late Cretaceous age; and the Mancos Shale, Gallup Sandstone, and Crevasse Canyon and Menefee Formations of Late Cretaceous age. The Chinle and Morrison Formations and the Dakota Sandstone (including the Twowells Tongue of the Dakota Sandstone and the Whitewater Arroyo Tongue of the Mancos Shale) are mapped separately on figure 2, but the other formations are put into two undifferentiated groups: (1) pre-Morrison; and (2) post-Dakota.

The Triassic (Stewart and others, 1972) and Jurassic (Harshbarger and others, 1957) rocks are of continental origin. The Lower(?) and Upper Cretaceous (Sears and others, 1941) rocks are of marginal marine or marine origin. Only the Morrison Formation and the Dakota Sandstone will be discussed in this report.

MORRISON FORMATION

Three members of the Morrison Formation are present in the report area (Craig and others, 1955). In ascending order, they are the Recapture Shale, Westwater Canyon Sandstone, and Brushy Basin Shale Members, shown undifferentiated as Morrison Formation on the geologic sketch map (fig. 2).

In the Grants mineral belt, Green (1975) has traced an unconformity at the base of the Westwater Canyon Member from outcrops near Gallup on the west end of the belt to Cañoncito on the east end of the belt. No uranium ore is found in the Recapture, and it is not described below. Santos (1970) described the stratigraphy and structure of the Morrison Formation in the Ambrosia Lake district.

WESTWATER CANYON SANDSTONE MEMBER

The Westwater Canyon Sandstone Member ranges in thickness from 9 to 82 m in the report area. The thinnest section in the Gallup area is 29 m at the Diamond No. 2 (Largo No. 2) mine. It is thin there because pre-Dakota erosion was accentuated along the Gallup hogback.

The member is predominantly a red, medium- to coarse-grained, fluvially crossbedded, first-cycle, arkosic to subarkosic sandstone, but it commonly includes lenses of conglomeratic sandstone, particularly in the western part of the report area. The proportion of siltstone and claystone increases toward the east.

The Westwater Canyon Member (fig. 3) was laid down as channel, overbank, and flood-plain deposits by a medium- to high-energy fluvial system, which included both braided and meandering streams of a coalescing alluvial fan complex. Stream flow was to the east-northeast, as indicated by the gradual change in predominant facies from midfan to distal in that direction (Green, 1975). The paleoclimate was probably warm and humid, as indicated by the presence of large accumulations of tree trunks and other plant remains in Westwater Canyon sediments.

BRUSHY BASIN SHALE MEMBER

The Brushy Basin Shale Member (fig. 3) ranges from 0 to 61 m in thickness in the report area. The maximum thickness in the Gallup district is 26 m, but the member is absent in the western part of the district as a result of pre-Dakota erosion. In the Ambrosia Lake district and in the eastern part of the Gallup district, the unit is mainly green, tuffaceous claystone and interbeds of sandstone similar to the Westwater Canyon Member. Locally in the Gallup mining district, the Brushy Basin Member is dominantly sandstone.

The Brushy Basin intertongues with the underlying Westwater Canyon, and in the vicinity of the U mine, where the Brushy Basin is composed entirely of sandstone, no stratigraphic break can be discerned. In the area north of the town of Continental Divide (fig. 1), as well as in the Ambrosia Lake district to the east, the Brushy Basin is mainly claystone or mudstone, and a mappable contact with the Westwater Canyon is present.

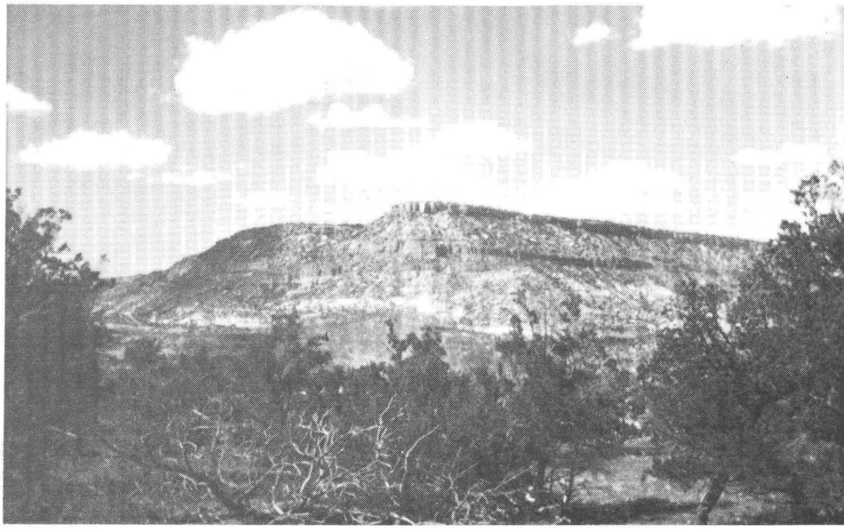


FIGURE 3.—Rock outcrops north of the town of Continental Divide, N. Mex. Prominent sandstone at top is the main body of the Dakota Sandstone. Below is a thick (24–37 m) claystone sequence of the Brushy Basin Shale Member of the Morrison Formation. The massive sandstone beds in the middle part of the cliff belong to the Westwater Canyon Sandstone Member of the Morrison. The Dakota in this area lacks uranium deposits, because the impermeable Brushy Basin does not permit entry of solutions from the underlying, uranium-bearing Westwater Canyon Member.

The fine-grained detritus that composes the Brushy Basin Member is interpreted to have been carried as suspended load by the fluvial system that deposited the sandstone of the Westwater Canyon. The claystone was deposited on top of the sandstone when basin filling lowered stream gradients, and fine-grained lithofacies migrated toward the basin margins over coarser grained deposits of the Westwater Canyon Member.

DAKOTA SANDSTONE

The intertongued, generally transgressive Dakota Sandstone-Mancos Shale sequence in west-central New Mexico has been divided into named formal and informal rock units by Landis, Dane, and Cobban (1973). In the present report, we are concerned only with the main body of the Dakota (Landis and others, 1973, p. J22), which underlies the lowest recognized unit of the Mancos, the Whitewater Arroyo Shale Tongue.

The main body of the Dakota Sandstone (fig. 3), which in the report area ranges in thickness from 21 to 54 m, generally comprises two parts. The lower part, which was probably deposited in a delta-plain environment similar to that described by Weimer (1976, p. 206–207), consists of interbeds of crossbedded, fine- to coarse-grained or locally conglomeratic sandstone of the distributary channel and levee; silty, carbonaceous sandstone of the crevasse splay; sandy, carbonaceous siltstone of the well-drained swamp; and clayey siltstone, lignite, and coal of the poorly drained swamp environment (fig. 4). The upper part consists of thick-bedded to massive, fine- to medium-grained beach or barrier-island sandstone. The lower part usually constitutes from one-third to one-half, and the upper part from one-half to two-thirds of the total thickness of the main body.

Pre-Dakota erosion has produced an important unconformity at the base of the Dakota. In the western part of the Gallup district, all of the Brushy Basin Member and part of the Westwater Canyon Member of the Morrison Formation have been truncated by the pre-Dakota erosion.

STRUCTURE

The report area lies on the gently north-dipping homoclinal Chaco slope (fig. 1) of the southern part of the San Juan Basin. The tectonic setting of the Grants uranium belt (southern San Juan Basin mineral belt of Hilpert and Moench, 1960) was described by Kelley (1963). Santos (1970) discussed the structure of the Ambrosia Lake district.

The structure of the area, which lies just north of the Zuni uplift (fig. 1), is generally simple. Strata dip 2–4° northeast except along The Hogback (Nutria monocline, fig. 2), where dips range from 30° to 85° W., and along the Coolidge (Pinedale) monocline (fig. 2) north of the town of Continental Divide, where dips of as much as 26° are found. The folding and tilting are largely post-Dakota in age, although a small amount of pre-Dakota deformation may have taken place.

Santos (1970, p. E17) noted that the Ambrosia Lake district probably occupies the most folded and faulted part of the Chaco slope or platform. The Gallup district has steeper dipping folds (Nutria and Coolidge monoclines) but is considerably less faulted than the Ambrosia Lake district. The westernmost faults in the report area belong to the Bluewater fault zone near Thoreau, several kilometers east of the eastern boundary of the Gallup district. The Bluewater fault zone is shown by the geologic maps of the Thoreau NE (Green and Pierson, 1971), and Thoreau (Robertson, 1973) quadrangles.

Joints are present in all strata in the report area. They are more readily recognized in the Dakota than in the Morrison, a fact that probably explains why Gilkey (1953) shows no joints in the Morrison on his map of the Zuni uplift area.

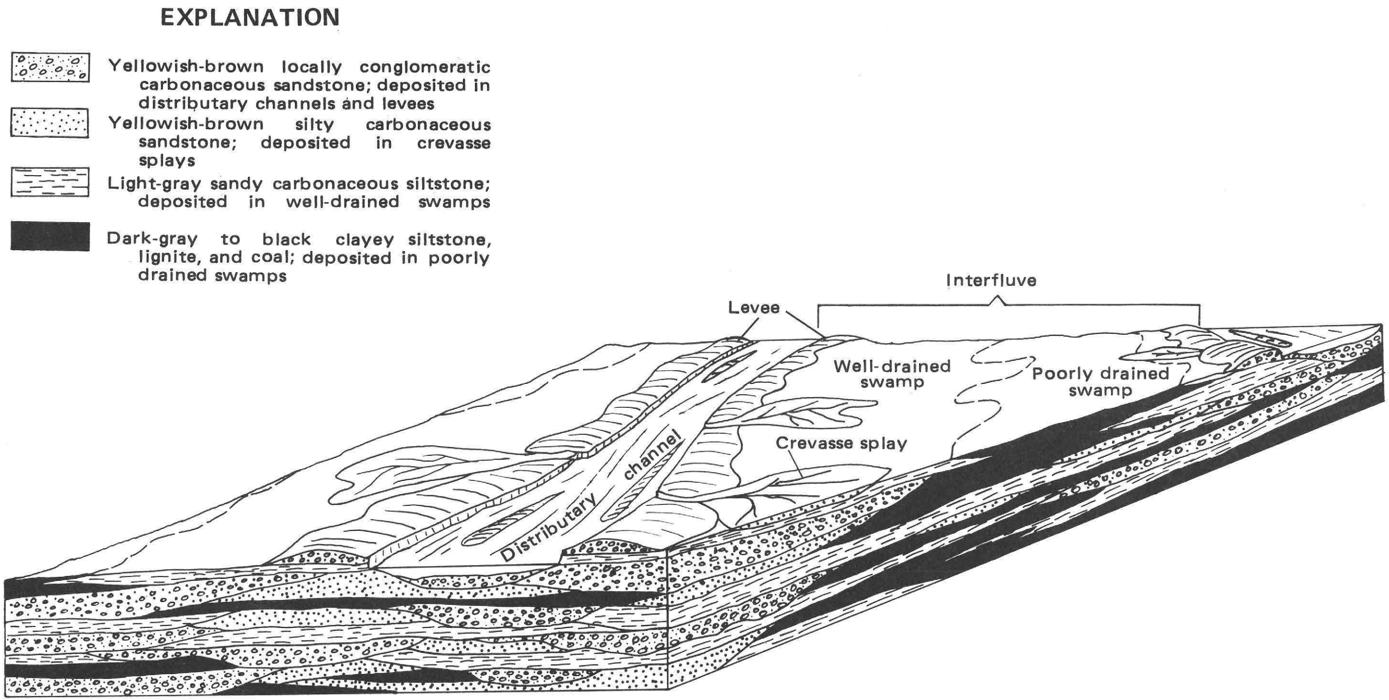


FIGURE 4.—Sketch showing lithologies and delta-plain environments in the lower part of the Dakota Sandstone in the Gallup, N. Mex., area. Modified from Weimer (1976, fig. 20).

URANIUM DEPOSITS

PRODUCTION

Hilpert (1969, table 4) noted that most of the uranium deposits in Cretaceous rocks in northwest New Mexico occur in the Dakota Sandstone, and he listed 14 Dakota deposits, 11 of which are in McKinley County. One of the deposits, the Church Rock, is partly in the Morrison Formation. Hilpert (1969, p. 89) gives the order of magnitude of production of these deposits. He stated that, "Of 14 that are listed, 9 yielded a total during the 1952–64 period of about 110,000 tons of ore that ranged from 0.12 to 0.30 percent U_3O_8 and averaged about 0.22 percent U_3O_8. More than 90 percent of this ore was mined from the Church Rock and Diamond 2 mines." Chenoweth (1977, table 1, p. 260) notes that, for the Grants mineral belt, 9 mines in the Dakota Sandstone produced 243 tons (223 t) U_3O_8 during the period 1951–70.

DEPOSITS IN THE MORRISON FORMATION

Uranium deposits in the Morrison Formation are mentioned here briefly because redistribution of uranium from these deposits or leaching of the host rock in which they are found is believed to be the source of most of the uranium present in the Dakota deposits.

Morrison mines in the Gallup and Ambrosia Lake districts have been described by Hilpert (1969) and are shown on a map of the Grants uranium region by Chapman, Wood and Griswold, Inc. (1974). In the present report, the only Morrison mines shown are those found in part of the Gallup district (fig. 2); these are the Foutz Nos. 1–3 and the Westwater No. 1 mines. The Francis mine (not shown), in the Ambrosia Lake district, is discussed briefly below.

Granger (1968) has presented an hypothesis for the geologic controls for formation of the uranium deposits in the Morrison in the southern San Juan Basin (Grants) mineral belt. It is sufficient here to note that the main deposits in the Gallup and Ambrosia Lake districts are found in sandstone of the Westwater Canyon Member. Some smaller deposits are found in lenses and tongues of sandstone in the Brushy Basin Shale Member or in channel-fill sandstone beds at the top of the Brushy Basin Member.

The Foutz No. 3 mine (fig. 2) in the Gallup district and the Francis mine, located in the Ambrosia Lake district about 10 km north of Prewitt (fig. 1), are examples of mines in the Brushy Basin Member. The Foutz No. 3 mine is in a tongue of Westwater Canyon-like sandstone in the Brushy Basin. The Francis mine is in a similar sandstone found as a channel fill at the top of the Brushy Basin.

At the Foutz No. 3 mine, uranium is not found in the Dakota, probably because claystone of the Brushy Basin prevented uranium-bearing solutions of the Morrison from entering the Dakota. At the Francis mine there is no uranium in the Dakota, despite the fact that claystone of the Brushy Basin is not present above the ore. The scarcity of carbonaceous reducing material in sandstone lenses of the basal Dakota probably accounts for the absence of uranium in the Dakota at the Francis mine locality.

DEPOSITS IN THE DAKOTA SANDSTONE

MINERALOGY, HABITS, AND AGE OF THE DAKOTA DEPOSITS

The mineralogy and habits of the Dakota uranium deposits are mentioned only briefly in the present report. More information, however, is available from Hilpert (1969, p. 90–92), Gabelman (1956), Granger (1963), and Chico (1959).

Minerals in the sandstone consist of uraninite and various yellow secondary uranium minerals. Uranium minerals have not been identified in the radioactive carbonaceous shales. As noted by Hilpert (1969, p. 90), "* * * the deposits consist of tabular masses that range from thin seams a few feet in width and length to crudely tabular masses as much as 2,500 feet [760 m] in length and at least 1,000 feet [300 m] in width. The larger deposits range from a few inches to as much as 25 feet [8 m] in thickness, but generally average a few feet." The uranium minerals are closely associated with "* * * carbonaceous debris, which is generally distributed in crude bedlike zones within the sandstone units* * *. Ore bodies, which generally compose the high-grade parts of deposits, range from small masses that comprise only a few tons of material to masses that include as much as or more than 50,000 tons [45,000 t] of material. They range in thickness from a foot or so to 25 feet [8 m], but most of them are only a few feet thick and comprise only a few hundred tons of material."

The only direct evidence of the age of the Dakota ore has been provided by Ludwig, Szabo, and Granger (1977). According to them, the age of a uraninite-pyrite-rich sample from an ore pile at the Hogback No. 4 mine, as determined from U-Pb isotope and U-series methods, is late Pleistocene.

MINES IN THE GALLUP DISTRICT

Detailed descriptions of mines in the Dakota Sandstone in the Gallup district (fig. 2) are given by Mirsky (1953), Gabelman (1956), Hilpert (1969), and Reimer (1969). Three mines (Diamond No. 2, Becenti, and Hogback No. 4) are found in steeply dipping Dakota strata of The Hogback. The remainder of the Dakota mines and prospects are found in gently dipping rocks at White Rock Mesa (Delter prospect), north of Springstead Trading Post (Church Rock mine), and southeast of Springstead Trading Post (U and Rats Nest mines). The mines in the Morrison Formation are found northeast of Navajo Church (Foutz No. 3 mine) and west of Midgit Mesa (Foutz Nos. 1 and 2 and Westwater No. 1 mines). The Church Rock mine produced ore from the Morrison Formation and Dakota Sandstone through a shaft in the valley floor in the north-central part of the area shown by figure 2 (Hilpert, 1969, p. 77). The shaft is now abandoned.

DIAMOND NO. 2 (LARGO NO. 2) MINE

Gabelman (1956) gave a good description of the geologic setting and ore occurrence at the Diamond No. 2 mine; a geological map as well as longitudinal sections are included in his report. The U.S. Atomic Energy Commission (1959, p. 3–33 to 3–34) briefly described the Diamond No. 2 mine, and Chico (1959) recorded the results of detailed underground and surface studies made at the mine.

Outcrop observations show that the ore is found in the basal distributary-channel sandstone of the Dakota at the Diamond No. 2 mine (fig. 5). This sandstone, which rests on the truncated Westwater Canyon Sandstone Member of the Morrison, is overlain by the thickest part of a lenticular, lignitic, carbonaceous shale unit. The sandstone is about 5.5 m thick, and the shale is about 1.2 m thick in a measured section about 50 m southeast of the mine portal (section 1). The ore is associated with plant debris in medium- to coarse-grained, crossbedded, medium-energy, fluvial sandstone.

Gabelman (1956, p. 315) noted that the uranium minerals are in pods and elongate lenses that plunge downdip. He also stated that with few exceptions the deposits are found beneath the black shale caprock, although they commonly protrude as much as several feet beneath the shale edges.

BECENTI MINE

Uranium ore at the Becenti mine (fig. 6) is found in the same stratigraphic position (section 3) as ore at the Diamond No. 2 mine; but at the Becenti, the basal Dakota Sandstone beds are 3.1 m thick, and the overlying carbonaceous shale is 1.2 m thick. The ore is associated with thin laminae of carbonaceous material interbedded with fine- to medium-grained, ripple-marked, crossbedded, medium-energy fluvial sandstone. Oxidized uranium minerals are visible in joints.

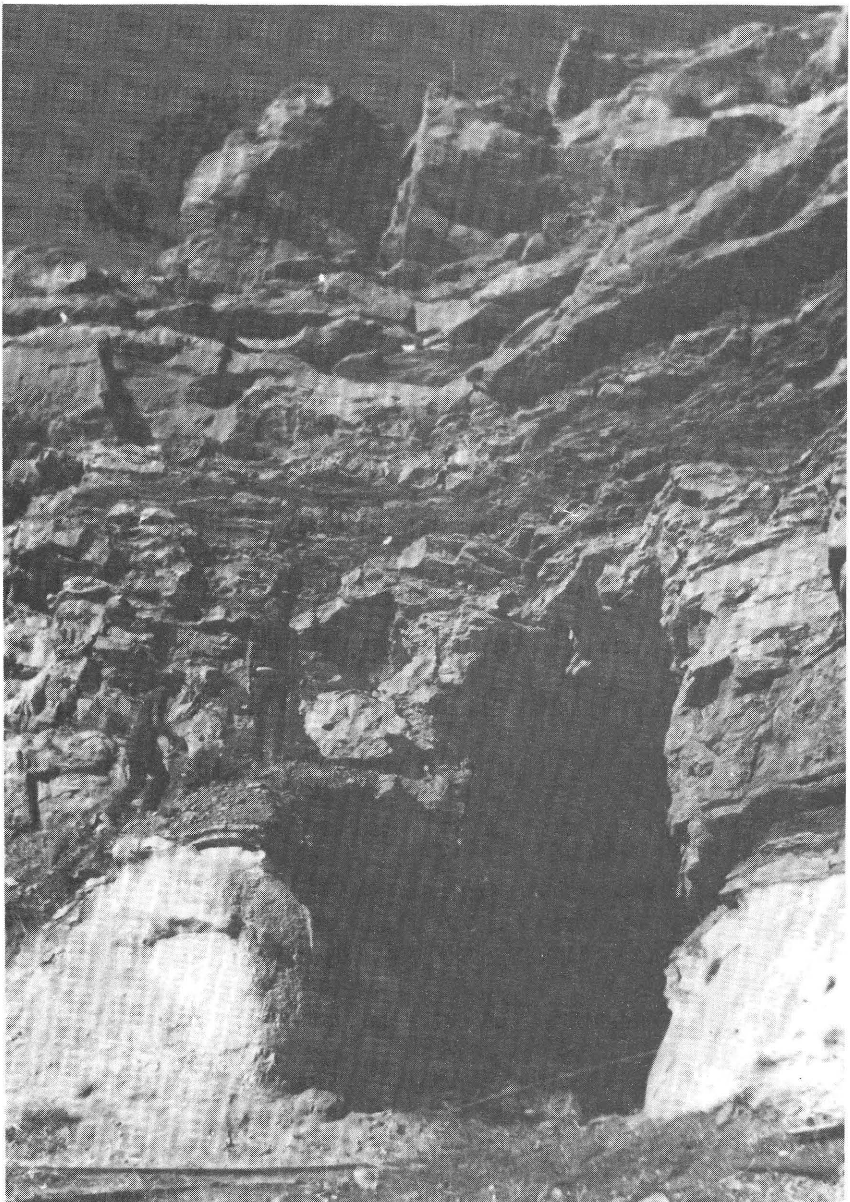


FIGURE 5.—Portal of Diamond No. 2 (Largo No. 2) mine located in the upper part of Morrison Formation (bleached sandstone at adit level) and the lower part of the overlying Dakota Sandstone (lignite-sandstone sequence). The lignite-sandstone sequence (swamp and distributary channel) is overlain by a massive (beach?) sandstone unit. Uranium was deposited in medium-energy distributary-channel sandstone containing pockets of carbonaceous trash. Portal is about 3 m high.

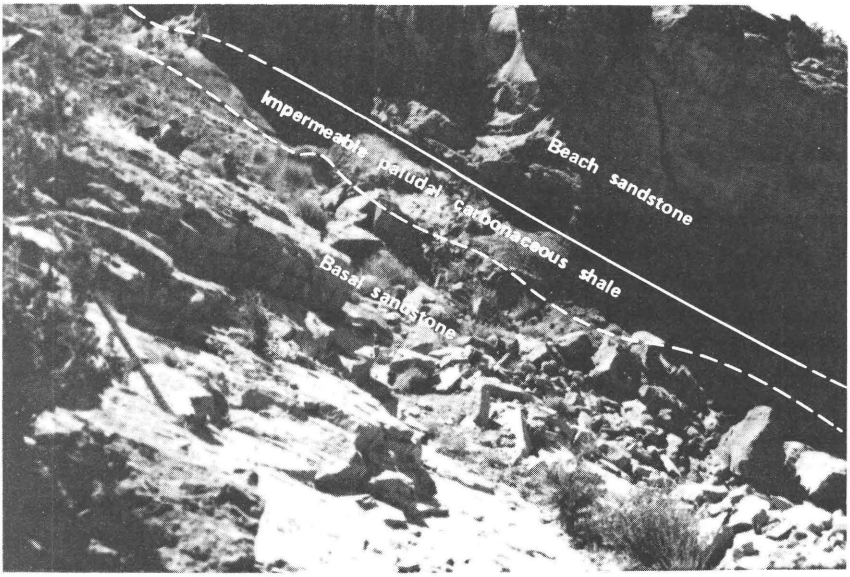


FIGURE 6.—Basal Dakota Sandstone sequence at the Becenti mine along The Hogback. Strata dip 31° W. Leveling rod rests on uranium-bearing strata of medium-energy distributary-channel sandstone in basal Dakota. Uranium is associated with carbonaceous laminae in partings and on bedding planes in the sandstone beds. Some oxidized uranium minerals are in joints. Overlying black, paludal carbonaceous shale acted as a permeability barrier to uranium-bearing solutions. Basal sandstone was stripped in mining. Massive sandstone above carbonaceous shale may be a beach deposit. Scale shown by 5-foot (1.5-m) rod.

HOGBACK NO. 4 (HYDE) MINE

At the Hogback No. 4 mine, the ore is found in the lower part of the main body of the Dakota (section 4), as is the case at the Diamond No. 2 and Becenti mines. However, the host rock, which is a 1.5-m-thick carbonaceous shale containing some sandstone, was deposited in a well-drained swamp environment, whereas most outcropping Dakota uranium deposits are found in distributary-channel sandstones. A good description of well-drained and poorly drained swamp environments is given by Weimer (1976, p. 206).

Gabelman (1956) has described the stratigraphy and mineralization at the Hogback No. 4 mine. On pages 307–308, he describes the ore bed as "* * * a black shale 1–3 feet [0.3–1.0 m] thick that is extremely fissile and can be split into paper-thin sheets, with abundant partially carbonized plant fragments. Locally it is very nearly a peat. It contains numerous thin gray carbonaceous fluvial crossbedded sandstone lenses averaging ¾ inch [2 cm] in thickness and 18 inches [46 cm] in length."

Mirsky (1953, p. 19) states that the ore bed "* * * overlies an apparent channel sandstone which is approximately at the same stratigraphic horizon as the two other hogback mines, the Becenti and Diamond No. 2. However, only a few very minor traces of yellow uranium color have been found within the sandstone below the black shale." Gabelman (1956, p. 308) observed that "* * * the amount of uranium in the lower bed is minor."

DELTER PROSPECT

The Delter prospect (figs. 7 and 8) has been described briefly by Gableman (1956). The highest radioactivity (2,500 cps) is found in a 0.5-m-thick, sandy, carbonaceous shale (section 5) 3 m above the base of the Dakota. The shale unit is part of the fill of a channel cut into the Westwater Canyon Sandstone Member of the Morrison Formation.

According to Gabelman (1956, p. 316), "The mineralized body is an elongate lens 50 feet [15 m] wide and 2 feet [0.6 m] thick which occupies the bottom of the channel and, although undeveloped, is presumed to follow the channel for some distance. * * * The host sandstone is capped with black carbonaceous shale and is strongly contaminated with angular carbonaceous trash fragments."

FIGURE 7.—View north toward White Rock Mesa. Delter uranium prospect is located in lowest part of Dakota Sandstone strata (dark colored), which fill channel cut into Westwater Canyon Sandstone Member of the Morrison Formation (light colored). Brushy Basin Member of the Morrison Formation was removed by pre-Dakota erosion.

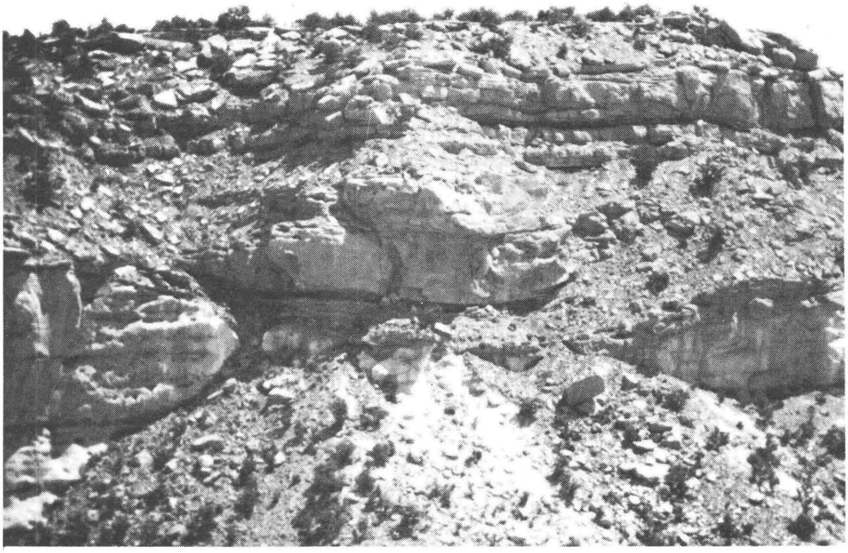


FIGURE 8.—Delter prospect. Radioactive carbonaceous sandy shale, conglomerate, and sandstone of the Dakota Sandstone, formed mainly in a medium-energy environment, at base of channel in Westwater Canyon Member of Morrison Formation. "Slug" of sandstone (unit 7, section 5) above radioactive zone is not mineralized, because high energy of fluvial environment has prevented deposition of organic material in an amount sufficient to have provided enough reductant to precipitate a significant amount of uranium. Claystone of the Brushy Basin Shale Member of the Morrison Formation was removed by pre-Dakota erosion.

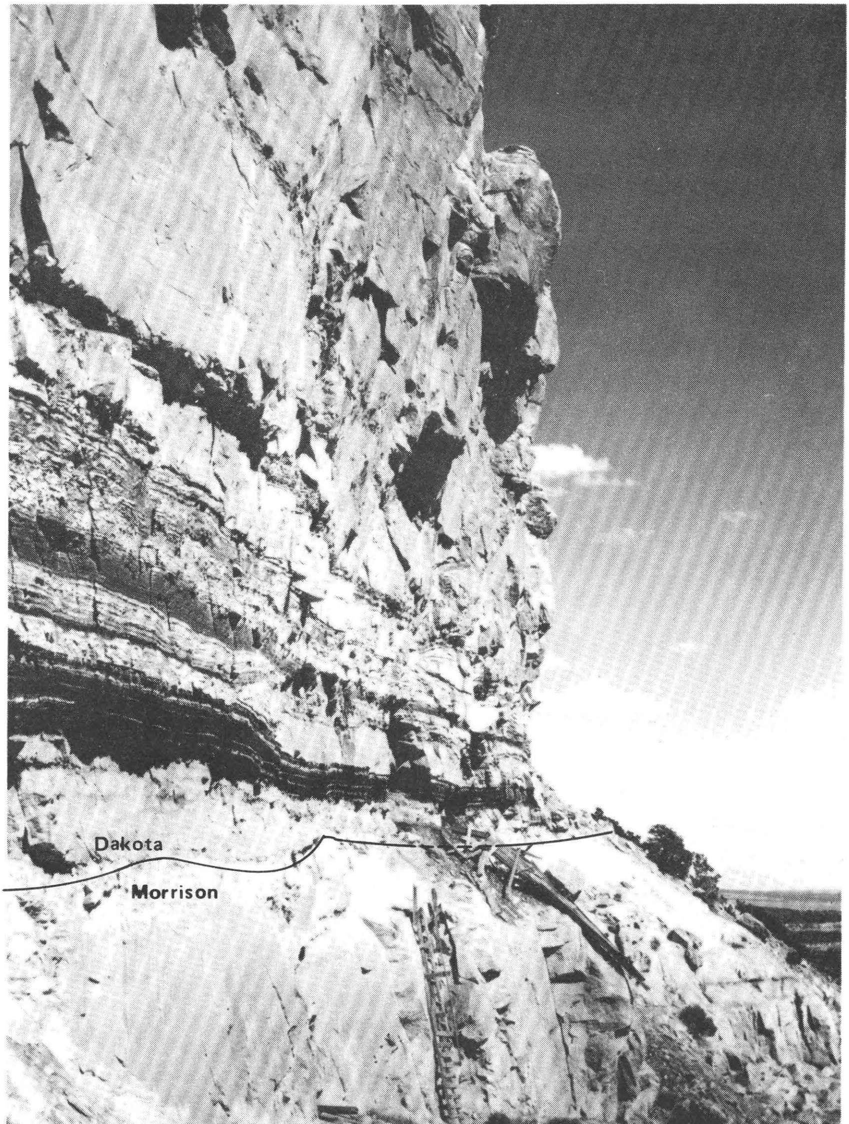
U AND RATS NEST MINES

The U and Rats Nest mines (fig. 2) have been described by Reimer (1969), who also presented a cross section giving radiometric and lithologic data.

The Morrison-Dakota contact is well exposed at the Rats Nest mine (fig. 9), and the lower part of the Dakota rests on sandstone of the Brushy Basin Shale Member of the Morrison Formation. Little if any of the Brushy Basin has been removed by pre-Dakota erosion at this locality, but only a small amount of claystone is present because of a facies change to sandstone.

The lower part of the main body of the Dakota consists of a thick (about 12 m) sequence of paludal carbonaceous shale and interbedded distributary sandstone units. As many as five shale, claystone, or lignite beds, as well as five sandstone lenses, are present along the outcrop.

Most of the radioactivity is associated with fine- to medium-grained sandstone containing laminae and pockets of organic detritus.



MINES IN THE AMBROSIA LAKE DISTRICT

In the Ambrosia Lake mining district, all known uranium deposits in the Dakota Sandstone are in area 6 of figure 1. Hilpert (1969, table 4) gives locations and brief descriptions of the mines.

During the present study only the Febco (Small Stake), Silver Spur, and Junior mines were visited, and discussion is limited to presentation of data that will allow comparison of the geologic setting of these mines with that of the Gallup district mines. Additional information may be obtained from Mirsky (1953), Gabelman (1956), and Hilpert (1969).

As shown by the geologic map of the Goat Mountain quadrangle (Thaden and others, 1966), the Febco (Small Stake) and Silver Spur mines are in sec. 31, T. 14 N., R. 10 W. Gabelman (1956, fig. 102) shows the Small Stake mine to be at the location labeled "Febco Tunnel" on the geologic quadrangle map.

At all of the mines, claystone of the Brushy Basin Member of the Morrison Formation is present beneath the Dakota Sandstone. As shown on the Goat Mountain geologic map, faulting is common near the Dakota mines.

Joints in the Dakota are common, and Mirsky (1953, p. 17), in referring to the Silver Spur mine, states that "Joint directions are N. 15° to 20° W. (major) and N. 25° to 40° E. and north (minor)." He further states that "Length of the ore bodies is aligned in the approximate direction of the secondary joint set * * * ." On page 19 of the same report, Mirsky says: "The Small Stake and Diamond No. 2 mines show less jointing (both are underground workings), but in this vicinity joints do not appear to influence ore deposition."

FEBCO (SMALL STAKE) MINE

At the Febco (Small Stake) mine the stratigraphic sequence (section 7) of the lower part of the main body of the Dakota is similar to the sequence at the U mine in the Gallup district, in that a thick series of interbedded distributary sandstones and paludal shales is overlain by a massive beach or barrier-island sandstone.

◀FIGURE 9.—Stratigraphic sequence at the Rats Nest mine. Uranium is in carbonaceous distributary sandstone in the basal part of the Dakota Sandstone. The distributary sandstones are interbedded with carbonaceous paludal shale and overlain by a massive barrier-island(?) sandstone. Contact between the Dakota and underlying sandstone of the Brushy Basin Member of the Morrison Formation is marked on the photograph. Uranium-bearing solutions entered the Dakota through the permeable Brushy Basin Member. Organic aqueous solutions from lignite in the Dakota bleached the Brushy Basin.

The highest radioactivity (550 cps) at the mine was found in the lower part of a fine- to medium-grained, 1.5-m-thick, slightly carbonaceous sandstone, which is 13.7 m stratigraphically above the base of the Dakota. This sandstone, which is parallel bedded and bioturbated, may be a tidal-flat deposit.

SILVER SPUR MINE

The stratigraphic setting at the Silver Spur mine is similar to that at the Febco mine in that the Dakota rests upon claystone of the Brushy Basin and consists of an upper, massive beach or barrier-island sandstone, which overlies distributary or tidal-flat sandstones interbedded with paludal carbonaceous shales. However, the thicknesses of the black shale units are less than at the Febco mine, and the ore is in the upper part of the main body of the Dakota rather than in the lower part.

Radioactivity is associated with carbonaceous trash along bedding planes in fine- to medium-grained, well-sorted sandstone of the upper ledge of the Dakota. The ore occurrence is similar to that at the Becenti mine, except that the overlying carbonaceous shale is a marine tongue of the Mancos Shale rather than a paludal shale of the Dakota.

JUNIOR MINE

The Junior mine is about 150 m west of the portal of the Dakota (Pat) mine, which is shown by the geologic map of the Goat Mountain quadrangle (Thaden and others, 1966). Mining at the Junior mine was by stripping.

The main production from the Dakota (Pat) mine was from the Westwater Canyon Member of the Morrison Formation. The only radioactivity noted in the Dakota Sandstone at the Junior mine is spottily distributed along a fault (Thaden and others, 1966) that brings the Westwater Canyon Member against the Dakota Sandstone.

ORIGIN OF THE URANIUM DEPOSITS IN THE DAKOTA SANDSTONE

The formation of uranium deposits in the Dakota is believed to have been controlled by five main factors: (1) previous existence of a ground-water flow with a stratigraphically upward component; (2) accessibility to the Dakota of uranium-bearing solutions, derived by aqueous dissolution of preexisting Morrison uranium deposits or by leaching of the arkosic sediments which compose the Morrison; (3)

sufficient permeability within the Dakota to allow passage of the solutions; (4) presence of an aquiclude to confine flow of the solutions, which are thought to have risen stratigraphically during their migration northward toward the San Juan Basin or westward toward the Gallup sag; and (5) availability of enough organic material in the Dakota to reduce and thereby precipitate the uranium from the rising solutions.

Paleomovement of the ground water was generally northward down the Chaco slope toward the center of the San Juan Basin. Gabelman (1956, p. 315), referring to the Diamond No. 2 mine, noted that "* * * the downdip orientation of ore pods suggest[s] deposition from solutions moving parallel to the dip in thin aquifers after tilting of the beds." Locally in the Gallup mining district, movement probably was westerly at the Gallup hogback. A stratigraphically upward component of movement probably existed where the dip of the strata was steeper than the hydraulic gradient. The ground-water movement from the Morrison to the Dakota, which could have taken place at any time from Early(?) Cretaceous to the present, was probably initiated by one of the recurrent uplifts of the Zuni Mountains.

Uranium-bearing ground water from the Morrison could have entered the Dakota in areas where (1) the upper part of the Brushy Basin Shale Member of the Morrison was permeable because it contained sandy facies, as at the U and Rats Nest mines in the Gallup district; (2) the Brushy Basin had been removed by pre-Dakota erosion, as along the Gallup hogback; or (3) faults (Kittle and others, 1967, p. 182) or joints provided conduits, as in the Ambrosia Lake district.

Permeable sandstones are found as distributary sandstones in the lower part of the Dakota, or as massive beach or barrier-island sandstones in the upper part of the Dakota. Carbonaceous shale beds, which acted as aquicludes, are in the lower part of the Dakota, where they are interbedded with the distributary sandstone units. Most of the Dakota uranium deposits in the report area are in distributary sandstone in the lower part of the Dakota. The exceptions are the deposits at the Silver Spur mine, which are in a beach or barrier-island sandstone of the upper Dakota; and those at the Hogback No. 4 (Hyde) mine, which are in sandy, paludal shale of the lower Dakota. At the Silver Spur mine, the amount of impermeable shale in the lower Dakota is small, and hence the uranium solutions were able to reach the upper Dakota. The aquiclude at the Silver Spur is the Whitewater Arroyo Shale Tongue of the Mancos. At the Hogback No. 4 (Hyde) mine, the uranium may have entered the sandy shale (unit 11, section 4) laterally, because the underlying shale bed (unit 10) is relatively impermeable.

Except for the Hogback No. 4 (Hyde) mine, radioactivity in sandstones at all of the mines in the Dakota in the report area is found in permeable sandstone containing either pockets of carbonaceous trash or thin laminae of carbonaceous material. Trash pockets are not common in the Dakota in the area examined, and therefore most of the uranium ore is associated with thin organic-rich laminae. The Diamond No. 2 is the only mine where the ore is associated mainly with carbonaceous trash.

The relative amount of carbonaceous to sand-size material in the rock is related to the energy level of the depositional environment. In high-energy environments such as distributary channels, most of the carbonaceous material either was not deposited or was winnowed out. Rocks formed in the low-energy paludal environment contain abundant carbonaceous material, but the permeability is low, and they are not likely to contain ore-grade uranium. The best host rocks are those formed in medium-energy environments, because they contain ample carbonaceous material for reductant yet retain sufficient permeability to allow the uranium solutions to enter.

SUGGESTIONS FOR EXPLORATION

Exploratory drilling for Dakota ore should include a search for the following stratigraphic conditions: (1) The beds of the Morrison directly underlying the Dakota should be sandy rather than clayey or should contain faults or joints to provide access for solutions to enter the Dakota. (2) The lower part of the Dakota should consist of fine- to medium-grained carbonaceous sandstone beds at least 1 m thick. (3) The sandstone should be interbedded with carbonaceous shale units, which should also be at least 1 m thick. (4) Where impermeable carbonaceous shale beds are thin or absent in the lower Dakota, the massive sandstone present in some areas in the upper part of the Dakota could contain ore, provided that sufficient organic material is present. The most favorable locality for upper Dakota ore is close to the base of the overlying Whitewater Arroyo Tongue of the Mancos Shale.

An exploration drilling program should cross the main paleochannel direction at right angles. The channel direction can be determined at the outcrop, but where drilling is some distance from the outcrop, the vertical and lateral sequences noted in wide-spaced pilot drilling can be used as a guide for closer spaced drilling, as described below.

Main distributary channels are composed principally of medium- to coarse-grained sandstone containing relatively little carbonaceous trash. Beds between the main channel and poorly drained swamps, located on either side of the channel, typically consist of fine- to medium-grained levee and crevasse-splay sandstones interbedded with siltstones of the overbank deposits and with gray, carbonaceous shale layers of the well-drained swamp areas. Black carbonaceous shale and lignite of the poorly drained swamp commonly overlie the above sequences in localities where the main channel has shifted position.

Dimensions of the channels will determine drill spacing. The distance between channels in the report area ranges from about 500 m to as much as 3 km. Initially, drilling on a 1,000-m grid is probably appropriate. When main channel, levee, and swamp deposits are found, a closer-spaced grid may be used to detail the more favorable carbonaceous sandstone units.

In conclusion, the levee and crevasse-splay sandstone units usually contain laminae of carbonaceous material, as well as scattered pockets of carbonaceous trash, and provide the best loci for uranium deposits. Sandstone of the main distributary channels, although permeable, is not generally favorable for uranium deposits because it lacks carbonaceous reductants necessary for the precipitation of uranium. The organic-rich swamp deposits are generally too impermeable to contain uranium deposits.

MEASURED STRATIGRAPHIC SECTIONS

Section 1, Diamond No. 2 (Largo No. 2) mine, about 50 m SE. of mine portal

[Measured by M. W. Green and C. T. Pierson, August 9, 1974. Dip, 30° W.; background gamma radiation, 120 cps (counts per second)]

Top of measured section.	*Thickness (meters)*
Dakota Sandstone, main body (incomplete at top):	
14. Covered	Unmeasured
13. Sandstone, yellow-brown, fine- to medium-grained; distributary channel environment	3.4
12. Shale, black; poorly exposed; probably contains some sandstone ledges; poorly drained swamp environment	9.5
11. Sandstone, yellow-brown, fine- to medium-grained; more massive than interval 13; distributary channel environment	4.9
10. Shale, light-greenish-gray; poorly exposed; well-drained swamp environment	4.3
9. Sandstone, yellow-brown; similar to interval 13; distributary channel environment	1.5
8. Shale, light-greenish-gray; poorly exposed; well-drained swamp environment	1.2
7. Sandstone, red-orange, coarse-grained, crossbedded; distributary channel environment	9.1
6. Lignite, black; poorly drained swamp environment, grades laterally to a well-drained swamp environment	1.2

Section 1—Continued	*Thickness (meters)*
5. Sandstone, yellow-brown, coarse-grained, conglomeratic; uranium ore found in this stratigraphic position at mine portal, 50 m NW.; distributary channel environment	5.5
4. Shale, black; poorly drained swamp environment	.6
Total measured section of Dakota Sandstone, main body (incomplete)	41.2
Westwater Canyon Sandstone Member of the Morrison Formation (all of the Brushy Basin Shale Member and an unknown amount of the Westwater Canyon Member removed by pre-Dakota erosion):	
3. Sandstone, light-pink, fairly well sorted; fluvial environment	3.1
2. Clayey siltstone, greenish-yellow to light-purple; fluvial overbank deposit	2.4
1. Sandstone, light-pink (darker than interval 3; not as extensively bleached), medium-grained, fairly well-sorted, crossbedded; reworked from underlying Cow Springs Sandstone; coarsens higher in section to conglomerate with abundant granules of chert and rock fragments; fluvial environment	23.8
Total Westwater Canyon Sandstone Member, Morrison Formation	29.3
Disconformable contact.	
Cow Springs Sandstone	Unmeasured

Section 2, Locality approximately halfway between the Becenti and the Diamond No. 2 mines

[Measured by M. W. Green, C. T. Pierson, and A. N. Khan, July 18, 1975. Dip, 30° W.; background gamma radiation, 120 cps (counts per second)]

Top of measured section.	*Thickness (meters)*
Dakota Sandstone, main body (incomplete at top):	
10. Sandstone, reddish-orange to reddish-brown, fine- to coarse-grained, moderately well to poorly sorted, quartzose; forms massive ledges laterally continuous for several hundred meters; ledges thin laterally to pinchout; massive to medium-scale trough crossbedding; plant trash imprints; forms cap and backslope along main hogback ridge; broad distributary channel or beach(?) environment	35.1
9. Shale, light-gray, carbonaceous; contains platy siltstone beds; poorly exposed; gamma radiation 80 cps in the shale and 120 cps at contacts between shale and sandstone; well-drained swamp environment	10.7
8. Sandstone, reddish-orange to reddish-brown, medium-grained, well-sorted, quartzose; low-angle, thin crossbedding; laterally continuous to Becenti mine area; gamma radiation 80–100 cps; probable beach environment	2.7
7. Shale, carbonaceous; swamp environment	2.1
6. Sandstone, yellow-brown, fine-grained; distributary channel environment	.6
5. Shale, carbonaceous; gamma radiation 600 cps; poorly drained swamp environment	.9

Section 2—Continued

	Thickness (meters)
4. Sandstone, yellowish-brown, fine- to medium-grained (coarse-grained locally), flat-bedded to low-angle crossbedded; upper part of bed platy; gamma radiation 200 cps; distributary channel environment	2.1
Total measured section of Dakota Sandstone, main body (incomplete)	54.2
Westwater Canyon Sandstone Member of the Morrison Formation (all of the Brushy Basin Shale Member and an unknown amount of the Westwater Canyon Member removed by pre-Dakota erosion):	
3. Sandstone, yellowish-white, medium- to coarse-grained, locally conglomeratic, poorly sorted; granules up to 4 cm in diameter consist of quartzite, weathered granite, and variously colored chert; contains kaolinite nests; low- to moderate-angle crossbeds; gamma radiation 160 cps; high-energy fluvial environment	3.0
2. Sandy siltstone; fluvial environment; forms barrier to altering solutions from the Dakota	1.5
1. Sandstone, reddish-brown; similar to unit 3	10.7
Total Westwater Canyon Sandstone Member, Morrison Formation	15.2
Disconformable contact.	
Cow Springs Sandstone	Unmeasured

Section 3, Becenti mine

[Measured by M. W. Green and C. T. Pierson, August 8, 1974. Dip, 31° W.; background gamma radiation, 120 cps (counts per second)]

	Thickness (meters)
Top of measured section.	
Dakota Sandstone, main body (incomplete at top):	
8. Sandstone, red, coarse-grained, poorly sorted; small-scale trough crossbeds, distorted in upper part, probably owing to slumping shortly after deposition or to overloading by rapid deposition; distributary environment	12.2
7. Sandy shale, light-green to gray, thin-bedded; poorly exposed; well-drained swamp environment	4.6
6. Sandstone, red, coarse-grained, poorly sorted; short trough crossbeds; similar to unit 8; distributary environment	9.1
5. Shale, black, carbonaceous; poorly drained swamp environment	1.8
4. Sandstone, fine-grained; distributary channel environment	1.2
3. Shale, black, carbonaceous; poorly drained swamp environment	1.2
2. Sandstone, yellow-brown; carbonaceous trash; thickness varies laterally; uranium minerals in joints; distributary channel environment	3.1
Total measured section of Dakota Sandstone, main body (incomplete)	33.2
Westwater Canyon Sandstone Member of the Morrison Formation (all of the Brushy Basin Member and an unknown amount of Westwater Canyon Member removed by pre-Dakota erosion):	
1. Sandstone, red, coarse-grained, conglomeratic, poorly sorted; fines upward; trough crossbedding; similar in appearance to unit 8; some shale interbeds near top; high-energy fluvial environment	35.7

Section 3—Continued

	Thickness (meters)
Total Westwater Canyon Sandstone Member, Morrison Formation	35.7
Disconformable contact.	
Cow Springs Sandstone	Unmeasured

Section 4, Hogback No. 4 (Hyde) mine

[Measured by M. W. Green and C. T. Pierson, August 8, 1974. Dip, 42° W.]

	Thickness (meters)
Top of measured section.	
Dakota Sandstone, main body (incomplete at top):	
13. Shale, green to gray, sandy, carbonaceous; contains minor interbedded distributary channel sandstones, 0–1 m thick; well-drained swamp environment	7.6
12. Sandstone, yellow; distributary channel environment	3.0
11. Shale, green to gray, carbonaceous; some sandstone present; uranium ore found in this unit; well-drained swamp environment	1.5
10. Shale, black, carbonaceous; poorly drained swamp environment	4.6
9. Sandstone, yellow-brown; some conglomerate present; distributary channel environment	2.1
8. Shale, dark-gray to black, carbonaceous; poorly drained swamp environment	.6
7. Sandstone, yellow-brown; same as unit 9, but contains more conglomerate; distributary channel environment	3.0
Total measured section of Dakota Sandstone, main body (incomplete)	22.4
Westwater Canyon Sandstone Member of the Morrison Formation (all of the Brushy Basin Member and an unknown amount of the Westwater Canyon Member removed by pre-Dakota erosion):	
6. Sandstone, very white; fluvial environment	12.8
5. Sandy shale, light-purple; flood-plain environment	3.0
4. Sandstone; fluvial environment	13.7
3. Shale, dark-purple; grades from sandy to silty; overbank environment	7.6
2. Sandstone; fluvial environment	7.6
1. Sandy shale, purple to green; flood-plain environment	12.2
Total Westwater Canyon Sandstone Member, Morrison Formation	56.9
Disconformable contact.	
Cow Springs Sandstone	Unmeasured

Section 5, Delter prospect

[Measured by M. W. Green, C. T. Pierson, and A. N. Khan, August 7, 1975. Dip, 3° N. (flanks of channel dip as much as 8°); background gamma radiation, 120 cps (counts per second)]

Top of measured section.

Dakota Sandstone, main body (incomplete at top):

15. Sandstone, yellowish-brown, medium-grained; heavily iron oxide stained on bedding surfaces and along joints; gamma radiation

Section 5—Continued

		Thickness (meters)
	100 cps; distributary channel environment	1.5
14.	Shale, medium- to light-gray, carbonaceous; poorly exposed; gamma radiation 150–200 cps; well-drained swamp environment	6.1
13.	Sandstone, yellowish-brown, fine- to medium-grained (coarse-grained locally); bedding planes iron oxide stained; clay clasts in base of unit; fairly clean, but contains some fossil wood fragments; unit composed of massive, channeled sandstone lenses; massive, structureless to crossbedded locally; current and oscillation ripples; unit intertongues laterally with dark carbonaceous shale; scouring at base; gamma radiation 100–150 cps; high-energy fluvial distributary channel environment	7.6
12.	Shale, carbonaceous; medium gray in upper part and black in lower part; upper part contains sandstone ledges 7–10 cm thick; unit grades downward from well-drained to poorly drained swamp environment	.9
11.	Sandstone, yellowish-brown, fine- to medium-grained, massive, well-sorted; poorly sorted in uppermost 0.3 m; sparse carbonaceous trash; upper part burrowed; low-angle crossbedded in lower part; gamma radiation 150–180 cps; beach(?) environment	2.3
10.	Shale, black, carbonaceous	.9
9.	Sandstone, siltstone, and shale; sandstone and siltstone are yellowish brown and thin bedded; sandstone is fine grained; shale partings are medium gray. Unit persists laterally past channel margins; has sharp upper and lower contacts; gamma radiation 150–180 cps; low-energy fluvial environment	3.1
8.	Shale, medium-gray to black, carbonaceous; coaly in upper 0.3 m; some thin-bedded to laminated sandy siltstone beds under coaly zone; unit is laterally continuous; gamma radiation 180–200 cps; grades upward from well-drained to poorly drained swamp environment	2.4
7.	Sandstone, yellowish-brown, fine- to medium-grained, well-sorted, thin-bedded to massive; carbonaceous trash locally along partings and bedding planes; unit pinches out along margins of channel; massive units become thin-bedded toward flanks of channel; unit ranges from 27.5 m thick to 0 m (on flanks); gamma radiation 150–200 cps in upper part of unit, 400–500 cps in basal part of unit; distributary channel environment	18.3
6.	Shale and siltstone, interbedded; unit becomes sandy laterally as well as upward; siltstone is sandy, finely laminated, and slightly carbonaceous; shale is medium to dark gray (ash gray locally); gamma radiation 200–250 cps in upper part of unit, 250 cps in center, and 800 cps at base; low-energy fluvial(?) and (or) well-drained swamp environment	5.2
5.	Sandstone, yellowish-brown, fine-grained, well-sorted, carbonaceous (carbonaceous material as disseminations and as concentrations along bedding planes), thin-bedded; locally crossbedded at low angles; bioturbated; gamma radiation 1,000 cps; low-energy fluvial environment	.9
4.	Sandy shale, black, carbonaceous; yellowish-brown sandy siltstone stringers as much as 1 cm thick contain carbonaceous material along partings; sandstone and silty sandstone with finely disseminated car-	

Section 5—Continued

	Thickness (meters)
bonaceous material make up about 40 percent of unit; unit grades vertically upward into overlying sandstone unit; basal contact sharp; gamma radiation 2,500 cps; poorly drained swamp environment	0.5
3. Sandstone, yellow-brown, medium- to coarse-grained, thin-bedded, locally crossbedded; scattered granules; sparse carbonaceous trash; gamma radiation 350–500 cps (higher count near contact with overlying carbonaceous shale); high-energy distributary channel environment	1.5
2. Granule conglomerate with sandstone matrix; 20–30 percent of the matrix material is iron oxide; woody plant material locally; unit pinches out laterally; gamma radiation 400–1,700 cps (high count near carbonaceous trash); lower contact is sharp and channeled; relief on channel is 15–20 m; distributary channel environment	1.5
Total measured section of Dakota Sandstone, main body (incomplete)	61.9
Westwater Canyon Sandstone Member of the Morrison Formation (all of the Brushy Basin Member and an unknown amount of the Westwater Canyon Member removed by pre-Dakota erosion):	
1. Sandstone, white, kaolinitic	Unmeasured

Section 6, U mine, composite section

[Compiled by C. T. Pierson, and H. Htay from data reported by Reimer (1969) and T. N. Parthasarathy (written commun., 1974). Dip, 3° N.]

Top of measured section.

	Thickness (meters)
Dakota Sandstone, main body (incomplete at top):	
12. Shale, carbonaceous	0.3
11. Claystone	.3
10. Sandstone, moderately well sorted; lower portion shaly	1.7
9. Lignite	.5
8. Sandstone, very fine grained, crossbedded; gray or buff on fresh surface; grains subangular to subrounded	1.4
7. Shale, laminated; weathers to rubble-strewn slope; lower contact uncertain	2.9
6. Sandstone, crossbedded, massive	.6
5. Lignite; fibrous gypsum in cracks and joints; poorly drained swamp environment	1.1
4. Sandstone, fine- to medium-grained, moderately well sorted, quartzose, well-cemented; quartz overgrowths; grains angular to subangular; weathers buff with iron oxide-stained spots; gray on fractures; considerable carbonaceous material present as small flecks; distributary channel(?) environment	.5
3. Sandstone interbedded with siltstone, carbonaceous	.6
2. Covered zone; base of the Dakota is within this covered interval	2.4
Total measured section of Dakota Sandstone main body (incomplete)	12.3

Disconformable contact (covered).

Section 6—Continued

Thickness (meters)

Brushy Basin Shale Member of the Morrison Formation:

1. Sandstone, white, kaolinized. Mudstone, usually present in this stratigraphic position, is absent because of facies change to sandstone ---------- Unmeasured

Section 7, Febco (Small Stake) mine

[Measured by M. W. Green, August 6, 1975. Dip, 2° N.; background gamma radiation, 120 cps (counts per second)]

Top of measured section.

Thickness (meters)

Dakota Sandstone, main body (incomplete at top):

10. Sandstone; yellowish-brown to reddish-brown, fine- to medium-grained, well-sorted, flat-bedded, siliceous, bioturbated; gamma radiation 110 cps ---------- 3.4
9. Sandstone; same as interval 1 but more bioturbated; gamma radiation 125 (upper part) to 150 (lower part) cps; beach(?) environment ---------- 2.1
8. Shale; covered interval ---------- 2.4
7. Sandstone; yellowish-brown to reddish-brown, fine- to medium-grained, well-sorted, flat parallel-bedded to massive; burrows present; sparse carbonaceous material; gamma radiation 150 cps; distributary channel environment ---------- .6
6. Shale; covered interval; gamma radiaton 175 cps ---------- 3.1
5. Sandstone, yellowish-brown to reddish-brown, fine- to medium-grained, well-sorted, flat parallel-bedded to massive; silty at base; carbonaceous shale partings in base; gamma radiation 250–300 cps ---------- 1.8
4. Shale, dark-gray to black, carbonaceous; minor sandy intervals; gamma radiation 300–400 cps; poorly drained swamp environment ---------- 2.1
3. Sandstone; yellowish-brown to reddish-brown, fine- to medium-grained, well-sorted, flat parallel-bedded to massive; Febco tunnel is in this sandstone; gamma radiation 300 (upper part) to 550 (lower part) cps ---------- 1.5
2. Shale, dark-gray to black, carbonaceous; largely covered; thinly interbedded sandstone ledges; gamma radiation 350 cps; poorly drained swamp environment ---------- 13.7

Total measured section of Dakota Sandstone main body (incomplete) ---------- 30.7

Disconformable contact (covered).

Brushy Basin Shale Member of the Morrison Formation:

1. Silty claystone, greenish-gray; only upper part exposed; some coarse-grained, grayish-brown sandstone as lenses and stringers; gamma radiation 250 cps (300 cps near contact); contact with Dakota may be in a slump block; flood-plain and lacustrine environment - Unmeasured

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