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FACTORS CONTROLLING LOCALIZATION OF URANIUM DEPOSITS IN THE DAKOTA SANDSTONE, GALLUP AND AMBROSIA LAKE MINING DISTRICTS, MCKINLEY COUNTY, NEW MEXICO

By

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FACTORS CONTROLLING LOCALIZATION OF URANIUM DEPOSITS IN THE DAKOTA SANDSTONE, GALLUP AND AMBROSIA LAKE MINING DISTRICTS, MCKINLEY COUNTY, NEW MEXICO

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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, New Mexico. Dakota mines in the adjacent Ambrosia Lake mining district were visited briefly 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 which dip gently northward toward the central part of the basin. Mines in the western part of the Gallup district are along the Gallup hogback (Nutria monocline) in strata which dip steeply westward into the Gallup sag.

Geologic factors which controlled formation of the uranium deposits in the Dakota Sandstone are: (1) 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 Dakota uranium deposits are found in the lower part of

the formation in marginal-marine distributary-channel sandstones which were deposited in the backshore environment. However, the Hogback no. 4 (Hyde) Mine (Gallup district) occurs in sandy paludal shale of the backshore environment, and another deposit, the Silver Spur (Ambrosia Lake district), is found in what is interpreted to be a massive beach or barrier-bar sandstone of the foreshore environment in the upper part of the Dakota.

The sedimentary depositional environment most favorable for the accumulation of uranium is that of backshore 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. Deposits of black carbonaceous shale which were formed in the poorly drained swamp deposits of the interfluve area 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 usually occurs in carbonaceous sandstone deposited under low- to medium-energy fluvial conditions within distributary channels. A prerequisite, however, is that such sandstone be overlain by impermeable carbonaceous shale beds.

Low- to 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 cause precipitation of uranium from solution. High-energy fluvial conditions result in the deposition of sandstones having little or no carbonaceous material included to provide a reductant. Very 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.

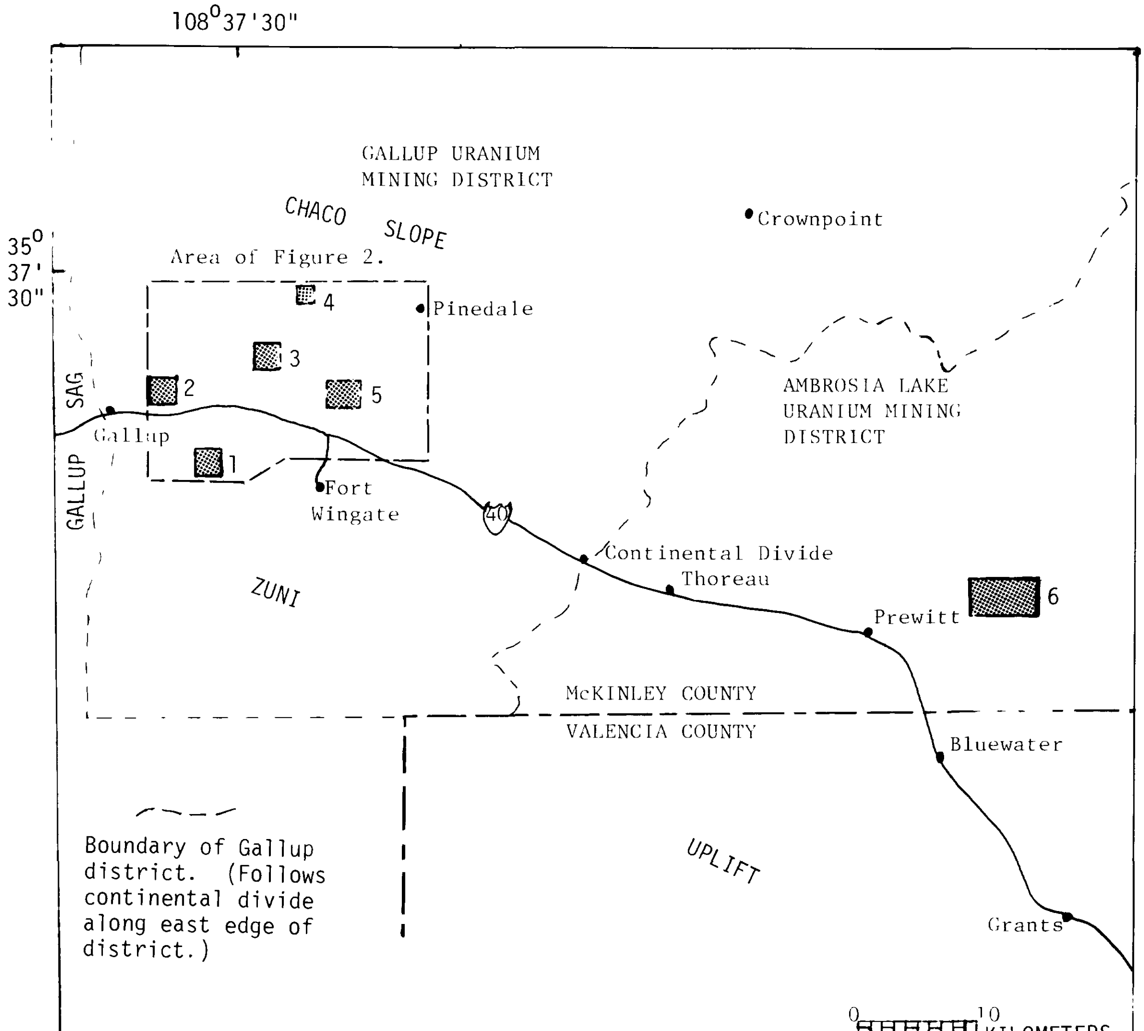
INTRODUCTION

Location and Geologic Setting

Uranium in the Dakota Sandstone of Early(?) and Late Cretaceous age is found in five areas (areas 1-5, fig. 1) in the Gallup mining district, and in one area (area 6, fig. 1) in the Ambrosia Lake mining district. 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 Mine, 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 numbers 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, and Dakota (Pat) mines (area 6, fig. 1) in the Ambrosia Lake mining district are also discussed, but no map showing their locations is included in this report. These mines are shown, however, on the geologic map of the Goat Mountain quadrangle (Thaden and others, 1966).



URANIUM MINES AND PROSPECTS IN THE DAKOTA SANDSTONE

1. Becenti and Diamond no. 2 (Largo no. 2) mines.
2. Hogback no. 4 (Hyde) Mine.
3. Delter Prospect.
4. Church Rock Mine.
5. U Mine and Rats Nest Mine.
6. Silver Spur no. 1, Silver Spur no. 5, Febco (Small Stake), Junior, Section 5, and Dakota (Pat) mines.

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.

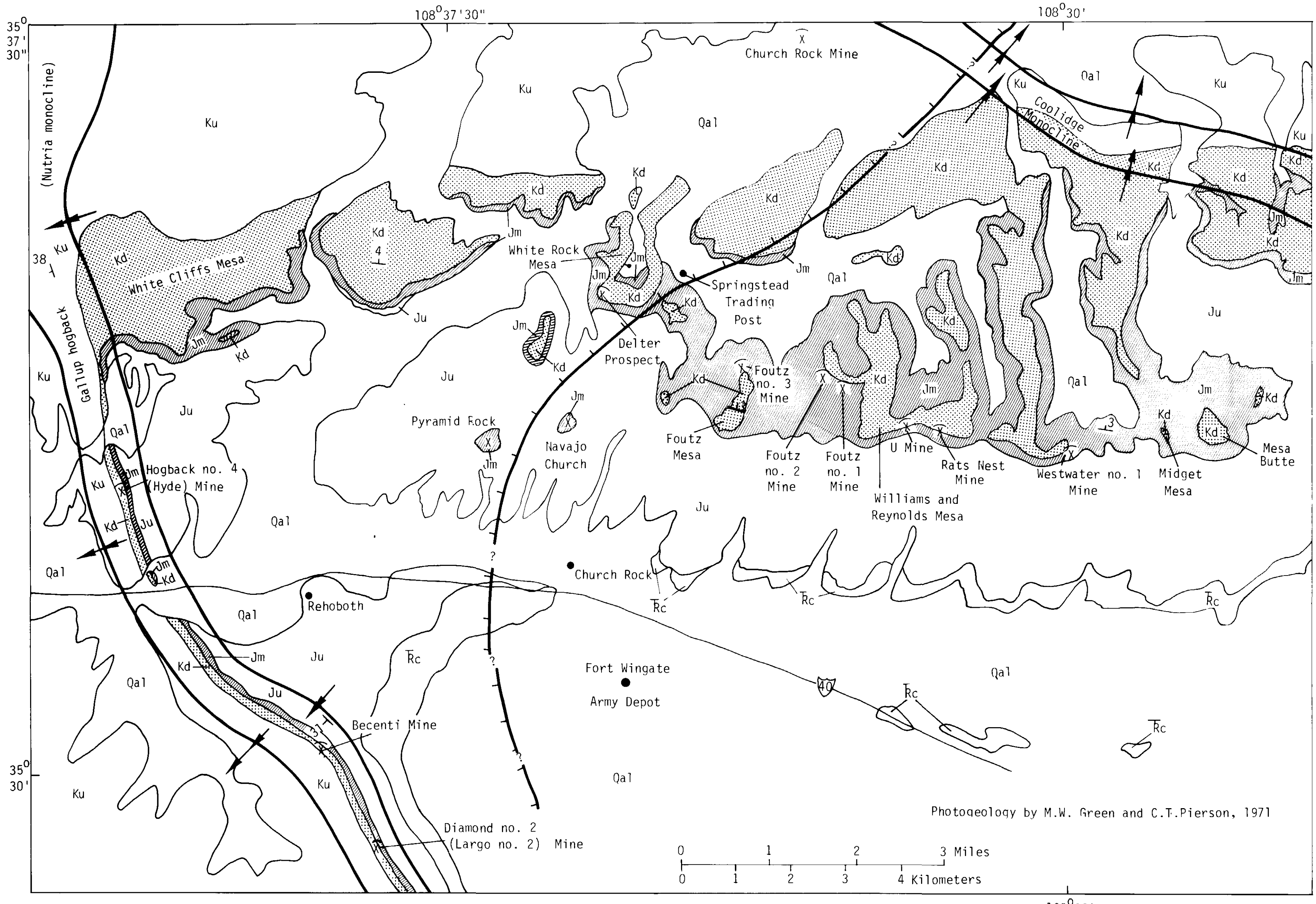


Figure 2. -- Geologic sketch map of part of the Gallup Mining District, McKinley County, New Mexico, showing locations of uranium mines and prospects.

The geologic settings of the parts of the two mining districts in which the Dakota deposits occur are somewhat similar. Except for the area of the Gallup hogback (Nutria monocline) (fig. 2), gently northeast-dipping beds of the Dakota uncomformably overlie strata of the Upper Jurassic Morrison Formation. A surface of erosion is everywhere present at the Morrison-Dakota contact.

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 either to pre-Dakota erosion, or to a facies change to sandstone.

Table 4 of Hilpert (1969) gives locations and brief descriptions of all of the Dakota mines referred to in the present report. 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), and Gableman (1956). 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 previously unpublished data used in the present report came from Reimer (1969).

Present Study

Work done by the authors in 1974-1975 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 the U Mine (measured stratigraphic section no. 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. J. M. Reyes of the U.S. Geological Survey drafted the maps and assisted materially in data compilation.

STRATIGRAPHY AND ENVIRONMENTS OF DEPOSITION

Pre-Quaternary sedimentary rocks exposed in the area covered by figure 2 include, in order of decreasing age, 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, 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 undifferentiated into two groups: (1) pre-Morrison; and (2) post-Dakota.

The Triassic (Stewart and others, 1972) and Jurassic (Harshbarger and others, 1957) rocks are interpreted to be all of continental origin. The Lower(?) and Upper Cretaceous (Sears and others, 1941) rocks are interpreted to be of marginal marine or marine origin. Only the Morrison Formation and 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 a depositional break 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 therefore only the Westwater Canyon and Brushy Basin Members, which intertongue, are described below. For the Ambrosia Lake district, stratigraphic details of the Morrison Formation are provided by Santos (1970) in his report on the stratigraphy of the Morrison Formation and the structure of 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. In the Gallup area, it is thinnest (29 m) at the Diamond no. 2 (Largo no. 2) Mine because of pre-Dakota erosion, which is accentuated along the Gallup hogback. The member is predominantly a red, medium- to coarse-grained, fluvially crossbedded, first-cycle, arkosic to subarkosic sandstone. Lenses of conglomeratic sandstone are common, particularly in the western part of the report area. Siltstone and claystone contents increase 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. The general direction of stream flow was to the east-northeast, as indicated by the gradual change from predominantly midfan to predominantly distal facies in this direction (Green, 1975). The paleoclimate was probably warm and humid, as indicated by large accumulations of detrital organic matter in the form of tree trunks and other plant remains incorporated with Westwater Canyon sediments.

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

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 south-southwest trending pre-Dakota erosion. In the Ambrosia Lake District, and in the eastern part of the Gallup District, the unit is composed mainly of green, tuffaceous claystone which interbeds with sandstone of the type found in the Westwater Canyon Member. Locally in the Gallup mining district, the Brushy Basin Member is composed dominantly of sandstone.

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

The environment in which sandstones of the Brushy Basin Member were deposited is the same as that for the Westwater Canyon Member. The claystone of the Brushy Basin is interpreted to be the distal deposits of the 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 meters, generally comprises: (1) a lower part consisting of paludal carbonaceous shale beds as much as 2 m thick interbedded with crossbedded, fine- to coarse-grained or conglomeratic distributary channel sandstone lenses as much as 4 m thick; and (2) an upper part consisting of thick-bedded to massive, fine- to medium-grained beach or barrier-bar 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 have been truncated by 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) has been described by Kelley (1963). Santos (1970) discusses 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 degrees northeast except along the Gallup hogback (Nutria monocline) (fig. 2), where dips range from 30 to 85 degrees west, and along the Coolidge (Pinedale) monocline (fig. 2), where dips of as much as 26 degrees are found north of the town of Continental Divide. 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), in his paper on the stratigraphy and structure of the Ambrosia Lake district, noted that the district probably occupies the most folded and faulted part of the Chaco slope or platform. The Gallup mining district has steeper-dipping folds (Nutria and Pinedale monoclines), but is considerably less faulted than the Ambrosia Lake district. The westernmost faults in the report area belong to the Bluewater fault zone (not shown), which passes near Thoreau (fig. 1) 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 area. They appear to be more prominent in the Dakota than the Morrison, but no systematic regional study has been made of joint orientations and distributions.

URANIUM DEPOSITS

Production

Hilpert (1969) noted that most of the uranium deposits in Cretaceous rocks in northwest New Mexico occur in the Dakota Sandstone, and he listed (Hilpert, 1969, table 4) 14 Dakota deposits, 11 of which are in McKinley County. One of the deposits, the Church Rock, is partly in the Morrison Formation. The following quote from Hilpert (1969, p. 89) gives the order of magnitude of production: "Of 14 that are listed, 9 yielded a total during the 1952-1964 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 no. 2 mines."

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 control of the uranium deposits in the Morrison in the southern San Juan Basin (Grants) mineral belt. For the purposes of the present report, it is sufficient to note that the main deposits are found in sandstone of the Westwater Canyon Member. Some smaller deposits occur in lenses and tongues of sandstone in the Brushy Basin Shale Member, or in channel-fill sandstones 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 no claystone of the Brushy Basin is present above the ore. This is probably because not much carbonaceous reducing material is present in sandstone lenses of the basal 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), Granger (1963), and Chico (1959).

Minerals in the sandstone consist of primary pitchblende and uraninite(?), as well as various yellow secondary uranium minerals. No uranium mineral has 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 K. R. Ludwig and B. J. Szabo of the U.S. Geological Survey (written commun., 1975). According to them, the age of a pitchblende from the Hogback no. 4 mine, as determined from combined U-lead and U-series data, 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), Gableman (1956), Hilpert (1969), and Reimer (1969). Three mines (Diamond no. 2, Becenti, and Hogback no. 4) occur in steeply dipping Dakota strata of the Gallup 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 at Williams and Reynolds Mesa (U mine and Rats Nest mine). The mines in the Morrison Formation are found at Foutz Mesa (Foutz no. 3 mine), and at the southeast tip of the mesa just east of Williams and Reynolds Mesa (Westwater no. 1 mine). Production from the Church Rock mine, which had ore in both the Morrison and Dakota (Hilpert, 1969, p. 77), came from a shaft located in the valley floor in the north-central part of the area shown by figure 2. The shaft is now abandoned.

Diamond no. 2 (Largo no. 2) mine.--Gableman (1956) has given 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. Chico (1959) has recorded the results of detailed underground and surface studies made at the mine.

Outcrop observations we made at the Diamond no. 2 mine (fig. 4) show that the ore is found in the basal distributary-channel sandstone of the Dakota. This basal 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 section (measured stratigraphic section 1) measured about 50 m southeast of the mine portal. The ore is associated with plant debris in medium- to coarse-grained, crossbedded, medium-energy, fluvially deposited sandstone.

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

Figure 4.--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 (lignite-sandstone sequence) of the overlying Dakota Sandstone. The lignite-sandstone sequence (swamp and distributary channel) is overlain by a massive sandstone unit (beach ?). Uranium occurs in medium-energy distributary-channel sandstones containing pockets of carbonaceous trash. Portal is about 3 m high.

Becenti mine.--Uranium ore at the Becenti mine (fig. 5) is found in the same stratigraphic position (measured stratigraphic section 3) as ore at the Diamond no. 2 mine. At the Becenti mine, 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, low- to medium-energy fluvial sandstone. econdary uranium minerals are visible in joints.

Figure 5.--Basal Dakota Sandstone stratigraphic sequence at the Becenti mine along Gallup hogback. Strata dip 31 degrees west. Levelling rod rests on uranium-bearing strata of low- to medium-energy distributary-channel sandstone of basal Dakota. Uranium is associated with carbonaceous laminae in partings and on bedding planes in the sandstone beds. Some secondary uranium minerals occur in joints. Overlying black, paludal carbonaceous shale acted as a permeability barrier. Mining was by stripping of basal sandstone. 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 (measured stratigraphic 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. This contrasts with the fact that most outcropping Dakota uranium deposits are found in distributary-channel sandstones.

Gableman (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 [0.3-1.0 m] feet 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 3/4 inch [2 cm] in thickness and 18 inches [46 cm] in length."

Mirsky (1953, p. 19), in discussing the ore bed, notes that it "...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." Gableman (1956, p. 308) observed that "...the amount of uranium in the lower bed is minor."

Delter prospect.--The Delter prospect (figs. 6 and 7) has been described briefly by Gableman (1956). The highest radioactivity (2,500 cps) is found in a 0.5-m-thick, sandy, carbonaceous shale (measured stratigraphic section 5) 3 m above the base of the Dakota. The unit is part of the fill of a channel cut into the Westwater Canyon Sandstone Member of the Morrison Formation.

According to Gableman (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 6.--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).

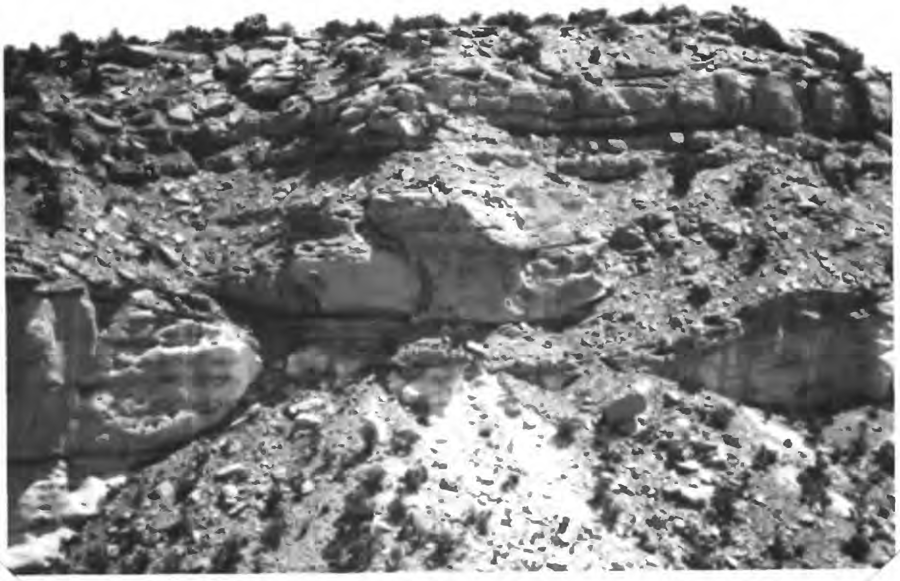


Figure 7.—Delter prospect. Carbonaceous sandy shale, conglomerate, and sandstone, formed mainly in a low- to medium-energy environment at base of channel is radioactive. "Slug" of sandstone (Unit 9, measured stratigraphic section 5) above radioactive zone is not mineralized, because high fluvial energy of depositional environment has prevented deposition of reducing organic material. Claystone of the Brushy Basin Shale Member of the Morrison Formation removed by pre-Dakota erosion.

Mines at Williams and Reynolds Mesa.—The mines (Rats Nest and U mine) at Williams and Reynolds Mesa (fig. 2) have been described by Reimer (1969), who also presented a cross section giving radiometric and lithologic data. Measured stratigraphic section 6 is a generalized composite section compiled from Reimer's unpublished field notes (written commun., 1968), and from an unpublished panel diagram drawn by T. N. Parthasarathy (written commun., 1974).

At the Rats Nest mine (fig. 8), the Morrison-Dakota contact is well exposed, 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 facies change to sandstone.

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

Most of the radioactivity is associated with fine- to medium-grained sandstone containing laminae and pockets of organic detritus. Adits at the U mine are usually in carbonaceous shale rather than sandstone because of the relative ease of mining.

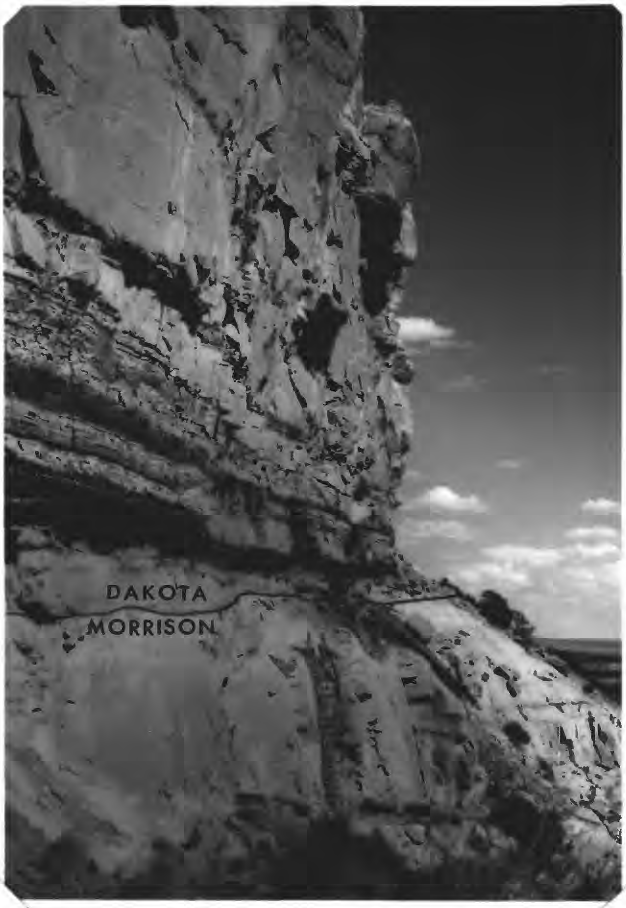


Figure 8.--Stratigraphic sequence at the Rats Nest mine. Uranium occurs in carbonaceous distributary sandstones in basal part of the Dakota Sandstone. The distributary sandstones are interbedded with carbonaceous paludal shale and overlain by a massive barrier-bar(?) sandstone. Contact between the Dakota and underlying sandstone of the Brushy Basin Member of the Morrison is marked. Uranium-bearing solutions gained access to Dakota through sandy Brushy Basin Member. Bleaching of Brushy Basin was by organic solutions from lignite in the Dakota.

Mines in the Ambrosia Lake District

In the Ambrosia Lake mining district, all known uranium deposits in the Dakota Sandstone occur in area no. 6 (fig. 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 Dakota (Pat) 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), Gableman (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. Gableman (1956, Figure 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, a considerable amount of faulting exists in the general area of 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 (measured stratigraphic 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-bar sandstone.

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-bar 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 occurs 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 carbonaceous shale of the Dakota.

Dakota (Pat) mine.—The main production from the Dakota (Pat) mine came from the Westwater Canyon Sandstone Member of the Morrison Formation, but some stripping of the Dakota Sandstone was done west of the Dakota mine. The only radioactivity noted in the Dakota Sandstone is spottily distributed along a fault shown just to the west of the mine by the geologic map of the Goat Mountain quadrangle (Thaden and others, 1966).

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 oxidation of preexisting Morrison uranium deposits, or by leaching of the arkosic sediments which compose the Morrison; (3) sufficient transmissivity within the Dakota to allow passage of the solutions; (4) presence of an impermeable caprock to concentrate 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. Gableman (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 Williams and Reynolds Mesa 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-bar sandstones in the upper part of the Dakota. Carbonaceous shale beds, which acted as aquicludes, occur 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 sandstones in the lower part of the Dakota. The exceptions are the deposits at the Silver Spur mine, which are in a beach or barrier-bar sandstone of the upper Dakota; and those at the Hyde mine, which occur 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. Caprock at the Silver Spur is the Whitewater Arroyo Shale Tongue of the Mancos. At the Hyde mine, the uranium may have entered the sandy shale (Unit 3, measured stratigraphic section 4) laterally, because unit 4 below is relatively impermeable.

Except for the 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. Ore consisting of uranium associated with thin organic-rich laminae in sandstone is more common than ore formed by the association of uranium with carbonaceous trash. The Diamond no. 2 mine is the most important example of uranium associated with such trash.

The amount of carbonaceous material present is related to the energy level at which the distributary channel sandstones were deposited. If the energy level was high, most of the carbonaceous material present in the system was not deposited or was washed out. If the energy level was very low, which in the basal Dakota meant that swamp conditions prevailed, the ratio of carbonaceous material to sandstone was high, and hence, permeability was low. A low- to medium-energy environment, in which permeable sandstone contains adequate carbonaceous material, is most favorable for uranium.

SUGGESTIONS FOR EXPLORATION

Exploratory drilling for Dakota ore should include search for the following stratigraphic conditions: (1) the lithology of the Morrison directly underlying the Dakota should be sandy rather than clayey (if claystone of the Brushy Basin Member is present, faults or joints are necessary 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, also at least 1 m thick; (4) where impermeable carbonaceous shale beds are thin or absent in the lower Dakota, the massive sandstone usually present 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.

Exploration diamond drilling should be designed to cross the main paleochannel direction at right angles. Near the outcrop, the channel direction can be determined by geologic observation. Where drilling is done at some distance from the outcrop, the vertical and lateral sequences noted in wide-spaced pilot drillings can be used as a guide to closer-spaced drilling, as described below.

The main distributary channel is 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 channel will determine drill spacing. The distance between channels in the report area ranges from about 500 m to as much as 3 km. Initial drilling on a 1,000-m grid would seem to be appropriate. After the main channel, levee, and swamp deposits have been found, a closer-spaced grid should be chosen to test the more favorable-appearing carbonaceous sandstone units.

In conclusion, the levee and crevasse-splay sandstones usually contain laminae of carbonaceous material, as well as scattered pockets of carbonaceous trash, and therefore provide the best loci for uranium deposits. Sandstones of the main distributary channel, although permeable, are not generally favorable hosts for uranium deposits because they usually lack 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.; scintillation meter background 120 cps (counts per second).

Top of measured section.

Dakota Sandstone, main body (incomplete at top):

		meters
1.	Covered	Unmeasured
2.	Sandstone, yellow-brown, fine- to medium-grained; distributary channel environment	3.4
3.	Shale, black, poorly exposed; probably contains some sandstone ledges; poorly drained swamp environment	9.5
4.	Sandstone, yellow-brown, fine- to medium-grained; more massive than interval 2; distributary channel environment	4.9
5.	Shale, light-greenish-gray; poorly exposed; well-drained swamp environment	4.3
6.	Sandstone, yellow-brown; similar to interval 2; distributary channel environment	1.5
7.	Shale, light-greenish-gray; poorly exposed; well-drained swamp environment	1.2
8.	Sandstone, red-orange, coarse-grained, cross-bedded; distributary channel environment	9.1
9.	Lignite, black; poorly drained swamp, grades laterally to a well-drained swamp environment	1.2

10.	Sandstone, yellow-brown, coarse-grained, conglomeratic; Uranium ore found in this stratigraphic position at mine portal, 50 m NW.; distributary channel environment	5.5
11.	Shale, black; poorly drained swamp environment	0.6
	Total Dakota Sandstone, main body (incomplete)	41.2

Westwater Canyon Sandstone Member of the Morrison Formation (truncated; all of the Brushy Basin Shale Member, and an unknown amount of the Westwater Canyon Member removed by pre-Dakota erosion):

12.	Sandstone, light-pink, fairly well sorted; fluvial environment	3.1
13.	Siltstone, clayey, greenish-yellow to light-purple; fluvial overbank deposit	2.4
14.	Sandstone, light-pink (darker than interval 12; not as extensively bleached), medium-grained, fairly well sorted; reworked from underlying Cow Springs Sandstone; coarsens higher in section to conglomerate with abundant granules of chert and rock fragments; foreset crossbedded; fluvial environment	23.8
	Total 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.; scintillation meter background 120 cps (counts per second).

Top of measured section.

	meters
Dakota Sandstone, main body (incomplete at top):	
1. Sandstone, brick-orange to reddish-brown, fine- to medium-grained (locally coarse-grained), moderately well to poorly sorted, quartzose; forms massive ledges laterally continuous for several hundred meters; ledges thin laterally to pinchout; massive to foreset crossbedded; plant trash imprints; forms cap and backslope along main hogback ridge; broad distributary channel and beach(?) environment------------------	35.1
2. Shale, light-gray, carbonaceous; contains platy siltstone beds; poorly exposed; 80 (in the shale) - 120 cps (at contacts between shale and sandstone); well-drained swamp environment--------------------	10.7
3. Sandstone, brick-orange to reddish-brown, medium-grained, well-sorted, quartzose; low-angle, thin cross-bedding; laterally continuous to Becenti mine area; 80-100 cps; probable beach environment----------------------------------	2.7
4. Shale, carbonaceous; splay or swamp environment------	2.1

5. Sandstone, yellow-brown, fine-grained; distributary channel environment-------------------------	0.6
6. Shale, carbonaceous; 600 cps; poorly drained swamp environment--------------------------------	0.9
7. Sandstone, yellowish-brown, fine- to medium-grained (coarse-grained locally), flat-bedded to low-angle crossbedded; upper part of bed platy; 200 cps; distributary channel environment-----------	2.1
Total Dakota Sandstone, main body (incomplete)------	54.2

Westwater Canyon Sandstone Member of the Morrison Formation (truncated; all of the Brushy Basin Shale Member, and an unknown amount of the Westwater Canyon Member removed by pre-Dakota erosion):

8. 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 fluvial crossbeds; 160 cps; high energy fluvial environment-------------------	3.0
9. Sandy siltstone; fluvial environment; forms barrier to altering solutions from the Dakota-------	1.5
10. Sandstone, reddish-brown; similar to unit 8----------	10.7
Total 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.; scintillation meter background 120 cps (counts per second).

Top of measured section.

	meters
Dakota Sandstone, main body (incomplete at top):	
1. Sandstone, red, coarse-grained, poorly sorted; short foreset crossbeds, distorted in upper part, probably owing to slumping shortly after deposition or to overloading by rapid deposition; similar in appearance to the Westwater Canyon Member (below); distributary fluvial environment-------------	12.2
2. Sandy shale, light-green to gray, thin-bedded; poorly exposed; well-drained swamp environment-------------------------------	4.6
3. Sandstone, red, coarse-grained, poorly sorted; short foreset crossbeds; similar to unit 1; distributary fluvial environment-------------	9.1
4. Shale, black, carbonaceous; poorly drained swamp environment---------------------------	1.8
5. Sandstone, fine-grained; distributary channel environment-------------------------------	1.2
6. Shale, black, carbonaceous; poorly drained swamp environment---------------------------	1.2

7. Sandstone, yellow-brown; carbonaceous trash; thickness varies laterally; uranium minerals in joints; distributary channel environment---- 3.1

Total Dakota Sandstone, main body (incomplete)- 33.2

Westwater Canyon Sandstone Member of the Morrison Formation (truncated; all of the Brushy Basin Member, and an unknown amount of Westwater Canyon Member removed by pre-Dakota erosion):

8. Sandstone, red, coarse-grained, conglomeratic, poorly sorted; fines upward; foreset cross-bedding; some shale interbeds near top; high-energy fluvial environment-------------------- 35.7

Total 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.

Top of measured section

	meters
Dakota Sandstone, main body (incomplete at top):	
1. Shale, green to gray, sandy, carbonaceous; contains minor interbedded distributary channel sandstones, 0-1 m thick; well-drained swamp environment----------	7.6
2. Sandstone, yellow; distributary channel environment-----	3.0
3. Shale, green to gray, carbonaceous; some sandstone present; uranium ore found in this unit; well-drained swamp environment----------------------------	1.5
4. Shale, black, carbonaceous; poorly drained swamp environment---	4.6
5. Sandstone, yellow-brown; some conglomerate present; distributary channel environment----------------------	2.1
6. Shale, dark-gray to black, carbonaceous; poorly drained swamp environment----------------------------	0.6
7. Sandstone, yellow-brown; same as unit 5, but contains more conglomerate; distributary channel environment------------------------------------	3.0
Total Dakota Sandstone, main body (incomplete)--------	22.4

Westwater Canyon Sandstone Member of the Morrison Formation (truncated; all of the Brushy Basin Member, and an unknown amount of the Westwater Canyon Member removed by pre-Dakota erosion):

8.	Sandstone, very white; fluvial environment-------------	12.8
9.	Shale, light-purple, sandy; overbank environment--------	3.0
10.	Sandstone; fluvial environment------------------------	13.7
11.	Shale, dark-purple; grades from sandy to silty; overbank environment-------------------------------	7.6
12.	Sandstone; fluvial environment------------------------	7.6
13.	Shale, sandy, purple to green; overbank environment--	12.2
	Total 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°.); scintillation meter background 120 cps (counts per second).

Top of measured section.

	meters
Dakota Sandstone, main body (incomplete at top):	
1. Sandstone, yellowish-brown, medium-grained; heavily iron-stained on bedding surfaces and along joints; 100 cps; distributary channel environment--	1.5
2. Shale, medium- to light-gray, carbonaceous; poorly exposed; 150-200 cps; well-drained swamp environment--	6.1
3. Sandstone, yellowish-brown, fine- to medium-grained (coarse-grained locally); bedding planes iron-stained; clay chips in base of unit; fairly clean, but some fossil wood fragments; unit composed of massive, channeling sandstone lenses; massive structureless to crossbedded locally; current and oscillation ripples; unit intertongues laterally with dark carbonaceous shales; scouring at base; 100-150 cps; high energy fluvial distributary channel environment------------------------------------	7.6

4. Shale, carbonaceous; medium gray in upper part and black in lower part; upper part contains sandstone ledges 1-2 cm thick; unit grades downward from well-drained to poorly drained swamp environment---------------------------------- 0.9

5. 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; 150-180 cps; beach(?) environment-- 2.3

6. Shale, black, carbonaceous---------------------------- 0.9

7. Sandstone, siltstone, and shale; sandstone and siltstone are yellowish brown; thin-bedded; sandstone is fine grained; shale is medium gray and occurs as partings. Unit is laterally persistent with sharp upper and lower contacts; 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; 180-200 cps; grades upward from well-drained to poorly drained swamp environment---------------------------------- 2.4

9. Sandstone, yellowish-brown, fine- to medium-grained, well-sorted, thin-bedded to massive; carbonaceous trash locally along partings and bedding planes; unit pinches out at flanks of channel; massive units become thin-bedded toward flanks of channel; unit ranges from 27.5 m thick to 0 m (on flanks); 150-200 cps in upper part of unit; 400-500 cps in basal part of unit; distributary channel environment------------------- 18.3

10. Shale and siltstone; interbedded; unit forms laterally persistent slope; sands up laterally as well as upward; siltstone is sandy and finely laminated, but not particularly carbonaceous; shale is medium to dark gray (ash gray locally); 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

11. Sandstone, yellowish-brown, fine-grained, well-sorted, carbonaceous (carbonaceous material as disseminations and as concentrations along bedding planes), thin-bedded; locally cross-bedded at low angles; bioturbated; 1,000 cps; low-energy fluvial environment----------------------- 0.9

12. Shale, black, sandy, carbonaceous; yellowish-brown, sandy siltstone stringers as much as 1 cm thick contain carbonaceous material along partings; sandstone and silty sandstone with finely disseminated carbonaceous material make up 40 percent of unit; unit grades vertically upward into overlying sandstone unit; basal contact sharp; 2,500 cps; poorly drained swamp environment--	0.5
13. Sandstone, yellow-brown, medium- to coarse-grained, thin-bedded, locally crossbedded; scattered granules; sparse carbonaceous trash; 350-500 cps (higher count near contact with overlying carbonaceous shale); high energy distributary channel environment--------------	1.5
14. Granule conglomerate with sandstone matrix; iron oxide comprises 20-30 percent of the matrix material; woody plant material locally; unit pinches out laterally; 400-1,700 cps (high count near carbonaceous trash); lower contact is sharp and channeling; relief on channel is 15-20 m; distributary channel environment--	1.5
Total Dakota Sandstone, main body (incomplete)--------	61.9

Westwater Canyon Sandstone Member of the Morrison Formation (truncated; all of the Brushy Basin Member, and an unknown amount of the Westwater Canyon Member removed by pre-Dakota erosion):

15. Sandstone, white, kaolinized---------------------------- 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

	meters
Dakota Sandstone, main body (incomplete at top):	
1. Shale, carbonaceous----------------------------------	0.3
2. Claystone--	0.3
3. Sandstone, moderately well sorted; lower portion shaley--	1.7
4. Lignite--	0.5
5. Sandstone, very fine grained; gray or buff on fresh surface; grains subangular to subrounded; cross-bedded--	1.4
6. Shale, laminated; weathers to rubble-strewn slope; lower contact uncertain----------------------------	2.9
7. Sandstone, crossbedded, massive-----------------------	0.6
8. Lignite; considerable amount of gypsum as secondary mineral deposited in cracks and joints; poorly drained swamp environment---------------------------	1.1
9. Sandstone, fine- to medium-grained, moderately well sorted, quartzose, well-cemented; grains angular to subangular; weathers buff with rusty spots; gray on fractures; considerable carbonaceous material present as small flecks; sparkles as surface is rotated; distributary-channel(?) environment-----------------	0.5

10. Sandstone interbedded with siltstone; carbonaceous------ 0.6

11. Covered zone; base of the Dakota is within this

covered interval-------------------------------------- 2.4

Total Dakota Sandstone, main body (incomplete)-------- 12.3

=====

Disconformable contact (covered)

Brushy Basin Shale Member of the Morrison Formation:

12. 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.; scintillation meter background 120 cps (counts per second)

Top of measured section.

	meters
Dakota Sandstone, main body (incomplete at top):	
1. Sandstone; yellowish-brown to reddish-brown, fine- to medium-grained, well-sorted, flat-bedded, siliceous, bioturbated; 110 cps	3.4
2. Sandstone; same as interval 1 but more bioturbated; 125 (upper part) to 150 (lower part) cps; beach(?) environment	2.1
3. Shale; covered interval	2.4
4. Sandstone; same as interval 1; flat parallel-bedded to massive; burrows present, but sparse carbonaceous material; 150 cps; distributary channel environment	0.6
5. Shale; covered interval; 175 cps	3.1
6. Sandstone; same as interval 4 except more silt at the base; carbonaceous shale partings in base; 250-300 cps	1.8
7. Shale, dark-gray to black, carbonaceous; minor sandy intervals; 300-400 cps; poorly drained swamp environment	2.1
8. Sandstone, same as unit 4; Febco tunnel is in this sandstone; 300 (upper part) to 550 (lower part) cps	1.5

9. Shale, dark-gray to black, carbonaceous; largely covered; thin interbedded sandstone ledges; 350 cps; poorly drained swamp environment----- 13.7

Total Dakota Sandstone, main body (incomplete)-------- 30.7

Brushy Basin Shale Member of the Morrison Formation:

10. Claystone, silty, greenish-gray; only upper part exposed; some coarse-grained grayish-brown sandstone as lenses and stringers; 250 cps (300 cps near contact); contact with Dakota may be in a slump block; overbank fluvial and lacustrine environment------------------------------- Unmeasured

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