URANIUM DEPOSITS IN PALUDAL BLACK SHALES, DAKOTA SANDSTONE, SAN JUAN BASIN, NEW MEXICO

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ILLUSTRATIONS

ABSTRACT

Uranium deposits of commercial grade are present in the basal black shales of the Dakota sandstone of Cretaceous age around the south and east upturned edges of the San Juan Basin, northwestern New Mexico. These shales are paludal and littoral and constitute portions of minor cyclothems formed before deposition of Dakota beach sands and final inundation by the Mancos sea. These discontinuous shale beds interfinger with, and are enclosed by, equally discontinuous stream-channel and flood-plain sandstone lenses. The shales are richly carbonaceous and locally grade into peat and low-rank coal. They contain miniature lenses and channels filled with fine- to medium-grained sandstone. The interbedded sandstone layers and lenses are gray, medium to coarse grained, and highly contaminated with carbonaceous mascerated plant material.

Epigenetic secondary uranium minerals whose deposition was locally joint controlled occur most commonly in the carbonaceous sandstone lenses of greatest lithologic variability. The lenses are as much as several feet thick and are enclosed by carbonaceous shale or mudstone beds. Yellow uranium minerals impregnate the most carbonaceous portions of the sandstone. Less commonly, beds of black carbonaceous shale or peat overlying stream-channel sandstones have been mineralized, rather than the neighboring sandstones. No uranium minerals are apparent in the shales, and the uranium is presumed to be adsorbed by the carbonaceous matter.

Deposits in the sandstone lenses have been exploited, but those in shale or peat, although of high grade, are not amenable to present processing methods.

The Diamond No. 2 and Becenti deposits in carbonaceous sandstone beds and the Hogback No. 4 deposit in black carbona-

ceous shale are in the Gallup area of the Zuni uplift, southwestern San Juan Basin.

The U-mine and Delter prospects are in carnotite impregnations of Dakota sandstone in the Church Rock area on the northeast flank of the Zuni uplift near Gallup. The Delter deposit is in an ancient stream channel cut into the underlying Morrison formation.

The Silver Spur and Small Stake deposits, in the Grants area of the Zuni uplift, southern San Juan Basin, are in a basal carbonaceous sandstone of the Dakota capped by shale. The Butler deposit is in the Nacimiento uplift, on the east side of the San Juan Basin, in a thin peat lens in the basal zone of interbedded black shale and sandstone of the Dakota sandstone.

INTRODUCTION

Carbonaceous shale containing uranium ore occurs at the base of the Dakota formation, which crops out around the edges of the San Juan Basin of northwestern New Mexico (fig. 93). Uranium deposits in paludal black carbonaceous shale and in related interbedded sandstone and coal are locally of ore grade. These deposits are so closely related to Dakota sandstone ore bodies and to the structure of the San Juan Basin that all are discussed together. Less important deposits of similar lithologic relations occur at the base of several sandstones of the Mesaverde in the San Juan Basin.

STRATIGRAPHY

The San Juan Basin contains sedimentary rocks of Paleozoic, Mesozoic (fig. 94), and Cenozoic ages which

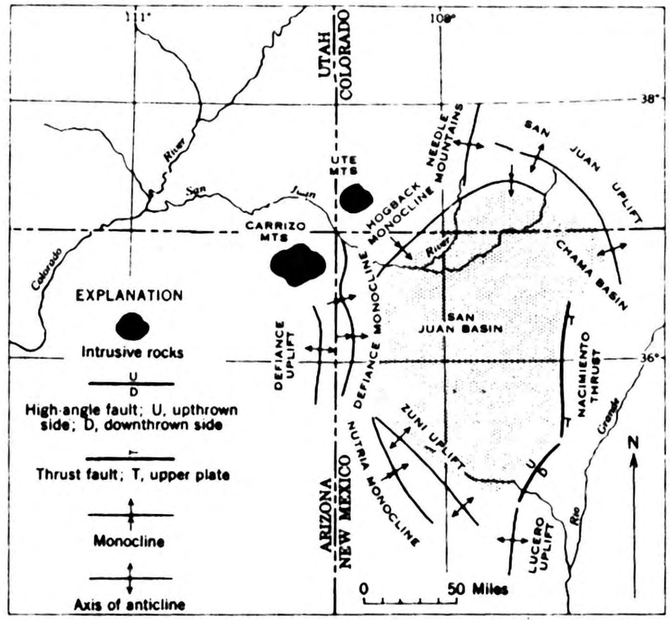


FIGURE 93.—Index map of San Juan Basin, N. Mex.

are partially exposed in concentric bands around its edges (fig. 95). The Dakota sandstone is the lowest Upper Cretaceous formation in the San Juan Basin and in most areas crops out as the resistant caprock of hogbacks. The Dakota consists of a lower unit of interbedded and interfingering sandstone, carbonaceous

AGE: ERA	AGE: PERIOD		WESTERN		SOUTHERN		EASTERN		NORTHERN	
MESOZOIC	CRETACEOUS	UPPER	Mesaverde formation	Allison, Gibson, and Dilco members	Mesaverde formation	Allison and Gibson members	Mesaverde formation	La Ventana member (sandstone)	Mesaverde group	Cliff House sandstone
								Allison and Gibson members (shale and sandstone)		Menefee formation (shale)
				Gallup member (sandstone)		Gallup member (sandstone)		Hosta member (sandstone)		Point Lookout sandstone
			Mancos shale		Mancos shale		Mancos shale		Mancos shale	
		– ? – LOWER	Dakota sandstone (lower part interbedded shale and sandstone)		Dakota sandstone (lower part interbedded shale and sandstone)		Dakota sandstone (lower part interbedded shale and sandstone)		Dakota sandstone (lower part interbedded shale and sandstone)	
									Burro Canyon formation sandstone	
	JURASSIC		Morrison formation	Brushy Basin member (mudstone)	Morrison formation	Brushy Basin member (mudstone)	Morrison formation		Morrison formation	Brushy Basin member (mudstone)
				Westwater Canyon member (sandstone)		Westwater Canyon member (sandstone)		Westwater Canyon member (sandstone)		Westwater Canyon member (sandstone)
				Recapture member (mudstone)		Recapture member (mudstone)		Recapture member (mudstone)		Recapture member (mudstone)
										Salt Wash member (sandstone)
			Bluff sandstone		Bluff sandstone				Bluff sandstone	

FIGURE 94.—Generalized correlation diagram, Dakota sandstone and adjacent formations, San Juan Basin, N. Mex.

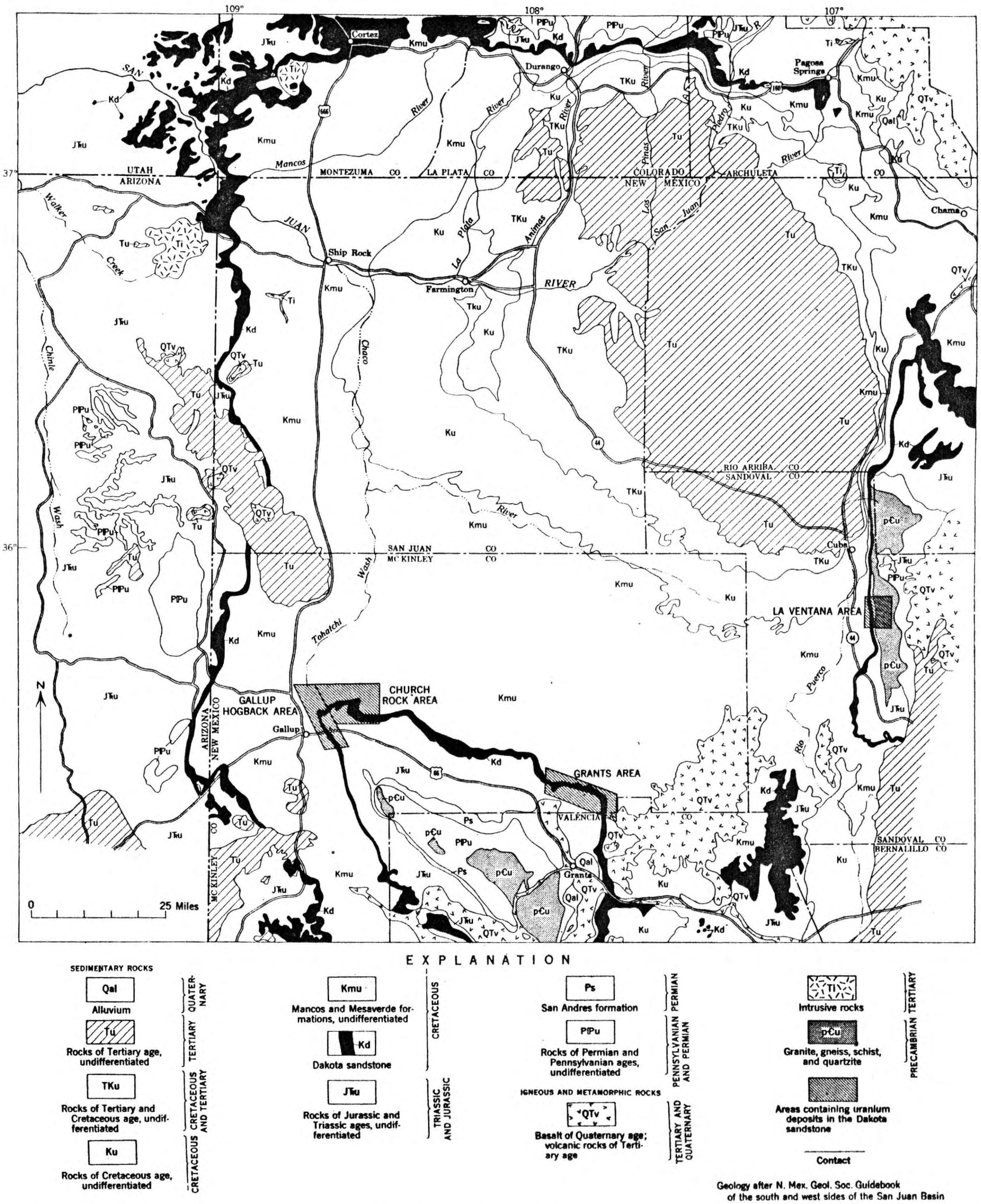


FIGURE 95.—Generalized geologic map showing outcrops of the Dakota sandstone and areas containing uranium deposits in the Dakota sandstone, San Juan Basin and adjacent regions, New Mexico.

shale, and low-rank coal, and an upper unit of thick sandstone.

The Dakota sandstone overlies the variegated Brushy Basin member, or, where that is absent, the gray coarse poorly sorted Westwater Canyon member of the Morrison formation. The lower Dakota unit contains lenses and interfingering beds of fine- to medium-grained poorly sorted crossbedded sandstone. The sandstones contain local concentrations of coalified plant material. Interfingering carbonaceous shale is silty and contains numerous lenses of siltstone and gray sandstone. Local increases in sapropelic content result in gradations to peat and lignite.

The lower unit is best characterized by its rapid lateral lithologic variation. Beds of each rock type enclose small irregular bodies of other types. Long, narrow lenses of siltstone or sandstone, commonly several inches wide, are miniature channel fills in the black shale.

Throughout the Colorado Plateau the Dakota sandstone marks the transition from continental deposition of the Upper Jurassic to marine deposition of the Upper Cretaceous. It was deposited along a migrating strandline which probably moved southward across the San Juan Basin and finally buried the Jurassic landmass, the source of Morrison clastic rocks. The sandstone of the Dakota therefore extends diagonally upward and southward across time lines.

The lower Dakota units represent a combined paludal and lagoonal environment retreating ahead of the encroaching beaches and offshore bars of the upper unit. Moderately active streams are suggested by poor sorting and torrential crossbedding. Sandstone lenses are broad channel fills suggesting braided stream courses.

STRUCTURE

Diagenetic structures in the lower unit of the Dakota are common; most are the result of slump, where partly consolidated sandstone beds slid into channels along surfaces which are continuous with bedding planes that die out in the shales. Also, thinly layered shale and silt beds crumpled from lateral pressure and sliding.

Structures in hogbacks along the margins of the San Juan Basin resulted from uplift of bordering tectonic units in Laramide (Eocene) time, as shown by the overlap of hogbacks by the Wasatch formation along the east margin. The more severely deformed hogbacks and monoclines are more closely related to bordering uplifts than to basin subsidence. Locally hogbacks are crossed by faults originating in the uplifts, such as in the Nacimiento thrust block and the Zuni Mountains. However, such faults are uncommon; the most prevalent structures are small cross and diagonal folds, joints, and faults which have resulted from the uptilting of the beds. Folds and joint patterns are closely related geometrically, and folds indicating stress relief in incompetent or thin-bedded sediments are analogous to relief along joints in competent beds. These small structures are remarkably similar in the several widely separated hogbacks and are directly involved in the localization of uranium and other related minerals. The hogbacks also contain similar but very large plunging cross folds. The mechanics of deformation of small structural features were the same as those of the large features.

A joint pattern diagonal to the bedding strike and a reticulate pattern of fold axes have been noted in several deposits.

URANIUM DEPOSITS

Within the basal interbedded sandstone and shale zone of the Dakota, uranium occurs both in black carbonaceous shale and in coarse- or medium-grained carbonaceous sandstone, although seldom in commercial amounts in both rock types at the same deposit. The lower Dakota rocks contain intricately arranged lenses of sandstone, siltstone, black mudstone, and vegetal accumulation. Barren sandstone lenses occur within bodies of uraniferous shale. Uranium is restricted to 1 or 2 units despite the occurrence of favorable carbonaceous trash in adjacent barren beds. The greatest concentrations of uranium are in richly carbonaceous sandstone or in carbonaceous shale, or peat, in which the host rock is mostly mascerated vegetal trash. No uranium minerals are visible in the shale or peat, and it is presumed that uranium was adsorbed by the carbon (Vine, Bachman, Read, and Moore, 1953). Yellow secondary uranium minerals (principally carnotite) impregnate the carbonaceous sandstone.

Gruner (1954) has suggested that all Colorado Plateau carnotite-type ores which have a high vanadium content represent the oxidation in place of black uraninite or coffinite ores, and it is possible that the lower sandstone ores in the Dakota are so oxidized. The principal evidence for this conclusion is the low solubility of uranium vanadates (carnotite, tyuyamunite, and others) under oxidizing conditions. Because a strong reducing environment precipitates uranium as uraninite or coffinite, the uranium and vanadium may have been brought to their present position under mild acidic and oxidizing conditions, probably as a uranyl sulfate. As would be expected according to these conditions, two ore bodies recently discovered below the oxidized zone at the Diamond No. 2 mine are composed entirely of primary pitchblende ore.

The ratio of uranium to vanadium in ores in Dakota sandstone ranges from 1:1 to 1.68:1. In ore-bearing black shale with no uranium minerals, it ranges from 6.3:1 to 10:1. This difference indicates that, although uranium and vanadium were nearly equal in amount or that uranium greatly exceeded vanadium as introduced in solution, uranium was adsorbed on carbon, whereas vanadium was not. Thus the relative amount of vanadium is greatly increased in the sandstone ores. However, the reducing environment presumed to exist during initial introduction, by virtue of deep burial, would probably prevent precipitation of carnotite, regardless of the vanadium excess required to form the mineral.

DEPOSITS IN CARBONACEOUS BLACK SHALE

HOGBACK NO. 4 MINE

The Hogback No. 4 mine is in McKinley County, N. Mex. (fig. 96). The ore bed is a black shale 1–3 feet thick that is extremely fissile and can be split into paper-thin sheets, with abundant partially carbonized

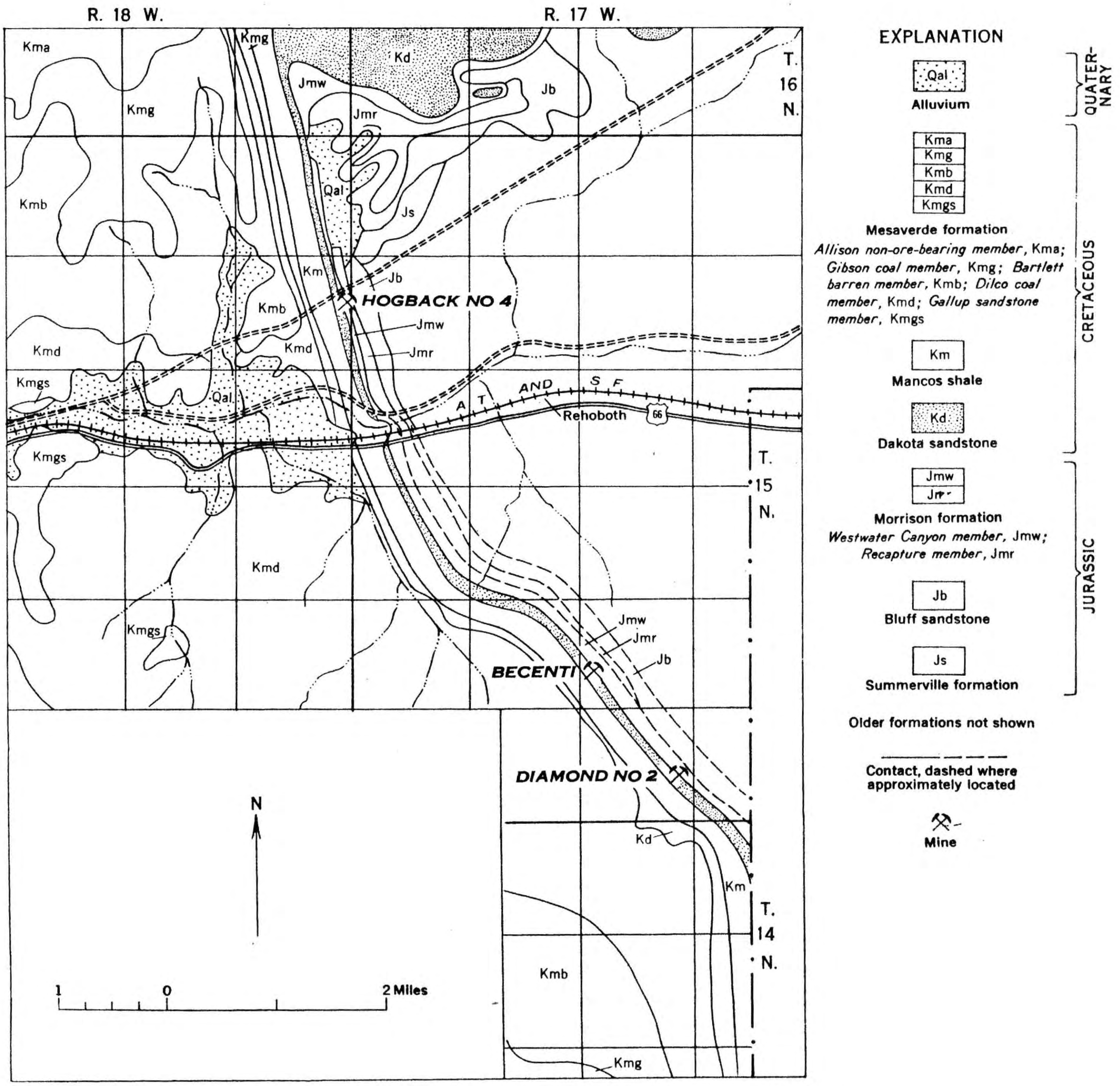


FIGURE 96.—Geologic sketch map, Gallup hogback area, McKinley County, N. Mex.

plant fragments. Locally it is very nearly a peat. It contains numerous thin gray carbonaceous fluvial crossbedded sandstone lenses averaging ¾ inch in thickness and 18 inches in length. A map of the mine is shown in figure 97 and a general view in plate 8.

Stratigraphy.—The lower part of the Dakota sandstone, in which the uranium deposits occur at the Hogback No. 4 mine, is described below.

Section of lower Dakota sandstone at Hogback No. 4 mine

	Feet
Dakota sandstone:	
Sandstone, light-buff, medium-grained	4
Shale, light-gray, very thin-bedded, yellow-stained	4
Sandstone, buff, fine-grained	3
Clay, brown and gray shale, limonite-stained	5
Sandstone, gray, thin-bedded, fine-grained, with thin shale lenses; indistinct crossbedding	9
Sandstone, green, thin-bedded, clay-rich	3
Shale, gray, interbedded with black carbonaceous shale and thin sandstone beds	5
Sandstone, gray to white, medium-grained	3
Shale, black, carbonaceous, ore-bearing	1–3
Sandstone, brown to orange, fine-grained	1
Shale, gray, lenses out locally	1
Sandstone, grit, yellow-brown, coarse- to very coarse-grained, moderately arkosic, poorly sorted, massive; contains small mud balls and carbonaceous vegetal trash; fine grained and uniform at top	9
Mudstone, gray to black, and carbonaceous shale	½–4
Sandstone, brown, fine-grained; carnotite in vacated carbonaceous-trash holes	4
Mudstone, light-gray	1
Sandstone, gray to brown, clay-spotted, fine-grained, quartzose	5
	63
Westwater Canyon member (sandstone) of the Morrison formation.	

Structure.—In this area the Gallup hogback forms the steep west and southwest flanks of the Zuni uplift, the northwest nose of which is about 2 miles north of the Hogback No. 4 mine. The Dakota sandstone and the Gallup sandstone member at the base of the Mesaverde formation which dip 35° W. and 75° W. respectively, form caprocks of 2 hogbacks which trend northward and are separated by a narrow valley in the Mancos shale. A cross fault is suggested by a water gap several thousand feet north of the mine, and a small cross fault striking east-northeast apparently bounds the north side of the deposit (fig. 97). Other faults near the deposit show less than 3 feet of movement. One set of joint strikes N. 70° W. and dips 60°–70° SW.; a second set strikes N. 15° E. and dips 60°–70° SE. One to three feet of movement on joint surfaces (pl. 9*A*, *B*) probably resulted from tilting of the hogback. On joints nearly parallel to the strike of the beds, the updip side usually has been raised (fig. 97), although many joint blocks have moved indiscriminately.

Tectonic folds of large or moderate size are abs however, small diagenetic slump (?) folds occu the shale beds of the hanging wall, and the ore-bea shale bed is strongly wrinkled. Some of the crum in the shale may have resulted from stresses du Laramide (Eocene) time.

Uranium deposits.—Mineralized shale has been posed by an open pit that extends about 700 feet a the strike, is 80 feet in maximum width, and feet in depth on the crest of the Dakota hog (fig. 97). Except for the small cross fault there obvious external structural control for localizati the ore body or its variation in grade. The contains no recognizable uranium minerals. introduced gangue minerals are limonite, gypsum jarosite. The jarosite and gypsum occur in and in thin veinlets between beds.

The top of the sandstone of the footwall has exposed by stripping, which extends nearly 10 downdip from the outcrop. The top surface normally brown sandstone of the footwall is st stained with limonite. The surface is not plan undulates irregularly. The irregularities may b ositional. However, scarps with as much as 2 relief are geometrically disposed and result from ment along joints parallel to the strike (pl. 9. Locally the surface is knobby with spherical li concretions. Hard limonite joint fillings, which nally extended into the shale, stand out as small

Uranium solutions have deposited yellow sec minerals in a sandstone bed 13–15 feet below t bearing shale in holes formerly occupied by car ous trash, but the amount of uranium in th bed is minor.

Ore controls.—No broad ore controls are a because the same lithologic character and appar of small structures exist in adjacent unmin areas. The occurrence of the ore body at this pa locality is not readily explained. Within t bearing bed, however, veinlets of jarosite and suggest the movement of solutions along joints, a whether such movement is primary or secon unknown because both origins are possible f minerals. In most uranium deposits, howeve minerals suggest oxidation from pyrite.

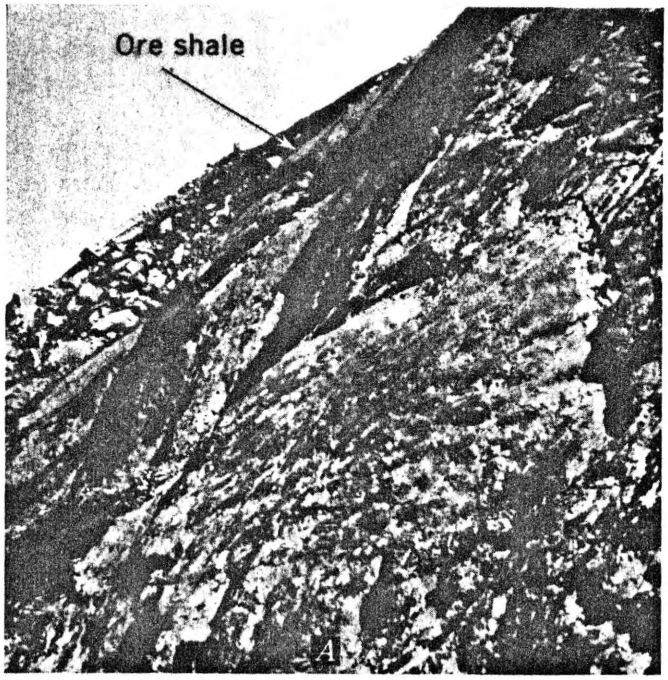
Several hundred tons of ore-bearing black sh been shipped from the mine, but the uraniu readily extractable from the shale by leaching p The ratio of uranium to vanadium is 6.3:1.

BUTLER DEPOSIT

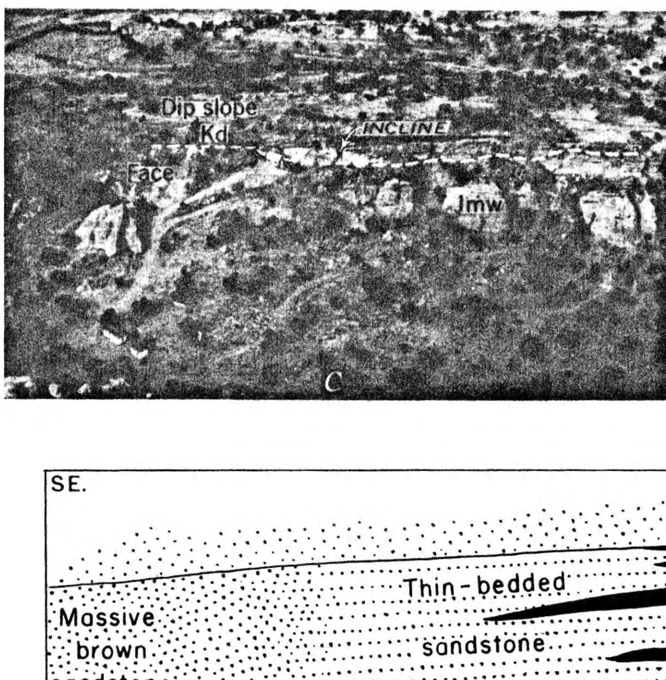
The Butler uranium deposit is in the Na Mountains, about 6 miles northeast of La Sandoval County, N. Mex. (fig. 98).

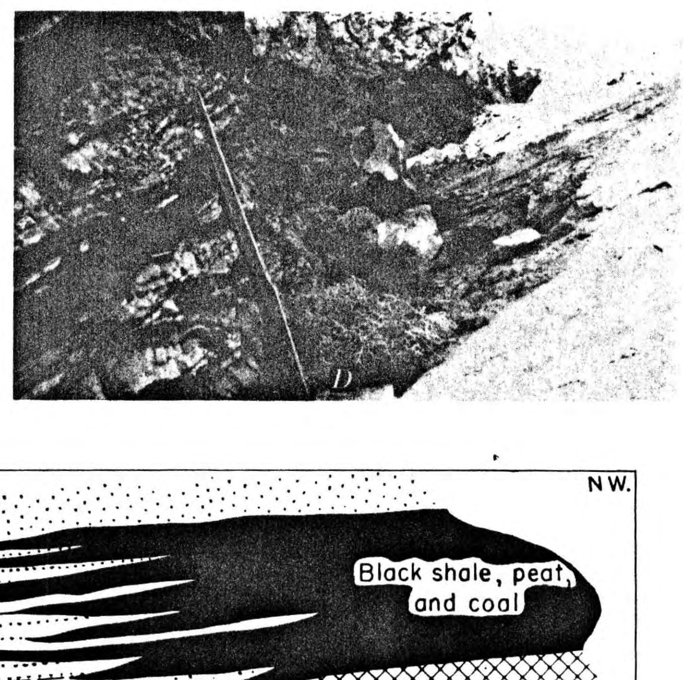
AERIAL VIEW, LOOKING NORTH, OF HOGBACK NO. 4 MINE, McKINLEY COUNTY, N. MEX.

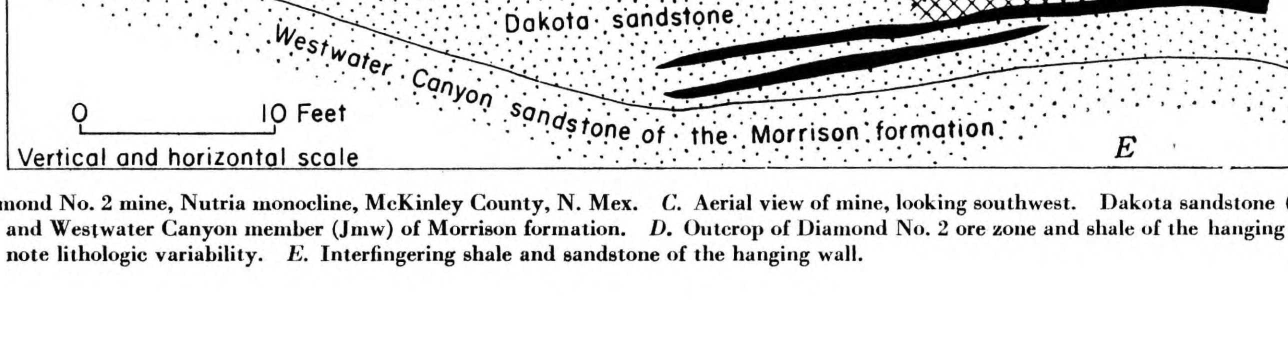
Dakota sandstone (Kd) and Westwater Canyon (Jmw) and Recapture members (Jmr) of the Morrison formation.



Views of Hogback No. 4 mine, McKinley County, N. Mex. *A*. Detail of footwall surface, looking north from mine; note ripple marks and linear features. *B*. Cross-sectional view of joints in sandstone of the footwall, looking south from mine.







Diamond No. 2 mine, Nutria monocline, McKinley County, N. Mex. *C*. Aerial view of mine, looking southwest. Dakota sandstone (Kd), and Westwater Canyon member (Jmw) of Morrison formation. *D*. Outcrop of Diamond No. 2 ore zone and shale of the hanging wall; note lithologic variability. *E*. Interfingering shale and sandstone of the hanging wall.

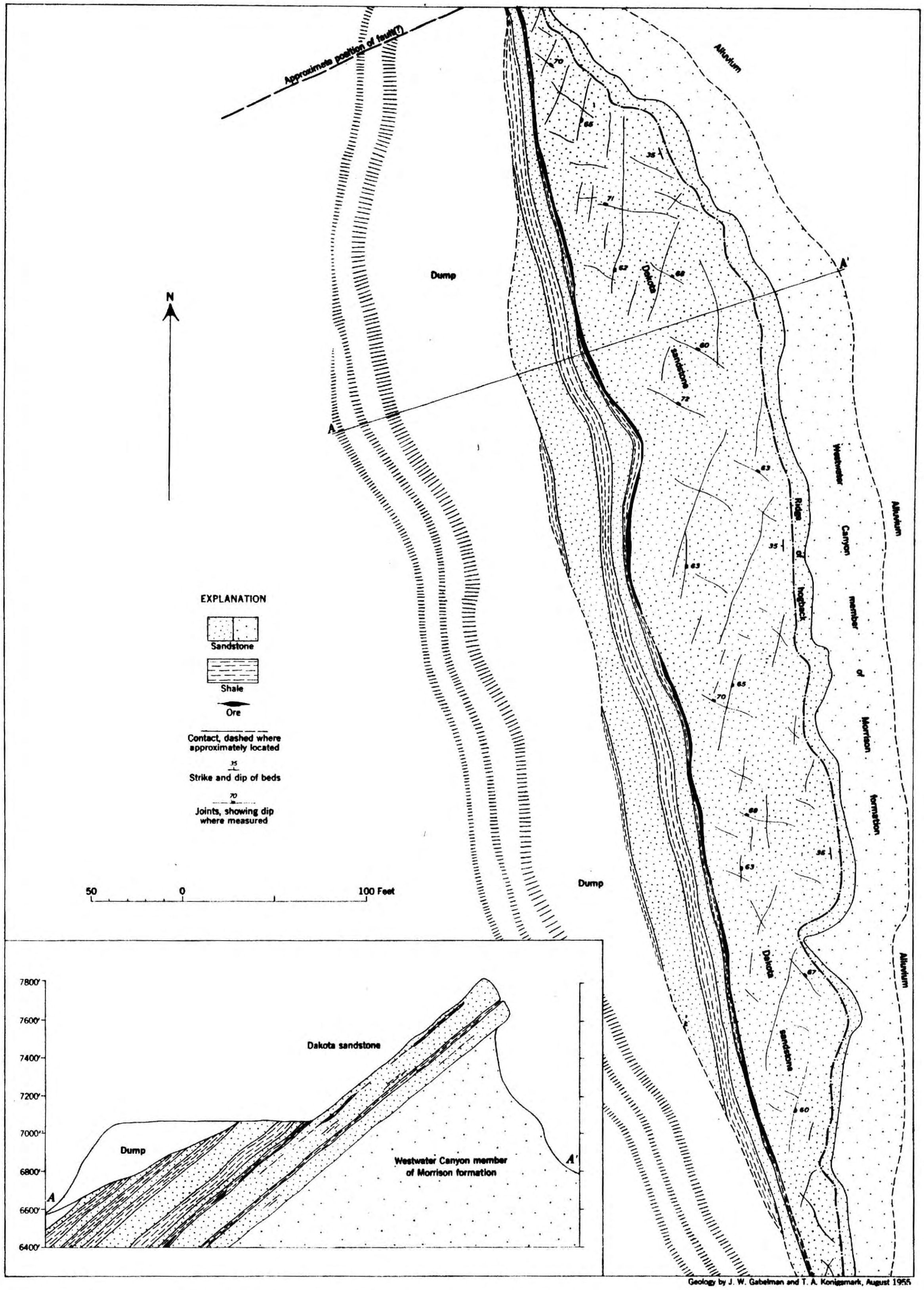


FIGURE 97.—Map and cross section, Hogback No. 4 deposit, McKinley County, N. Mex.

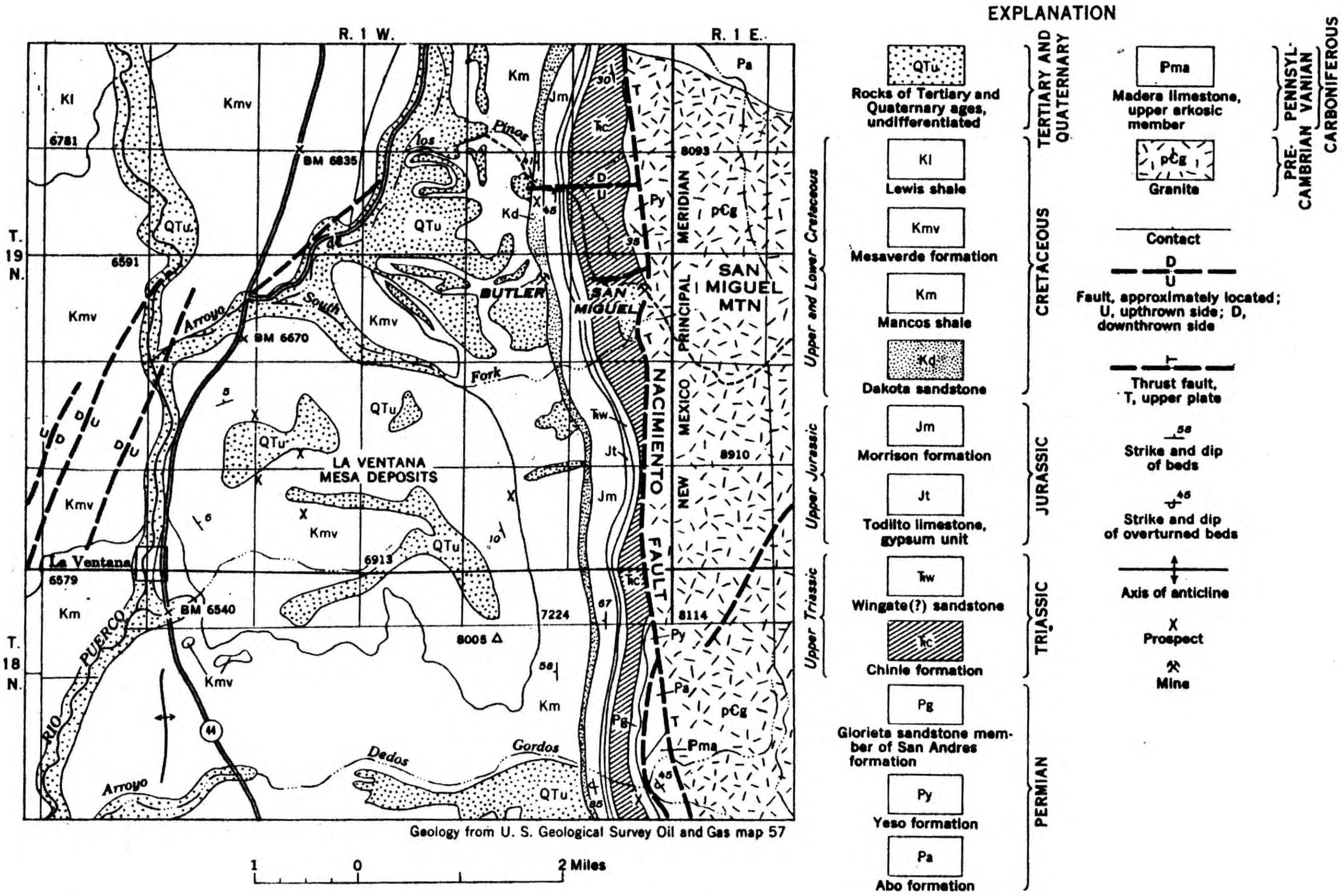


FIGURE 98.—Geologic map of the La Ventana area, Sandoval County, N. Mex.

Stratigraphy.—Formations present in the area of the Butler deposit are shown in figure 94, and the beds immediately associated with the uranium deposit are listed below.

Section of the Dakota sandstone at the Butler deposit

	Feet
Dakota sandstone:	
Sandstone, silty, thin-bedded	25+
Sandstone, tan, fine-grained, quartzose	2½
Shale, silty, gray, thin-bedded, rich in clay and carbonaceous debris	4
Sandstone, gray, fine-grained, silty, clay-rich	1
Peat, black, ore-bearing	1
Morrison formation, Westwater Canyon member: Sandstone, gray, massive, fine-grained, quartzose, rich in clay and carbonaceous trash	25+

The mineralized peat unit is a poorly bedded porous friable aggregate of mascerated partly carbonized plant fragments. It has a poorly developed nearly cubic joint pattern in which joints are oriented diagonally to the strike of the bedding.

Structure.—The beds have been tilted by drag resulting from the overthrusting of a granite block along the Nacimiento fault; the granite crops out about 1 mile east of the deposit. The Dakota hogback in the sole of the thrust strikes north and dips 45° W. In San Miguel Canyon, less than 1 mile north of the deposit, a tear fault offsets the hogback several hundred feet; smaller tear faults cut the hogback near the mine. The deposit is about 300 feet south of a tear fault along which beds have been dragged through an arc of 70° (fig. 99); the uranium is confined to the arc of drag. Displacement on the fault is less than 50 feet. A diagonal fault of 5–10 feet displacement, which possibly branches from the tear fault, bounds the downdip side of the deposit.

Small crenulations, common in the shale beds, do not extend into the sandstones. It is noteworthy that these folds closely resemble those on the Gallup hogback, where there is no thrusting.

Uranium deposits.—The carbonaceous material contains a maximum of 1.4 percent U_3O_8 within the outcrop and along the dip for more than 100 feet. The ratio of uranium to vanadium is 10:1. The exact size and shape of the irregular body are unknown. The north side of the ore body is exposed from the hogback crest down the dipslope of the hogback to its abrupt termination by a diagonal fault. No uranium minerals occur

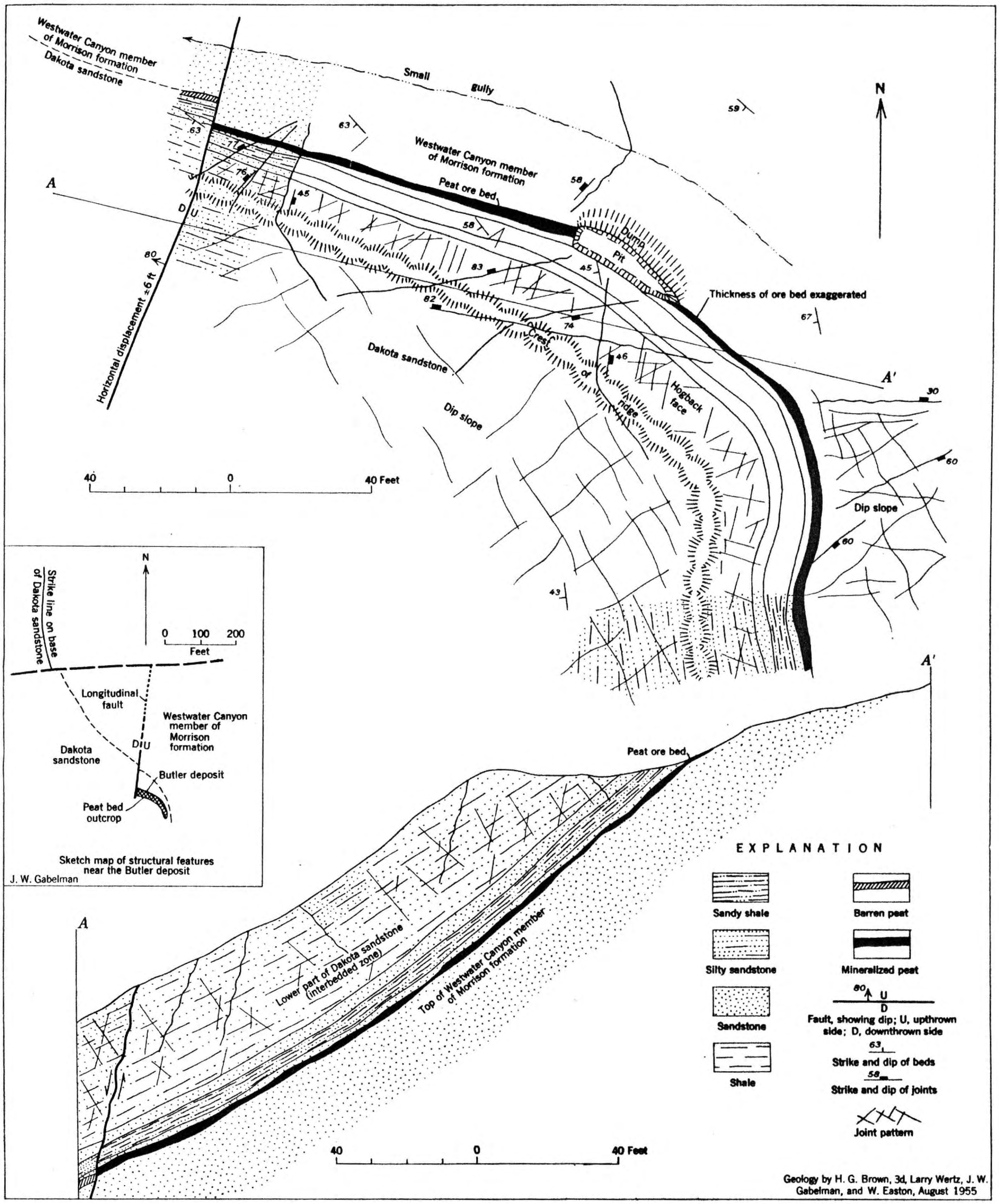


FIGURE 99.—Geologic map and cross section, Butler deposit, Sandoval County, N. Mex.

in the fault, in any related joints in sandstone or shale, or in sandstone.

No uranium minerals are visible, but bedding and joint surfaces are coated with jarosite, gypsum, and limonite, and the enclosing sandstones are impregnated with limonite and calcite. The uranium is contained entirely in the peat. Downdip termination of the uranium against the diagonal fault suggests damming in a structural trap after tilting of the sediments. This would further suggest that the solutions were descending, probably as ground water.

Related deposits.—Low-grade mineralization has occurred in the same black-shale bed in Los Pinos Canyon (Read, 1952) about 2,000 feet north of the Butler deposit, and other deposits probably occur between the 2 deposits. Mineralization effects are identical in both occurrences. Another deposit, presumably in the same shale horizon, occurs in Arroyo de Dos Gordos, about 5½ miles south of the Butler deposit. Approximately 3 miles southwest of the Butler deposit, black shale and coal at the base of the La Ventana and Hosta members of the Mesaverde formation contain similar low-grade uranium for several thousand feet around La Ventana Mesa (Vine, Bachman, Read, and Moore, 1953).

DEPOSITS IN CARBONACEOUS DAKOTA SANDSTONE

DIAMOND NO. 2 MINE

The Diamond No. 2 mine is in McKinley County, N. Mex., about 3 miles south of the town of Rehoboth (fig. 96). A plan of the mine is shown in figure 100, sections in figure 101, and views in plate 9*C*, *D*.

Stratigraphy.—The formations present are similar to those at the Hogback No. 4 mine.

Section of basal Dakota rocks at the Diamond No. 2 mine

	Feet
Dakota sandstone:	
Sandstone, tan, limonite-stained, fine-grained, with fluvial crossbedding	8
Shale, black, wrinkled, with lenses of peat, mud, sand, and silt; hanging-wall bed	5
Sandstone, gray, thin-bedded, poorly sorted, ore-bearing; abundant lenses of mud, shale, and carbonaceous material	3½
Shale, black, carbonaceous	1
Sandstone, gray, poorly sorted, crossbedded, arkosic	4

The wrinkled shale (pl. 9*D*) above the ore is similar to the ore bed at the Hogback No. 4 mine, about 5 miles to the northwest. The bed is extremely variable in lithologic character, with lenses and minute channels filled with sandstone, siltstone, and mudstone. On the outcrop about 30 feet southeast of the incline this bed abruptly interfingers into sandstone (pl. 9*E*). The bed also thins and pinches out downdip (figs. 100, 101). This shale lens and the other beds of the Dakota beneath it fill a channel scoured into the underlying Westwater Canyon sandstone member of the Morrison formation, a cross section of which is exposed in the hogback face (pl. 9*C*). The shale lens has about the same shape as the entire channel fill but appears to be slightly larger. However, other shale beds originate not far beyond where this bed dies out, so that, in general, several large rarely overlapping shale lenses exist at various elevations in a fluvial sandstone zone. Each shale lens may be in a channel. The aerial view (pl. 9*C*) shows the channel and the lensing of the hanging-wall shale. Ore bodies seem to occur along the abrupt southern margin of the lens.

The ore bed is a medium-grained poorly sorted quartz sandstone with little or no feldspar. It is strongly crossbedded locally and contains small thin lenses and channels of mudstone, shale, carbonaceous debris, and cannel coal. Some small channels contain minute local scours. Limonite and small amounts of calcite constitute the principal cement, but the sandstone is quite friable, and a weak pressure bond between the silica particles may be the only cement at many localities. White clay is a common cement in and near mineralized sandstone and may be an introduced gangue. Small detrital mudstone and claystone pellets are present.

Structure.—The deposit is in the Gallup hogback, a part of the southwest flank of the Zuni Mountains (figs. 94, 96). The structure of the hogback closely resembles that at the Hogback No. 4 mine several miles to the northwest. Here the hogback strikes N. 35° W. and dips 30° SW., although broad structural and stratigraphic irregularities cause variations of as much as 10° (fig. 100). Principal joints strike east and N. 10° W. and form a nearly cubic pattern almost symmetrical about the strike of the hogback. The eastward-trending joints dip 45° N., and those trending west of north dip at high angles. In this area the axis of the Zuni uplift has a northwest plunge of probably less than 3°. The strike of one minor joint set is normal to the bedding strike, and dips are at a high angle; another minor set is horizontal. Shear movement is generally less than a foot on the eastward-trending set, and locally there has been movement of several inches on the horizontal set.

Large folds are absent, but a reticulate network of small folds is prominent. Numerous short echelon cross folds, from several inches to 80 feet wide, plunge parallel to the dip of the hogback. In general smaller and shorter folds, parallel to the strike, are less common. The small longitudinal folds tend to occur between, rather than across, the plunging folds. The folds are probably tectonic, as indicated by the regular geometry of the pattern. Small irregular crenulations, as in the Hogback No. 4 and Butler deposits, are common in the

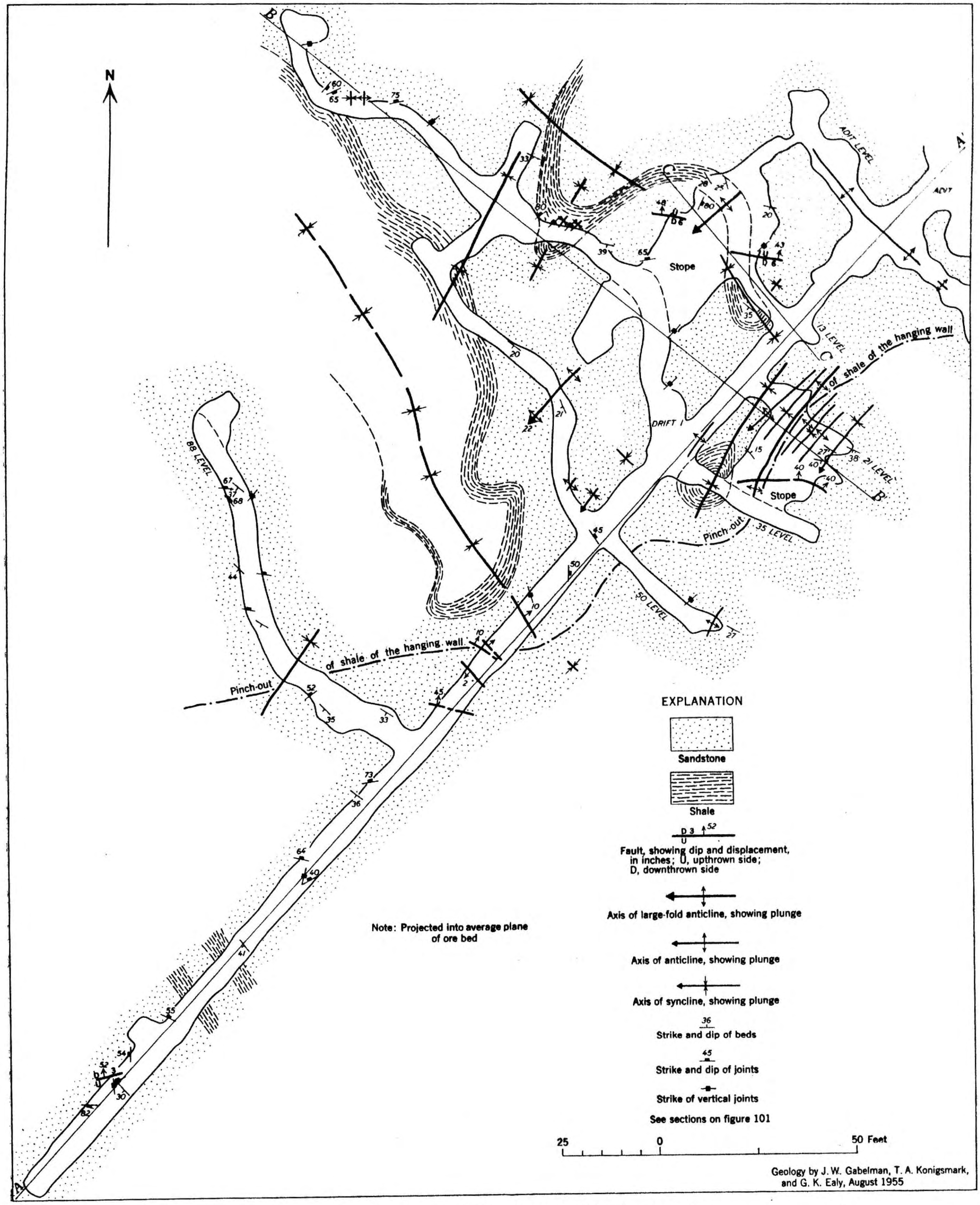


FIGURE 100.—Geologic map of the Diamond No. 2 mine, McKinley County, N. Mex.

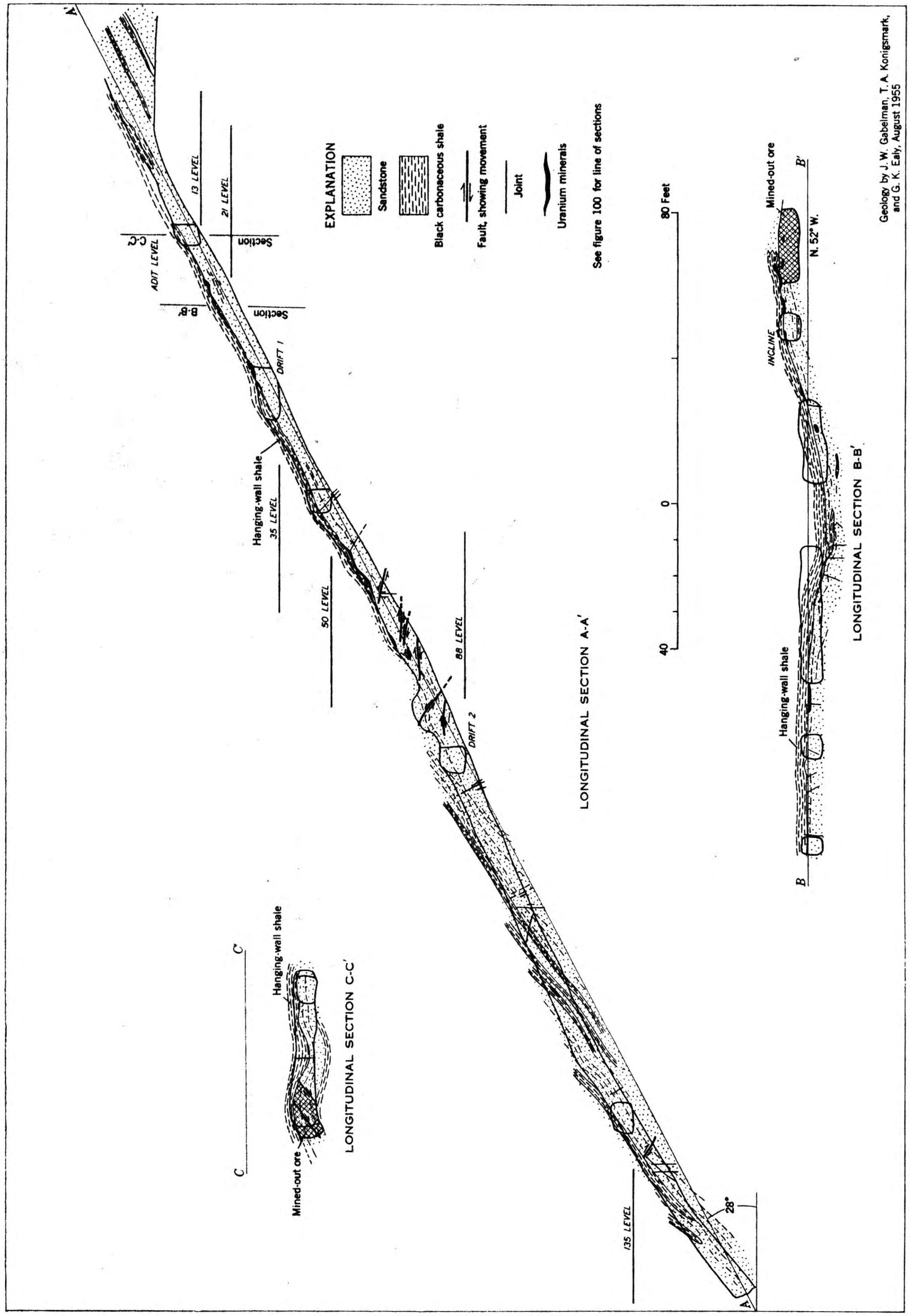


FIGURE 101.—Geologic sections of the Diamond No. 2 mine, McKinley County, N. Mex.

shale and to a lesser extent in the small sandstone lenses within the shale. These folds are consistently less than 1 foot wide. Their irregularity indicates they may be diagenetic.

Uranium deposits.—Uranium minerals in the sandstone occur in pods and elongate lenses which plunge downdip. Two large pods (stopes of figs. 100, 101) averaging about 60 feet in length, 20 feet in width, and 4 feet in thickness, have been mined out. They occurred in echelon, about 50 feet apart, on either side of the mine incline (fig. 100). The pods were confined to a lenslike area about 150 feet in strike length and 250 feet in dip length, and have the thickness of the sandstone. Two additional undeveloped ore bodies have been discovered several hundred feet downdip.

With few exceptions, uranium deposits are confined beneath the black-shale caprock but they commonly protrude as much as several feet from beneath the shale edges. Mineralization is not uniform beneath the shale. Pods are further confined beneath the axes of the plunging cross folds and, to a lesser extent, the longitudinal folds.

Many small pods and lenses of carnotite-impregnated sandstone several inches to several feet wide underlie similarly sized radioactive-shale and cannel-coal lenses and protrude several inches beyond the edges of the shale, as do the ore bodies. The small pods are also localized beneath small folds and crenulations and faithfully follow the distribution of folds and shale lenses within the mine area. Carnotite impregnates the sandstone, fills holes formerly occupied by carbonaceous trash, and fills bedding and joint fractures. The sandstone adjacent to carbonaceous debris is unusually rich. Mineralization locally extends into the shale of the hanging wall, but the shale contains no recognizable uranium minerals. The ratio of uranium to vanadium is 1.68:1. Gangue consists of jarosite, limonite, and calcite; limonite is not abundant but calcite impregnation is common.

Mineralization in the Diamond No. 2 mine was strongly controlled lithologically and structurally. Lithologic controls are the carbonaceous-shale caprock, carbonaceous trash, and clay-rich impregnations. Structural controls are the stream channels, cross and longitudinal folds, and the prominent joints. It is uncertain whether joints served as local channels, but it is obvious that they commonly served as barriers. Ore guides include the presence of paludal black shale, zones of highly variable lithologic character, debris-filled sandstones, and folds.

The ore-bearing sandstone has been bleached from a normal brown to white within 3 feet stratigraphically and 100 feet laterally of mineral deposits. The several sandstone beds beneath the ore bed become progressively darker brown downward. In addition to the removal of iron oxide cement, bleaching may result from the introduction of, or replacement of, cement by white clay, which is a common close associate of carnotite. Calcite is also closely associated with mineralization, but in moderate amounts as the ore is distinguished by its relatively low lime content in comparison with many other sandstone ores. Much of this calcite may have been an original cement because most of the lower part of the Dakota is somewhat limy. The underlying Westwater Canyon sandstone member is locally stained pinkish red 250 feet northwest of the mine and beyond, resembling burned-coal or clinker-bed outcrops, although no coal is known in the sandstone.

The epigenetic impregnation of sandstone with uranium and the downdip orientation of ore pods suggest deposition from solutions moving parallel to the dip in thin aquifers after tilting of the beds.

Descending ground-water solutions would be expected to travel on top of impervious layers and down the troughs of synclines rather than along anticlinal axes beneath shale beds. Also, impounding of solutions at depth is required unless uranium ions were supplied by passing solutions owing to the reducing environment. No downdip impounding structure is known, although sandstone that pinches out into shale could serve the purpose. However, had the solutions been descending, mineralization would be expected in the synclines. The restriction of ore to anticlines, where synclines are nearby, implies some sort of hydrostatic or intratelluric pressure to drive the solutions as high as possible. Rising solutions fit these conditions. The reducing environment occasioned by carbonaceous material was a prime factor in precipitation, but why sandstone rather than adjacent peat and strongly carbonaceous shale became the host rock cannot be explained.

BECENTI DEPOSIT

The Becenti mine is in McKinley County, N. Mex., about 1 mile northwest of the Diamond No. 2 mine (fig. 96).

Section of rocks in the lower interbedded zone of the Dakota at the Becenti deposit

	Feet
Dakota sandstone:	
Sandstone, reddish-brown, fine-grained, crossbedded; local pebble conglomerate at base	—15
Shale, gray, and black carbonaceous shale, irregularly interbedded; small sandstone and siltstone lenses and small channels	5
Sandstone, brown, poorly bedded, quartzose, fine-grained, ore-bearing; shale partings and disseminated carbonaceous trash are common; local ripple marks	13
Morrison formation, Westwater Canyon member (sandstone).	

Because the Becenti deposit occupies a position on the Gallup hogback similar to that of the Diamond No. 2 deposit, its structural features are similar, even to the presence of small cross folds in the plane of the bedding. However, the folds are small; they average about 6 feet in width, and their axes vary about 35° from the direction of dip of the bedding. Near the mine the hogback strikes N. 27° W. and dips 30° SW. The components of a square joint pattern strike N. 50° E. and N. 15° W. The joints are vertical.

As at the Diamond No. 2, carnotite impregnates the sandstone directly beneath the impervious shale cap and locally fills bedding and joint surfaces. The lithologic and structural controls are the same as those at the Diamond No. 2 mine. The ratio of uranium to vanadium is 1.51:1.

SILVER SPUR MINE

The Silver Spur mine (Mirsky, 1953) is in the Haystack Butte area, McKinley County, N. Mex., about 12 miles northwest of Grants (fig. 102). The Haystack Butte area is on the Thoreau homocline, which forms the gently dipping northeast flank of the Zuni Mountains. Sedimentary rocks, cropping out in cuestas, dip 2°–5° NE. Zones of cross faults and shallow cross folds occur at intervals of several miles along the homocline. The Haystack Butte area is in a zone of such faults and folds, but the nearest fault is nearly a mile from the Silver Spur mine.

As at the Diamond No. 2 and Becenti mines, the ore bed is a coarse-grained carbonaceous sandstone overlain by black carbonaceous shale. The footwall bed is a thin blue mudstone which overlies the Brushy Basin member of the Morrison formation. Maximum development of the ore bed is in a broad channel which is traceable for about 2,000 feet.

Mineralization has occurred in pods, six of which are known, elongated parallel to the secondary joint direction and perpendicular to the crossbedding. Yellow secondary uranium minerals, of which tyuyamunite is the most common, impregnate the sandstone in areas of abundant carbonaceous trash and are associated with jarosite, gypsum, calcite, and limonite. The ratio of uranium to vanadium is 1:1.

U MINE

The U mine (Mirsky, 1953) is in the Church Rock area (Sharp, 1955), McKinley County, N. Mex., about 10 miles east of Gallup (fig. 103). The Church Rock area is on the Thoreau homocline or northeast flank of the Zuni uplift just east of the northwest nose of the uplift. The sedimentary rocks dip 4° N. No local structures are known.

The lower part of the Dakota sandstone contains the same zone of interbedded fluvial sandstones and paludal shales as at the Silver Spur deposit. The mineralized bed is a light-gray fine-grained sandstone, 3 feet thick, enclosed by black carbonaceous shale, 15 feet above the contact with the Westwater Canyon member of the Morrison. The sandstones in this zone are locally ripple marked.

The components of a cubic joint pattern in the upper part of the Dakota sandstone strike N. 20° E. and N. 70° W., with the bedding as the third component. However, joints are irregular and poorly developed in the lower interbedded zone.

Mineralized sandstone is exposed in 3 adits in the ore bed; 2 are 100 feet long, and the third is 300 feet long. Each follows a separate mineralized zone. The zone in the longest adit is 1½ feet thick and 3 feet wide directly beneath black carbonaceous shale. Mineralization has affected only the top half of the ore bed. The mineralized body is long and sinuous, trends generally northward (downdip), and locally swells into larger pockets. Carnotite impregnates the sandstone and lines the contact with the overlying shale. The shale is locally radioactive but contains no recognizable uranium minerals.

DELTER PROSPECT

The Delter prospect (fig. 104) is in the Church Rock area, McKinley County, N. Mex., about 3½ miles northwest of the U mine (fig. 103). Here the Thoreau homocline is closer to the nose of the Zuni axis, and the sedimentary rocks strike generally N. 70° E. and dip 4° NW., forming large dissected cuestas.

At the Delter prospect the lower paludal and fluvial sediments of the Dakota fill a channel cut into the underlying Westwater Canyon sandstone member (fig. 104). At the mine the channel is 200 feet wide, 30 feet deep, and trends about N. 30° E. The lower interbedded zone of the Dakota consists of alternating conglomeratic to fine-grained sandstone and black carbonaceous shale.

The mineralized body is an elongate lens 50 feet wide and 2 feet thick which occupies the bottom of the channel and, although undeveloped, is presumed to follow the channel for some distance. Carnotite impregnates the lowest sandstone bed of the Dakota directly over the Westwater Canyon contact. The host sandstone is capped with black carbonaceous shale and is strongly contaminated with angular carbonaceous trash fragments.

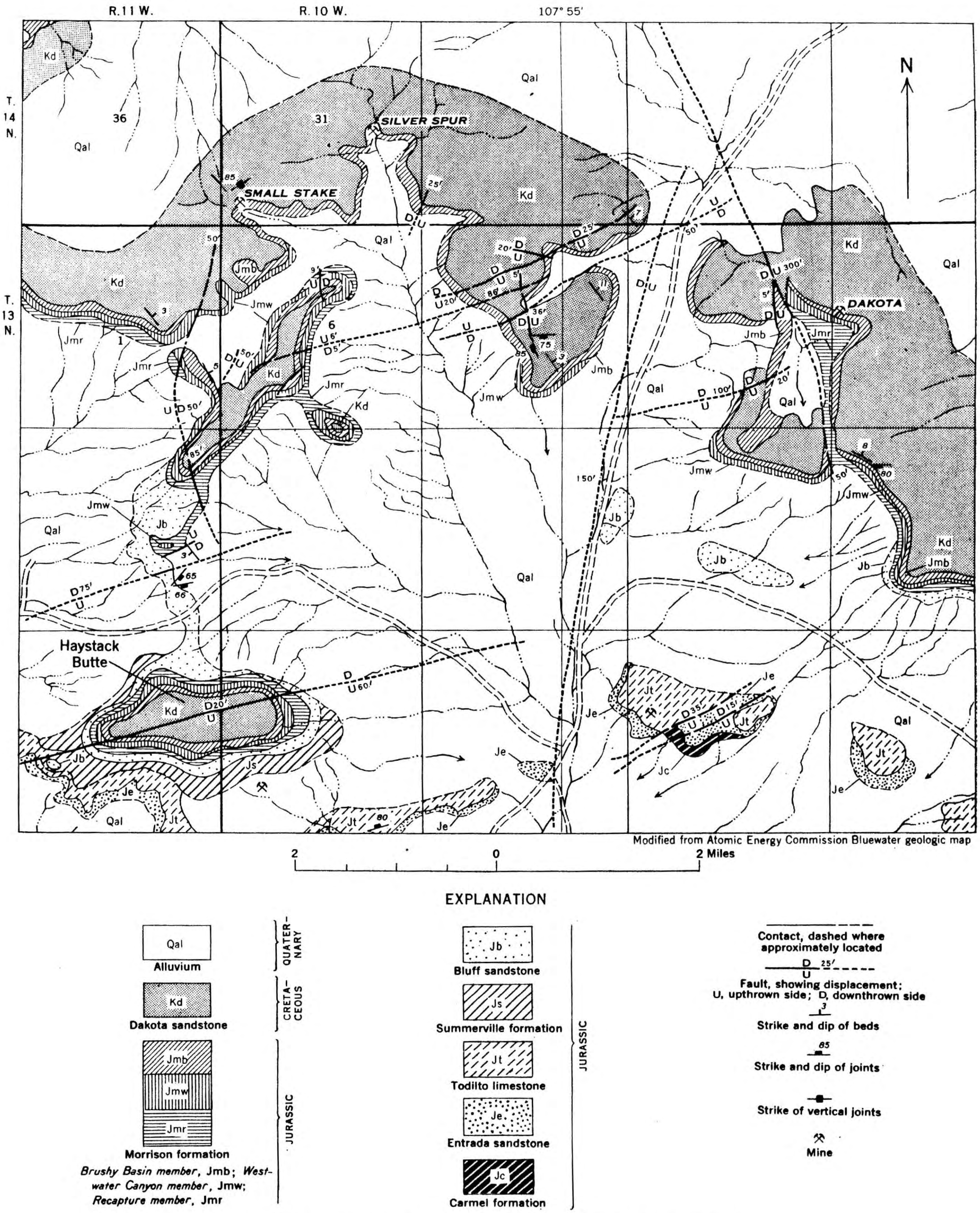


FIGURE 102.—Geologic map of the Haystack Butte area, McKinley County, N. Mex.

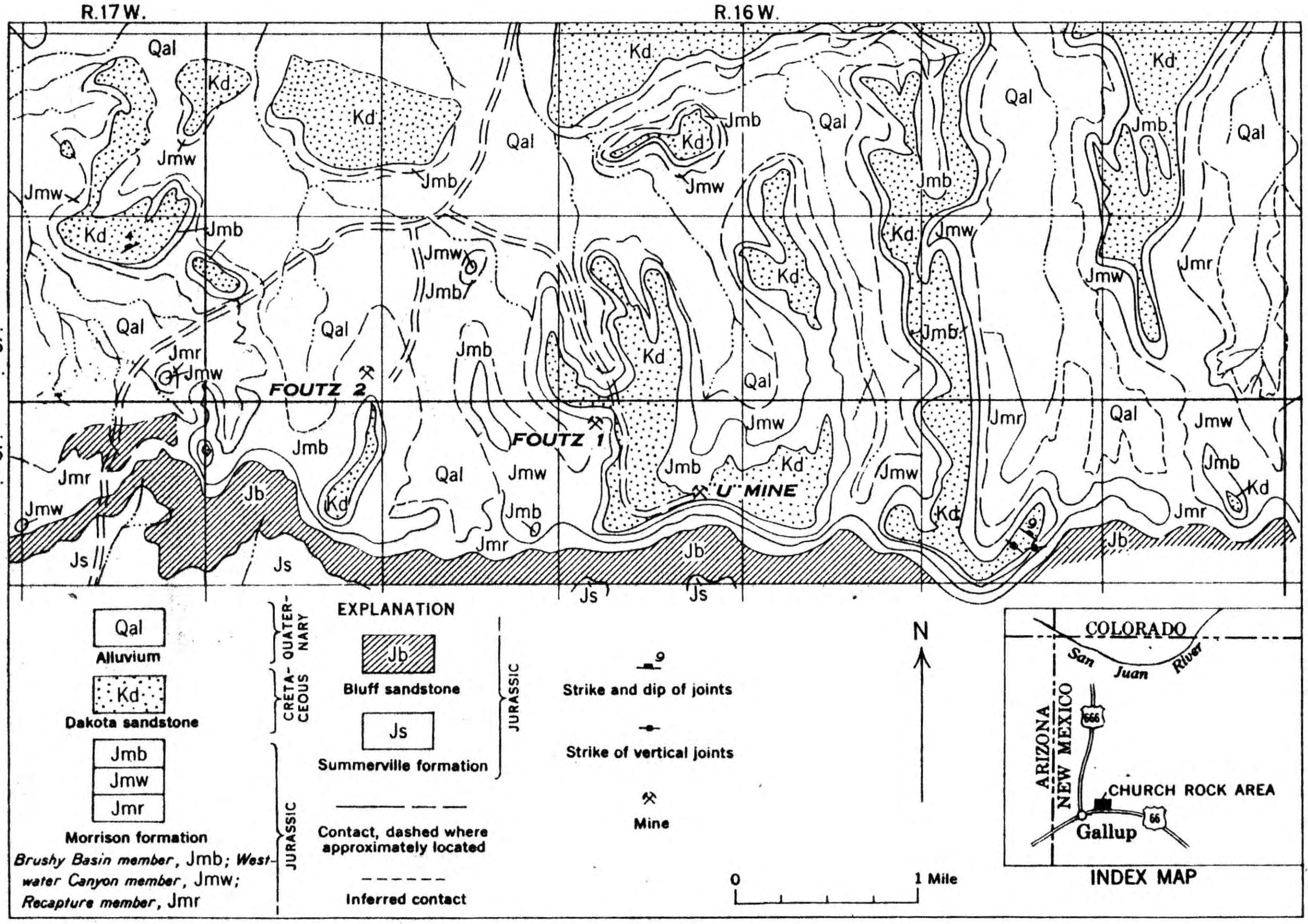


FIGURE 103.—Location and geology of the Church Rock area, McKinley County, N. Mex.

SUMMARY

Even though uranium deposits in the Dakota sandstone in the southern and eastern San Juan Basin differ widely in geographic location, structural setting, localizing features, and in minor textural and environmental detail, they have many features in common.

Mineralization has been confined to the lower zone of interbedded carbonaceous sandstone, richly carbonaceous shale, peat, and low-rank coals of the Dakota. Because uranium occurs in other nearby formations, uraniferous solutions probably migrated through many associated sedimentary units. Yet, because none of the immediately enclosing formations are so equally rich in carbonaceous matter or uranium, the reducing environment offered by the carbon probably trapped vagrant uranium in this zone. Migration of solutions and subsequent deposition of uranium within the zone were governed by local lithologic and structural features. The even greater quantity of carbonized matter (principally coal) and the apparent lack of uranium in the higher part of the Mesaverde in the same region is not readily explained unless by the greater lithologic variability or the lower rank of carbonization in the lower zone of the Dakota.

Within the zone, mineralization occurred either in black shale or in the sandstone immediately beneath the shale cap, even though these units may differ in elevation throughout the zone. No mineralization occurred in sandstone overlying the shale. Except at the Butler deposit where impounding of solutions by a small fault is suggested, these features indicate the rise of solutions against or along overlying semi-impervious barriers under intratelluric or hydrostatic pressure. Only at the Hogback No. 4 deposit is there a nearby solution channel in the form of a possible bounding cross fault. In others, the absence of noticeable cross-cutting channels suggests lateral migration.

The mineralogy is invariably 1 of 2 related types: either carnotite impregnating sandstone or uranium contained in carbonaceous matter in such a way that

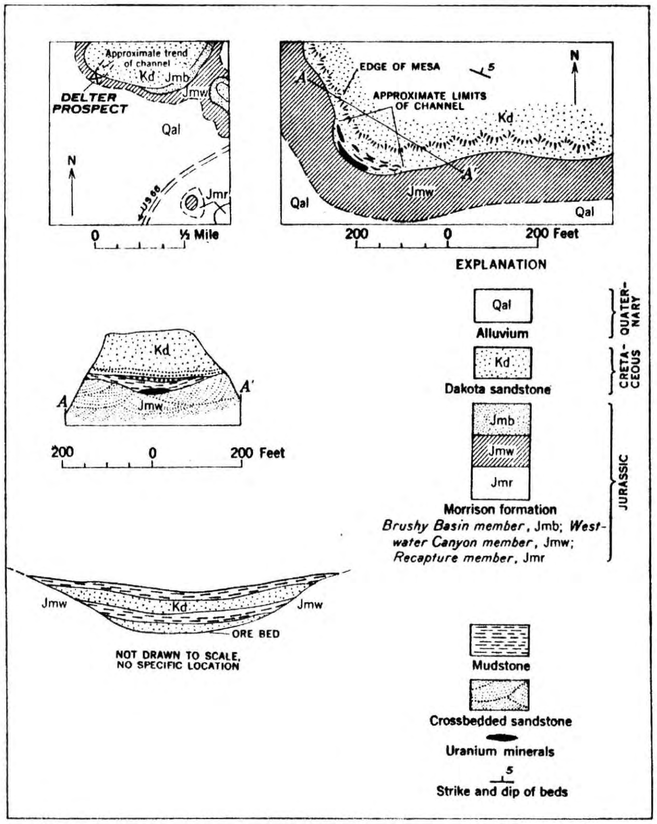


FIGURE 104.—Geologic map and sections of the Delter prospect, Church Rock area, McKinley County, N. Mex.

no uranium minerals exist. The ratio of uranium to vanadium is generally about 1:1 in the sandstones and 8:1 in the black shales. The gangue is always jarosite, gypsum, and limonite.

Close investigation reveals that deformational structures usually govern the distribution of mineralization. These structures are generally small folds or joint faults whose geometric pattern indicates a tectonic rather than a depositional origin. With the exception of the Delter channel and the Butler and Hogback No. 4 deposits, mineralization commonly took place under the crests of anticlines. Because the controlling structures are Laramide or later, Tertiary migration of uranium is implied.

A local lithologic control, the presence of carbon, invariably governs the position of mineralization. Where the capping shale pinches out, the sandstone ore also terminates, even though it commonly protrudes slightly beyond the limits of shale. At the Diamond No. 2 mine ore is localized principally along the abrupt pinching out of a shale bed along one side of a stream-channel fill.

Usually a combination of lithologic, structural, and stratigraphic features governs the occurrence of ore. Thus, only the crests of anticlines were mineralized beneath extensive shale caps, and only those anticlines which are capped by shale contain ore. At the Diamond No. 2, only those shale-capped anticlines near the large-scale pinching out of the shale contain ore. Along miles of carbonaceous shale or peat outcrop, some localities involving a possible cross-fault feeder are mineralized, but not all faults cutting black shale were mineralized.

There is no evidence that uranium was originally present in the Dakota sandstone. The known lithologic and structural controls suggest that the formation was simply a favorable host rock for vagrant uraniferous solutions.

REFERENCES CITED

Gruner, J. W., 1954, The problem of the primary ores of the Colorado Plateau, *in* Annual report for Apr. 1, 1953 to March 31, 1954—Part IV: U. S. Atomic Energy Comm. RME-3094, 37 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Mirsky, Arthur, 1953, Preliminary report on uranium mineralization in the Dakota sandstone, Zuni uplift, New Mexico: U. S. Atomic Energy Comm. RME-47, 21 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Read, C. B., 1952, U. S. Geol. Survey, unpub. inf.

Sharp, J. V. A., 1955, Uranium deposits in the Morrison formation, Church Rock area, McKinley County, N. Mex.: U. S. Atomic Energy Comm. RME-79, 19 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Vine, J. D., Bachman, G. O., Read, C. B., and Moore, G. W., 1953, U. S. Geol. Survey, unpub. inf.