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DEPARTMENT OF THE INTERIOR

URANIUM MINERALS IN OLIGOCENE GYPSUM NEAR CHADRON, DAWES COUNTY, NEBRASKA

By
R. J. Dunham

This report is preliminary and has not been edited or reviewed for conformity with U. S. Geological Survey standards and nomenclature.

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GEOLOGICAL SURVEY

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Trace Elements Investigations Report 525

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

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ABSTRACT

Carnotite, sabugalite [$HAl(UO_2)_4(PO_4)_4 \cdot 16H_2O$], and autunite occur in the basal 25 feet of a 270-foot sequence of nonmarine bedded gypsum and gypsiferous clay in the Brule formation of Oligocene age about 12 miles northeast of Chadron in northeastern Dawes County, Nebraska. Uranium minerals are visible at only two localities and are associated with carbonaceous matter. Elsewhere the basal 25 feet of the gypsum sequence is interbedded with carbonate rocks and is weakly but persistently uraniferous. Uranium probably was emplaced from above by uranyl solutions rich in sulfate.

INTRODUCTION

Secondary uranium minerals were found in northeastern Dawes County, Nebr., by the writer in November 1954, while investigating uraniferous black shales. The occurrences are in the lower 25 feet of a sequence of nonmarine bedded gypsum and gypsiferous clay in the Brule formation of Oligocene age. No uranium minerals were found outside the W 1/2 sec. 3, T. 34 N., R. 47 W., but the lower 25 feet of the gypsum sequence is weakly uraniferous at all localities examined.

The area described lies in Dawes and Sheridan Counties, Nebr., a few miles north of the Pine Ridge escarpment, south of the Black Hills. It has an average altitude of about 3,300 feet and is moderately rolling. Chadron, the county seat of Dawes County, lies 5 miles to the south and is served by the Chicago and Northwestern railroad and by U. S. Highway 20 and State Highway 19. County and private roads provide access to most of the area.

The writer is indebted to Wendell Walker of the U. S. Geological Survey for photomicrographs of mineralized gypsum. The Denver laboratory of the Geological Survey determined content of uranium and equivalent uranium in all samples, and supplied two spectrographic and one chemical analyses of the gypsum. J. W. Adams of the Geological Survey identified the uranium minerals. This investigation is part of a program that is being conducted by the U. S. Geological Survey on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission.

REGIONAL SETTING

The area lies across the broad irregular crest of the northwestward trending Chadron arch (fig. 1). The southeastern subsurface extension of this arch forms the eastern margin of the Denver-Julesburg Basin and continues into south central Nebraska, where it is known as the Cambridge arch. Between the northwestward plunging end of the Chadron arch and the Black Hills lies a syncline about 35 miles wide.

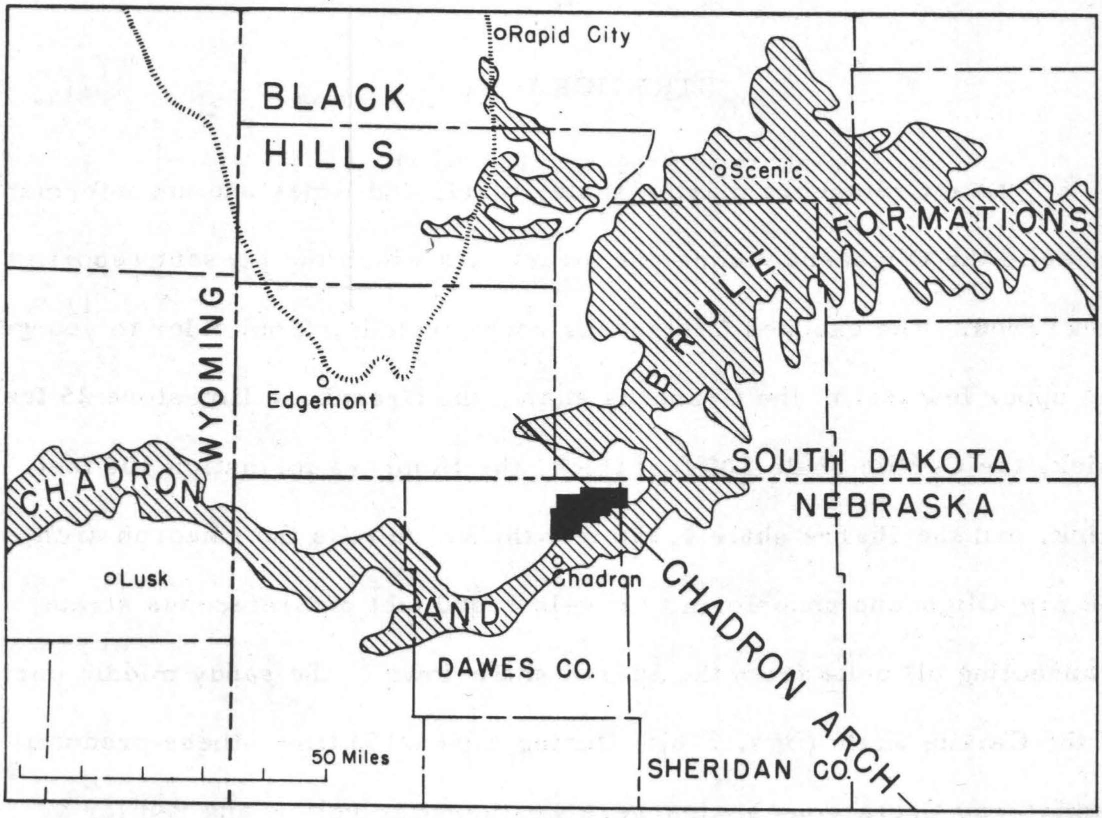


FIG. 1 --INDEX MAP SHOWING LOCATION OF AREA MAPPED NEAR CHADRON, NEBRASKA

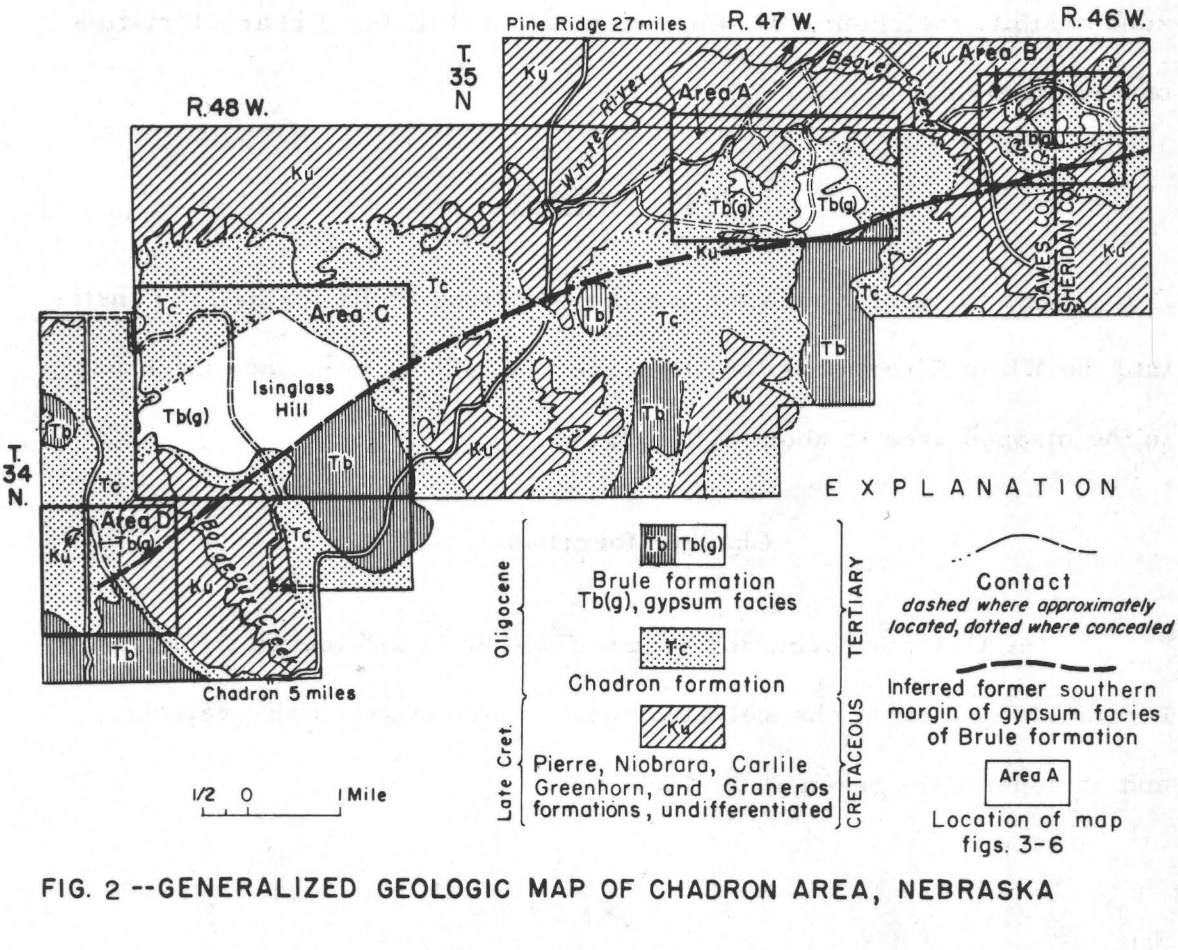


FIG. 2 --GENERALIZED GEOLOGIC MAP OF CHADRON AREA, NEBRASKA

STRATIGRAPHY

Late Cretaceous marine shale, marl, and limestone unconformably underlie the Oligocene nonmarine strata with which the present report is concerned. The exposed Cretaceous rocks include, from older to younger, the upper few feet of the Graneros shale, the Greenhorn limestone 25 feet thick, the Carlile shale 300 feet thick, the Niobrara formation 300 feet thick, and the Pierre shale 1,350 feet thick. Across the Chadron arch, the pre-Oligocene unconformity bevels 1,800 feet of Cretaceous strata, transecting all units from the Pierre shale down to the sandy middle part of the Carlile shale (figs. 2-6). During Eocene(?) time, these predominantly gray Cretaceous shales were weathered to yellow and red for as much as 55 feet below the unconformity. The upper part of the weathered zone exhibits the chemical, mineralogical, and textural characteristics of a maturely developed soil.

Oligocene rocks

The Chadron formation and the overlying Brule formation constitute the White River group of Oligocene age. Their combined thickness in the mapped area is about 375 feet.

Chadron formation

The Chadron formation ranges from 80 to 115 feet in thickness. It consists of a basal channel sandstone, a middle greenish-gray clay, and an upper light green silty clay.

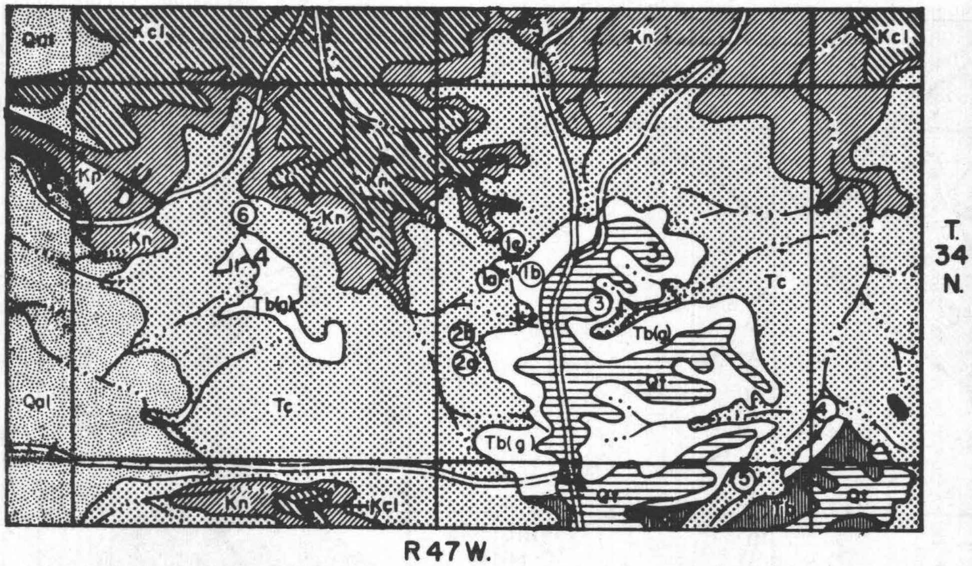


FIG. 3 --GEOLOGIC MAP OF AREA A, DAWES COUNTY, NEBRASKA

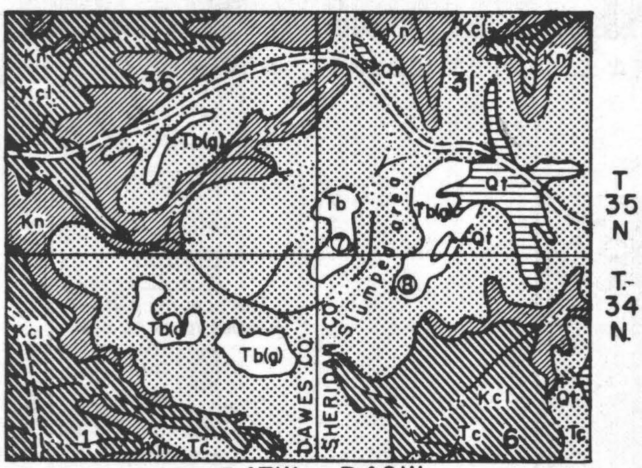
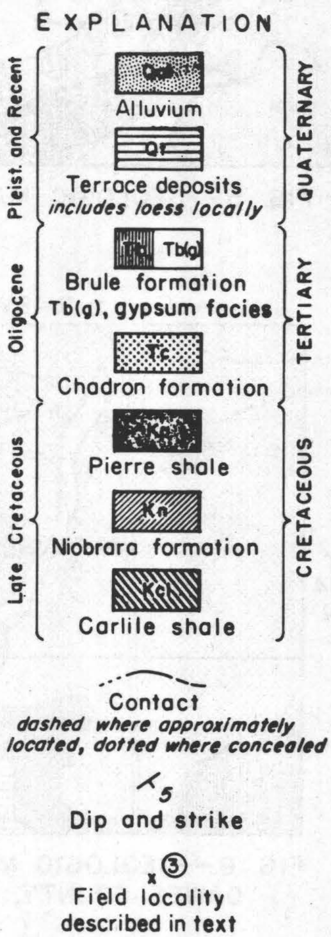


FIG. 4 --GEOLOGIC MAP OF AREA B, DAWES AND SHERIDAN COUNTIES, NEBRASKA



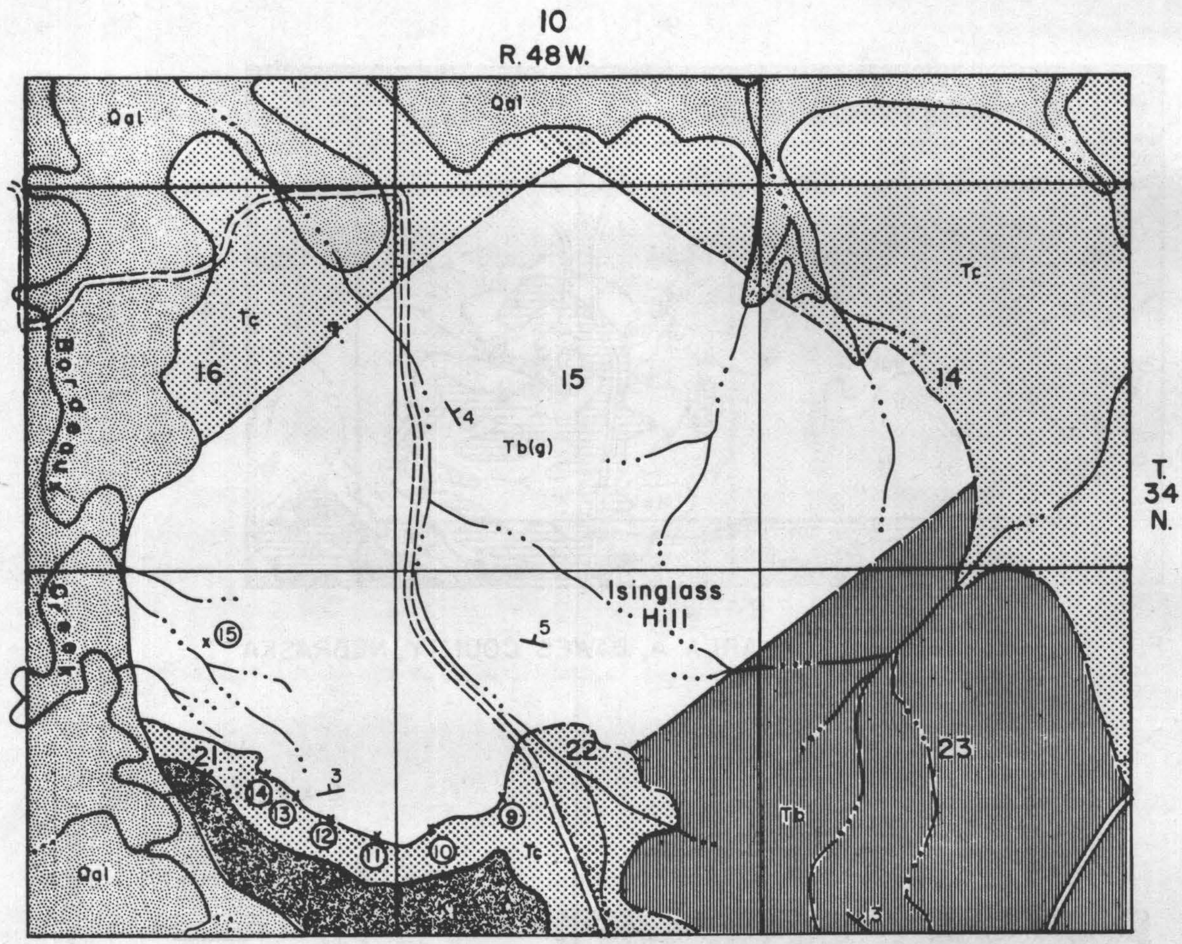


FIG. 5--GEOLOGIC MAP OF AREA C, DAWES COUNTY, NEBRASKA

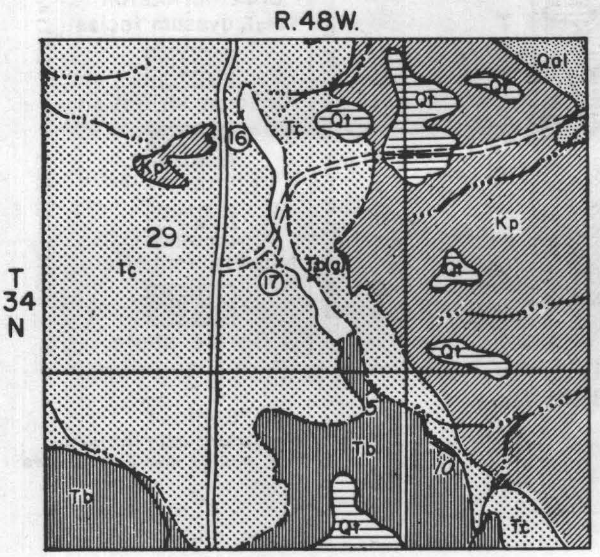
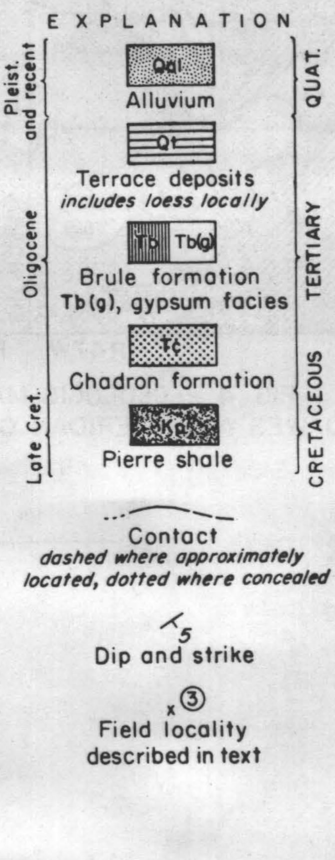


FIG. 6--GEOLOGIC MAP OF AREA D, DAWES COUNTY, NEBRASKA



The basal channel sandstone, where present, is 2-15 feet thick. In many places it is clayey, poorly sorted, and mottled red, white, and purple. Its pebbles consist of ferric iron oxide, manganese oxide, tough yellow-red clay, resistant white alunite-kaolinite clay, and Cretaceous vertebrate fragments, all derived from the pre-Oligocene weathered zone. In a discontinuous belt of outcrop that trends east-northeastward across the area, the sandstone is quartzose, clean, well sorted, and includes cobbles and pebbles of siliceous metamorphic and igneous rocks. Silicified fossil cycad and other wood, silicified fossil bone, and agate are prominent, especially in the SW 1/4 NW 1/4 of sec. 15, T. 34 N., R. 47 W. An Oligocene stream probably deposited this channel-fill. Where the basal channel sandstone is absent, a few feet of red or reddish-brown clay lies with gradational contact on weathered Cretaceous strata.

The extensive middle unit ranges from 25 to 115 feet in thickness. It consists of greenish-gray slightly silty clay that according to X-ray analysis is made almost entirely of montmorillonite and quartz. The clay in outcrop presents a hummocky surface marked by a multitude of closely spaced dessication cracks. Opal and chalcedony concretions probably pseudomorphic after gypsum and up to 6 inches in diameter are common. In some places, as in the NE 1/4 of sec. 14, T. 34 N., R. 47 W., the lower 1 to 10 feet of the middle unit is mottled red and contains 1-inch clusters of partly silicified granular gypsum, which though secondary constitute as much as 27 percent of the clay. Ward (1922, p. 22) reports similar occurrences of secondary gypsum from the lower Chadron of

South Dakota. Highly polished pebbles and cobbles of quartzite, vein quartz, silicified wood, silicified limestone, and chert are present at different levels in the lower 20 feet of the clay. The polished stones occur as isolated individuals and as circular lenses a few inches thick and 2 to 50 feet wide. In the lenses there is no interstitial sand and the stones are separated from each other by clay. A few of the stones are vaguely faceted in the manner of ventifacts.

The upper unit is 48 to 64 feet thick where recognized. It is predominantly a light greenish-gray, slightly silty, pellet clay that is lighter colored, more silty, more calcareous, and more resistant to weathering than the underlying middle unit. The pellets range from sand size to pebbles half an inch in diameter and are rounded to subangular. They can be distinguished from the matrix by a slight difference in silt content and by a very subtle difference in color, the matrix generally being less silty and darker colored. X-ray analyses of 5 samples show that the upper unit consists of quartz, montmorillonite, illite, kaolinite, and sodic plagioclase. One or two resistant beds of lime-cemented mudstone, which probably represent the 'C' horizon of a fossil pedocal soil, occur in the upper part of the upper unit. Pellets are readily observable in these beds for preferential cementation has left the pellets soft and green and the matrix hard and white. In the SE 1/4 of sec. 29, T. 34 N., R. 48 W., (Area D), the light greenish-gray of the upper unit changes laterally to the flesh pink that characterizes the siltstone of the overlying Brule formation.

Brule formation

Clastic facies.--In the Chadron area the Brule formation is about 270 feet thick and is represented by two distinct lithologic facies. One is a clastic facies; the other is a gypsum facies. The clastic facies of the Brule formation consists of a lower unit of interbedded varicolored siltstone, silty clay, and channel sandstone, which has fresh water limestone at the base, and an upper flesh pink siltstone. The lower unit is probably the Orella member of Schultz and Stout (1938, p. 1921), and the upper siltstone is probably their Whitney member. The Brule formation is more calcareous, siltier, and more resistant to weathering than the underlying Chadron formation. Grain size analyses reported from Box Butte County and elsewhere in western Nebraska (Wenzel and others, 1946, p. 67) show the Brule to consist not of clay, as implied by the old name "Brule clay", but of silt.

At the base of the Brule is a discontinuous zone of hard white micro-crystalline limestone, calcareous siltstone, and laminated limestone that reaches 15 feet in thickness. The limestone contains gastropods and ostracods, and as Wanless (1923, p. 209) concluded from fossil and other evidence in South Dakota it probably was deposited in a series of shallow ponds. The contact between the Brule and Chadron formations is drawn wherever possible at the base of this limestone. Where the limestone is absent, the contact is drawn at the top of the upper prominent lime-filled fossil-soil bed in the Chadron limestone. Opal and chalcedony replace part or even all of the limestone at many places.

Above the limestone, the lower part of the clastic facies of the Brule formation is 165 feet thick and consists of siltstone and silty clay color-banded in shades of brown, gray, and green. Numerous fine- to coarse-grained channel sandstones, consisting of poorly sorted, subangular arkosic sand, characterize this interval.

The complete thickness of the upper part of the Brule formation is not exposed in the Chadron area. East of the Chadron area, in northwestern Sheridan County, the Brule formation is 120 feet thick and is unconformably overlain by the Arikaree group of Miocene age. Elsewhere in western Nebraska it ranges in thickness from 250 feet to perhaps 500 feet (Lugn, 1939, p. 1251). This unit is characterized by steep-walled exposures and by lithologic uniformity. Except for poorly defined 2- to 8-inch subspherical calcareous concretions, and for a few beds of tuff and tuffaceous limestone, the upper part of the Brule consists of massive, slightly to moderately calcareous, flesh pink siltstone, which in part has pellets similar to those described in the upper part of the Chadron formation.

Gypsum facies.--A sequence of nonmarine gypsum and gypsiferous clay more than 270 feet thick is present in the Brule formation in a belt of isolated hills 12 miles long and a mile wide extending from sec. 29, T. 34 N., R. 48 W., Dawes County, to sec. 31, T. 35 N., R. 46 W., Sheridan County. The belt lies about a mile north of, and has the same trend as, the channel-fill of the Oligocene stream noted in the description of the basal sandstone of the Chadron formation. At two localities the interfingering of the gypsum and clastic facies can be observed. The better exposed of the two is on the southeast side of Isinglass hill (fig. 7). Erosion has destroyed the margin of the gypsum facies elsewhere. The inferred position of the southern margin is shown on fig. 2. The northern margin may lie at the north edge of the belt of hills in which gypsum occurs, or it may lie as much as 7 miles farther to the north, where there are extensive outcrops of the clastic facies. The upper contact of the gypsum facies is not preserved, although a thickness of 270 feet remains in the vicinity of Isinglass hill in Area C (fig. 5).

The gypsum beds are 2 to 8 feet thick, light yellow-gray or rarely pink, and form prominent ledges that persist for more than half a mile of outcrop. Gypsum also occurs as light yellow-gray granular laminae sparsely distributed in thicker beds of light yellow-gray or greenish-gray clay that rarely is well exposed. Bedding surfaces are 1/64 inch to several feet apart, most beds being remarkably thin bedded. At many exposures the bedding gently undulates in such a way as to suggest penecontemporaneous deformation by gravity or perhaps deformation resulting from expansion due to the alteration of anhydrite to gypsum. The gypsum sequence slumps readily and about 40 acres in sec. 6, T. 34 N., R. 46 W. (Area B), exhibits steep dips and anomalous fractures resulting from large-scale slumping.

In hand specimen the gypsum is granular and readily breaks into sand-size grains. The granularity and attendant porosity result in part from solution under present day weathering, for the least weathered

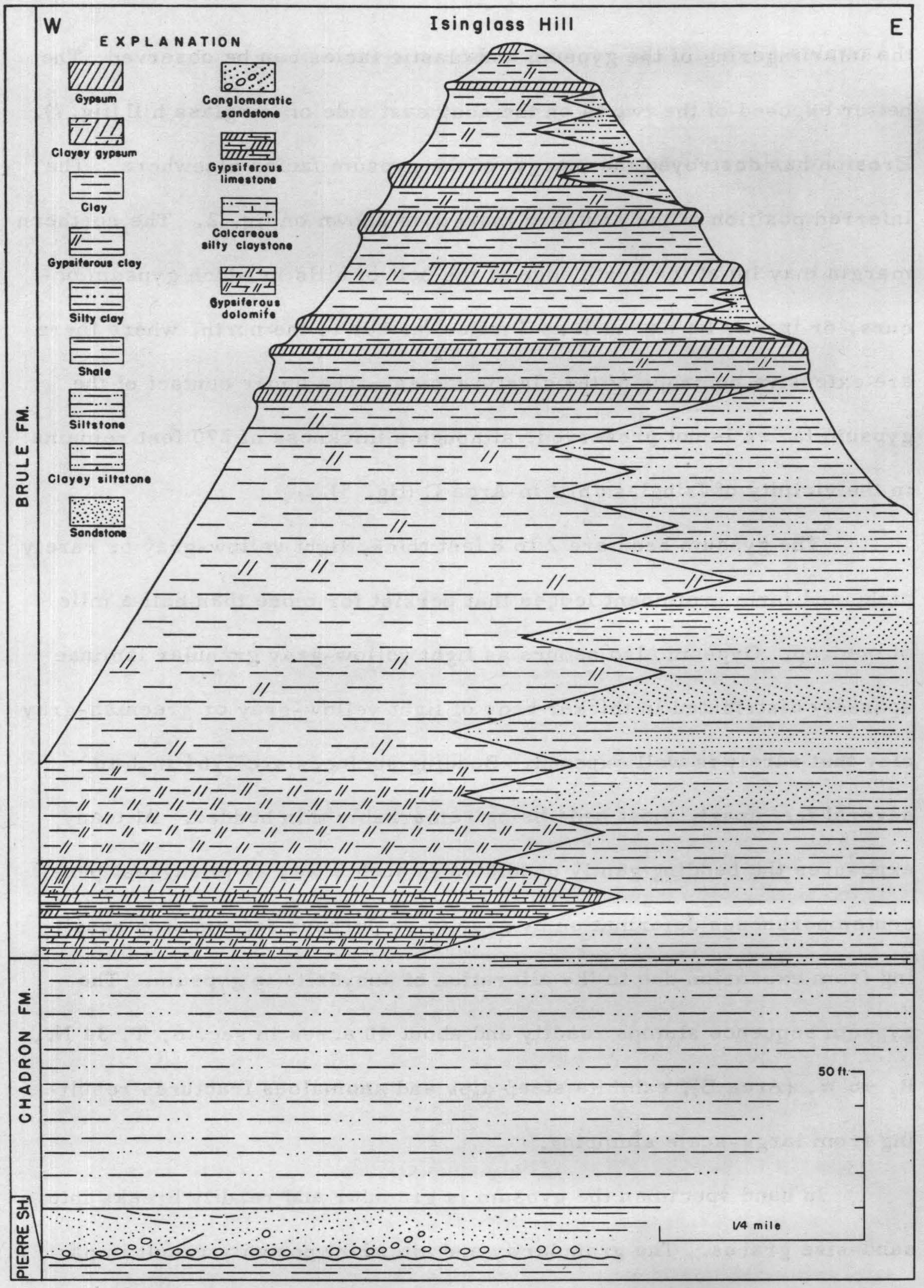


FIGURE 7—STRATIGRAPHIC DIAGRAM OF ISINGLASS HILL AND VICINITY SHOWING INTERFINGERING OF GYPSUM FACIES AND NORMAL CLASTIC FACIES OF BRULE FORMATION, SECS. 22 AND 23, T.34N., R48W., DAWES COUNTY, NEBRASKA (AREA C, FIGURE 5)

samples are the most compact. In thin section the gypsum is seen to consist of spindle-shaped anhedral grains of selenite about 0.2 mm long. The long axes of most of the grains lie parallel to bedding. Spherulitic texture similar to that figured by Goodman (1952, p. 75) is poorly and spottily developed as radiating spindles 0.5 mm long. High magnification shows the grains to be darkened by minute inclusions of calcareous or perhaps organic matter.

A grab sample of a 3-foot bed in the SE 1/4 NW 1/4 sec. 3, T. 34 N., R. 47 W., was analyzed by Irving Frost of the Denver laboratory of the Geological Survey, with results as follows:

Lime (CaO)	30.74 percent
Sulfur trioxide (SO_3)	44.06
Water driven off at 60° C	0.61
Water driven off at 300° C	19.27
Chloride (Cl^-)	0.10
Sesquioxide (principally Fe_2O_3)	0.50
Silica (SiO_2)	1.10
Total	96.38

This analysis gives an apparent equivalent of 94.5 percent gypsum, which is of commercial purity.

In its basal 25 feet the gypsum sequence ordinarily is interbedded with limestone and dolomite that correspond in stratigraphic position to the limestone zone at the base of the clastic facies of the Brule formation. The lower 25 feet of the gypsum sequence is of special interest because it is persistently, although usually weakly, uraniferous.

The limestone and dolomite beds in the lower 25 feet of the gypsum sequence are absent in the vicinity of localities 1 and 2 on the west side of the ridgein sec. 3, T. 34 N., R. 47 W., in Area A (fig. 3). These localities are unusual in other respects. Visible uranium minerals, which will be described later, occur sporadically in the basal gypsum bed and contiguous gypsiferous clays at both localities. Carbonaceous matter in the form of macerated plant fragments in gypsum and clay is associated more or less closely with the uranium minerals. The lower gypsum and gypsiferous clay beds progressively overlap each other from south to north between these localities, suggesting that a local unconformity separates the gypsum sequence from the underlying silty, pellet clay of the Chadron formation. In South Dakota Wanless (1923, p. 209) also found evidence suggesting a local unconformity beneath the limestone zone at the base of the Brule formation.

Replacement in the gypsum facies.--Secondary gypsum occurs in the gypsum facies as 1/16- to 4-inch veins of satinspar, narrower veins of selenite, 1-foot anhedral crystals of selenite in granular gypsum and smaller ones in limestone, 1/4- to 1-inch elongate crystals of selenite projecting from weathered surfaces, and as incomplete cavity fillings of selenite in limestone and dolomite. The presence of unsupported relicts of granular gypsum in the large anhedral crystals of selenite shows that the selenite did not fill a pre-existing cavity but is the result of replacement. Many of the gypsiferous limestone beds in the basal part of the gypsum sequence display a lustrous sheen analogous to that seen in "sand crystals," which is caused by the uniform crystallographic orientation of the secondary selenite.

Secondary opal and chalcedony are normally present on natural exposures. Much of the opal and chalcedony replaces secondary gypsum and probably was deposited during recent weathering. The large anhedral crystals of authigenic selenite are partially or completely sheathed in an envelope of opal and chalcedony where exposed to weathering. Samples taken a few feet behind the weathered surface lack the envelopes, and the associated fresh rock contains much less opal and chalcedony than does its equivalent at the surface. Nearly perfect pseudomorphs of opal and chalcedony after satinspar occur at locality 6 in sec. 4, T. 34 N., R. 47 W., in Area A (fig. 3). Plates of botryoidal opal and chalcedony are prominent in most of the soil developed on gypsum beds. The plates are derived from thin layers found mainly at the top or in the upper foot or so of gypsum beds. A "bladed" clay associated with carbonate beds in the lower part of the section is exceptionally sharp to the hand because thin interlacing veins of selenite have been partially or completely replaced by opal and chalcedony. The source of the silica possibly is devitrifying volcanic ash that is largely altered to clay.

Secondary calcite and dolomite make up as much as 4 percent of the gypsum beds. Staining with copper nitrate solution shows the calcite to be distributed as thin irregular crusts in pore spaces. Cavities in the limestone and dolomite in the lower part of the gypsum sequence commonly exhibit secondary calcite encrusting crystals of secondary selenite.

Origin of gypsum facies.--Fossils proving the nonmarine origin of the Nebraska gypsum have not been found. Nonmarine origin seems highly probable, however, because the gypsum occurs in a narrow belt far from marine deposits of Oligocene age, and it grades laterally into clastic sediments widely known for their land vertebrate remains.

The corresponding position and trend of the belt of outcrop of gypsum and the channel deposits of an older Oligocene stream may mean that the calcium sulfate was deposited in the center of a persistently renewed elongate valley-lake formed by the evaporation and partial damming of a major stream. Should the northern boundary of the gypsum facies prior to erosion be inferred to lie considerably north of its present extent, the valley-lake idea would be untenable, and a wider lake can be envisioned. Masson (1955) reports coastal mudflats in southwest Texas where recent clays are impregnated with selenite in large crystals and thin beds at a depth of a few inches. Perhaps the gypsum in the Chadron area was formed in a large and long-enduring Oligocene playa similar to the Texas mudflats. The presence of beds of calcium sulfate is by itself evidence that evaporation exceeded precipitation. Additional evidence of semi-arid conditions during White River time is advanced by Wanless (1923, p. 236-238) and includes the presence in the White River group of hackberry seeds and one hackberry trunk, caliche nodules, siltstones having abundant calcareous cement, and concretions of gypsum and barite. Ground water solution or weathering of Upper Cretaceous shales in other areas could provide an adequate source of the sulfate in the gypsum. Ten samples of these shales average 0.6 percent pyrite (Rubey, 1930, p. 11-12), and pyrite readily decomposes into soluble sulfate. A second possibility is solution of the gypsum in the Permian and Triassic red beds of the Black Hills, and reprecipitation in the Chadron area.

Quaternary deposits

Surficial deposits of Pleistocene and Recent age obscure much of the bedrock in the Chadron area. Dissected terrace deposits of silt, sand, and gravel a few tens of feet thick are present about 160 feet above Bordeaux Creek, Beaver Creek, and White River. Where upland deposits consist of silt, loess was mapped with terrace deposits. The major valleys and many of their tributaries are floored with fine-grained alluvium to depths of 20 feet or more.

STRUCTURE

The rocks of the mapped area are gently folded into irregular anticlines and synclines on the larger Chadron dome. Faults are small and rare.

Deformation had begun before Oligocene time, for 1,350 feet of folded and locally faulted Cretaceous strata were eroded from the Chadron arch to allow the Chadron formation to be deposited on Carlile shale in the Chadron area. Renewed folding after the Oligocene strata were deposited deformed the Chadron and Brule formations to dip as steeply as 11°. Structural features in the Chadron area are not related to uranium occurrences.

URANIUM OCCURRENCES

The occurrences of uranium described in this report are in the basal 25 feet of the gypsum facies of the Brule formation. (See table 1.) This basal zone is sporadically mineralized at localities 1 and 2, and attains ore grade at locality 1 (figs. 8 and 9). The amount of ore-grade material is probably small, about 40 tons of clay and gypsum having 0.2 percent U being indicated by surface measurements. Elsewhere the zone is weakly uraniferous (0.012 percent U, maximum), but rather persistently so. Where the zone is weakly uraniferous, it is associated with gypsiferous limestone and dolomite and there are no visible uranium minerals (figs. 10 and 11). Where the zone is more strongly uraniferous (0.43 percent U, maximum), it is associated more or less closely with carbonaceous matter and is visibly mineralized.

Mineralogy

Uranium minerals identified in the Chadron area are autunite [$Ca(UO_2)_2(PO_4)_2 \cdot 10\text{-}12H_2O$], carnotite [$K_2(UO_2)_2(VO_4)_2 \cdot 1\text{-}3H_2O$], and sabugalite [$HAl(UO_2)_4(PO_4)_4 \cdot 16H_2O$].

The autunite is yellow green and brightly fluorescent. It is restricted to gypsiferous clay directly above and directly below bedded gypsum that bears carnotite and sabugalite. At locality 1b (fig. 3) the gypsiferous clay is carbonaceous; at locality 1a (fig. 3) it is not. The autunite occurs as fracture coatings and as granular aggregates dispersed in the clay. It

Table 1.--Analyses of samples and description of localities, Chadron area, Nebraska

Locality number	Magnitude of anomaly (multiples of background)	Size of anomaly (feet)	Laboratory number	Thickness of sampled interval (feet)	eU (percent)	U (percent)	Rock type
			Area A (See figs. 3 and 9)				
1a	30X	2 x 3	(221497	2.0	0.11	0.12)	Gypsum, stained brown and yellow.
1a			(221499	1.0	.12	.15)	Carnotite and sabugalite.
1a	-	-	221500	1.5	.023	.043	Gypsum, clayey.
1a	-	-	221501	8.0	.009	.017	Clay, gypsiferous.
1a	65X	1 x 20	221502	1.0	.29	.43	Clay, gypsiferous. Autunite.
1a	-	-	221504	1.5	.089	.14	Clay, gypsiferous. Sparse autunite.
1a	-	-	221505	2.0	.006	.011	Pellet clay.
1b	20X	2 x 6	223137	1.5	.041	.011	Clay, gypsiferous. Sparse autunite. Stratigraphically above gypsum of 1a.
1c	40X	2 x 2	223138	1.0	.084	.010	Clay, gypsiferous. Sparse autunite. Probably stratigraphically below gypsum of 1a.
2a	-	-	223139	3.0	.005	.004	Gypsum.
2a	-	-	223140	1.0	.005	.006	Limestone, gypsiferous.
2a	-	-	223142	1.5	.006	.009	Gypsum, clayey.
2a	15X	2 x 50	(223141	1.5	.018	.024	Gypsum, carbonaceous. Contains carnotite and sabugalite.
2a			(223143 (	0.3	.046	.059	Clay, carbonaceous. Contains autunite and well preserved plant fragment.
2a	-	-	223144	1.0	.009	.008	Clay.
2b	10X	2 x 30	223145	2.0	.012	.014	Clay. Contains autunite and, in upper half, plant fragments. Overlying gypsum is not radioactive.
3	3X	4 x 300	-	-	-	-	Gypsum and gypsiferous clay.
4	3X	3 x 150	-	-	-	-	Limestone, gypsiferous.
5	3X	3 x 150	-	-	-	-	Dolomite, gypsiferous, finely laminated.
6	-	-	-	-	-	-	Limestone, gypsiferous, and gypsum. Exposures not investigated in detail, but radioactivity conforms to pattern shown by localities 9-14.
			Area B (See fig. 4)				
7	3-5X	5 x 600	(223135	2.0	.007	.004	Limestone, gypsiferous.
			(223136	1.0	.004	.004	Clay, gypsiferous.
8	3X	3 x 100	-	-	-	-	Limestone, gypsiferous.
			Area C (See figs. 5 and 10)				
9	See figure 10.		138897	8.0	.004	.004	Limestone, gypsiferous. Composite sample of 3 beds.
10			223147	3.0	.004	.004	Limestone, gypsiferous.
11			216658	3.0	.007	.008	Limestone, gypsiferous.
12			223149	1.0	.003	-	Limestone, gypsiferous.
12			223148	3.0	.005	.004	Dolomite, gypsiferous, and gypsum.
13			223152	1.0	.006	.006	Dolomite, gypsiferous.
13			223151	1.0	.006	.007	Dolomite, gypsiferous.
14			223150	1.0	.010	.011	Dolomite, gypsiferous.
15	5X	10 x 10	216657	-	.004	.004	Clay, gypsiferous. Grab sample.
			Area D (See fig. 6)				
16	3-5X	5 x 300	-	-	-	-	Limestone, slightly gypsiferous.
17	5X	3 x 50	216659	1.0	.011	.012	Limestone.

Analysts: G. Daniels, M. Finch, S. P. Furman, J. Goode, H. Lipp, R. Moore, J. E. Wilson.

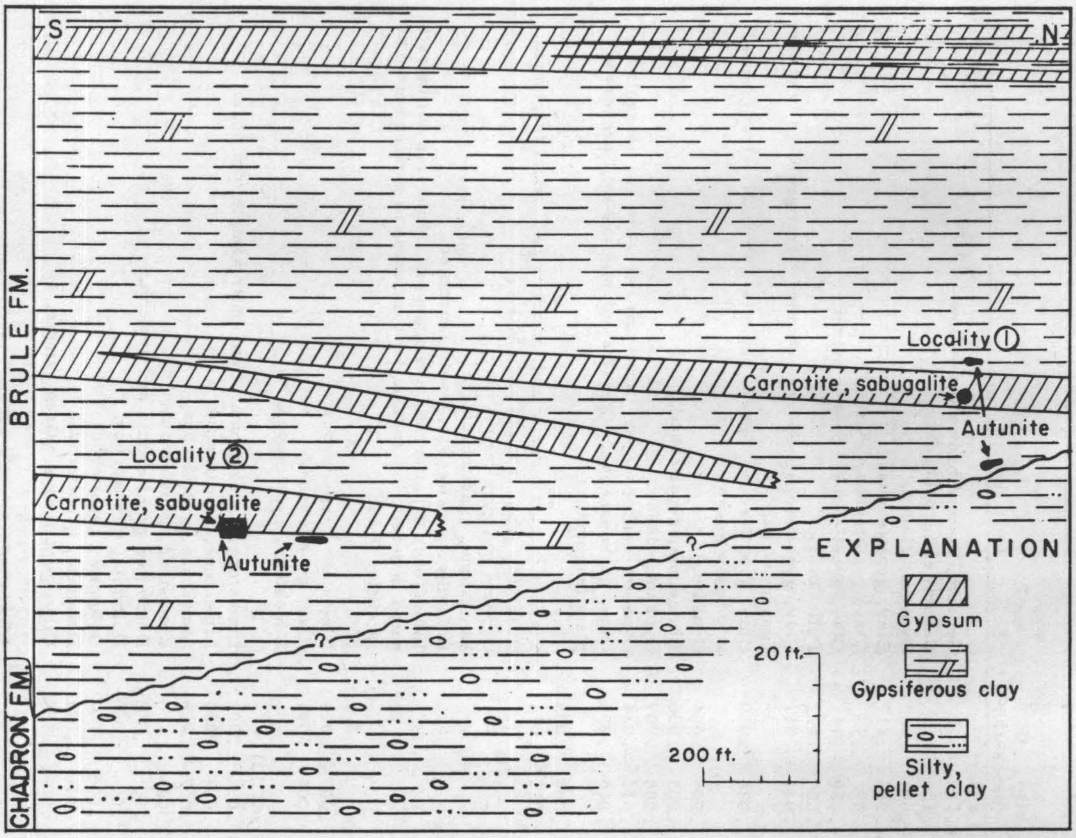


FIGURE 8— STRATIGRAPHIC DIAGRAM SHOWING RELATION OF URANIUM MINERALS TO GYPSUM BEDS OF BRULE FORMATION SEC. 3, T.34 N., R.47 W., DAWES CO., NEBRASKA (AREA A, FIG. 3)

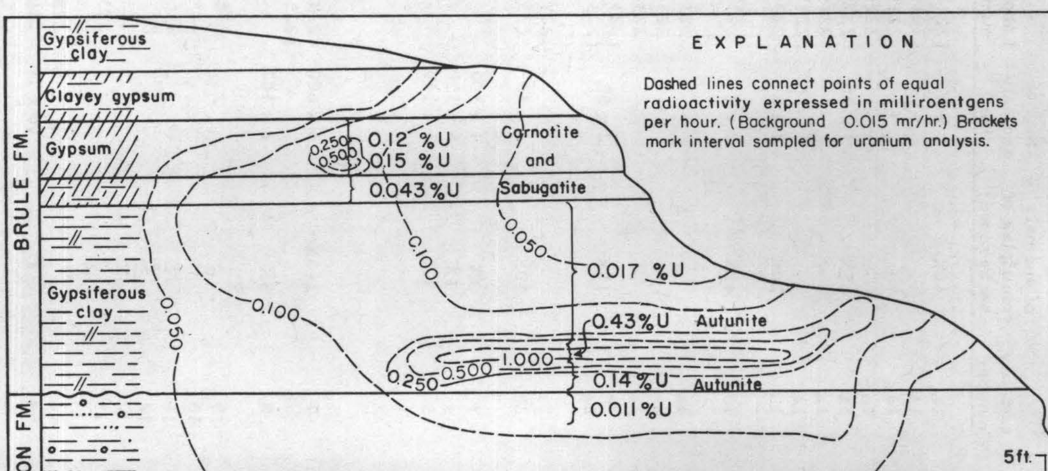


FIG. 9--SKETCH SHOWING DISTRIBUTION OF URANIUM AND RADIOACTIVITY AT LOCALITY 1a. C W1/2 SEC. 3, T.34N., R.47 W., DAWES COUNTY, NEBRASKA (AREA A, FIGURE 3)

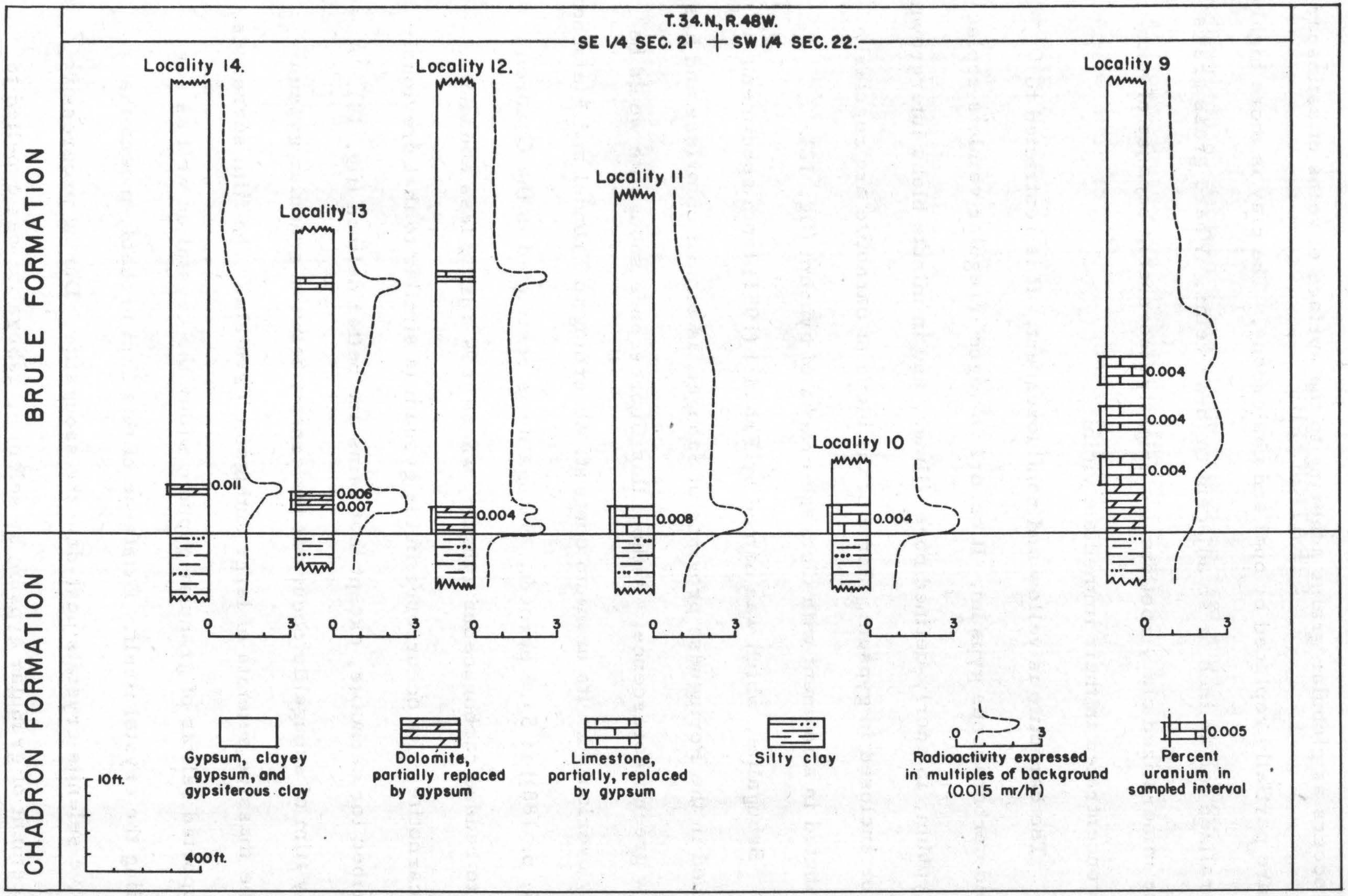


FIGURE 10—COLUMNAR SECTIONS SHOWING RELATION OF URANIUM AND RADIOACTIVITY TO CARBONATE ROCKS IN LOWER PART OF GYPSUM FACIES OF BRULE FORMATION NEAR CHADRON, NEBRASKA (AREA C, FIGURE 5)

also occurs as globular grains adhering to the surface of veins of satinspar that are partially replaced by opal and chalcedony. The clay is more highly mineralized for an inch or so adjacent to these veins. Where grass grows on the mineralized clay, rootlets are brightly fluorescent because of autunite concentrated in their immediate vicinity.

The carnotite is yellow and nonfluorescent. It is restricted to bedded carbonaceous gypsum. It occurs in vague irregular veinlets replacing gypsum, in poorly-defined pore fillings, and in minute blebs intergrown with or enclosed in gypsum. Some of the blebs of carnotite are regularly distributed in alinement with cleavage cracks of gypsum (fig. 12).

Sabugalite, which was named by Frondel (1951) from specimens obtained in the Portuguese province of Sabugal, is almost colorless and has yellow green fluorescence. Without this fluorescence sabugalite would be easily overlooked. Its uranium content, according to Frondel and Fleischer (1955, p. 188)) is 53.6 percent. Sabugalite is restricted in the Chadron area to bedded carbonaceous gypsum, where it is a little less abundant than carnotite. Its occurrence in the gypsum is similar to that previously described for carnotite, except that veins are better defined (fig. 13). A patchy film of sabugalite occurs at the contact between granular gypsum and the massive selenite of large authigenic crystals. The film surrounds unsupported relicts of granular gypsum within the crystal as well as surrounding the crystal itself. Existence of this film probably means that massive selenite crystals post-date the sabugalite. During progressive replacement of granular gypsum by selenite, sabugalite was expelled to the margins of the growing crystal.

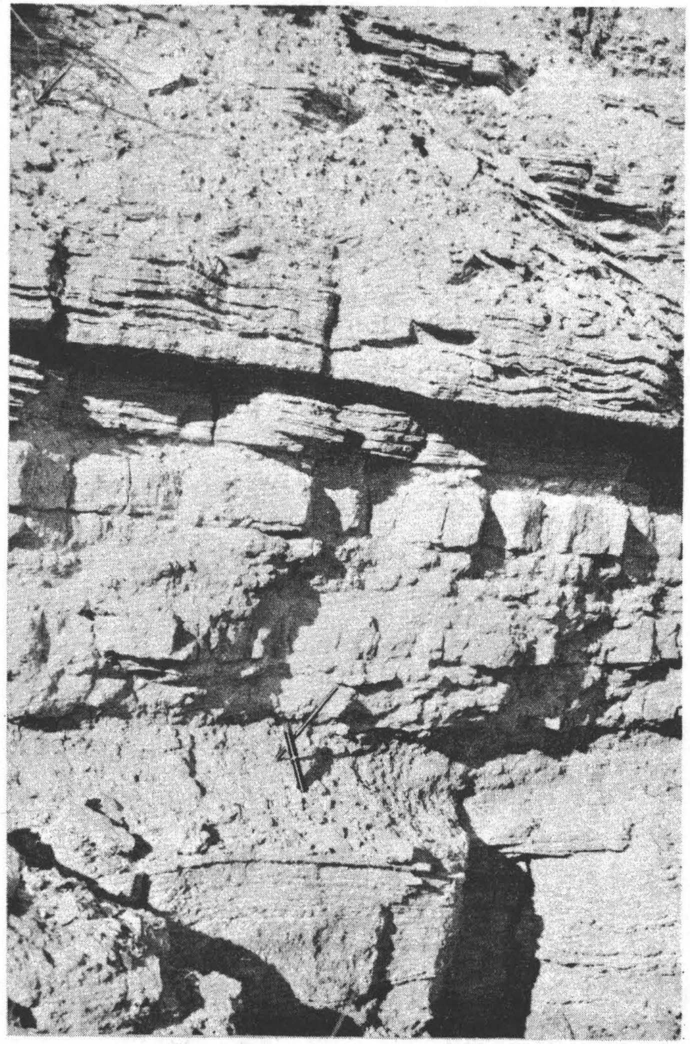


Fig. 11. --Photograph of weakly uraniferous limestone interbedded with laminated gypsum at locality 7, Area B.

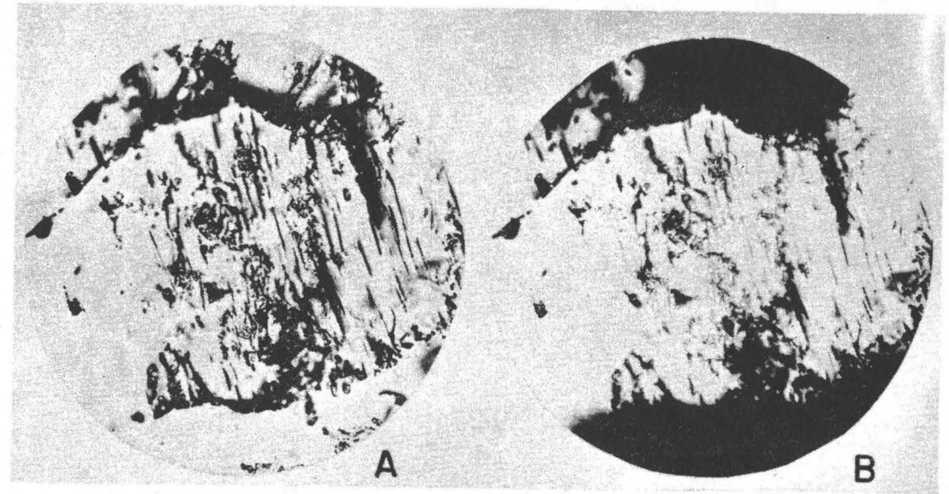


Fig. 12. --Photomicrographs of carnotite blebs in crystal of gypsum: A. plane light; B. polarized light (magnification 360X).

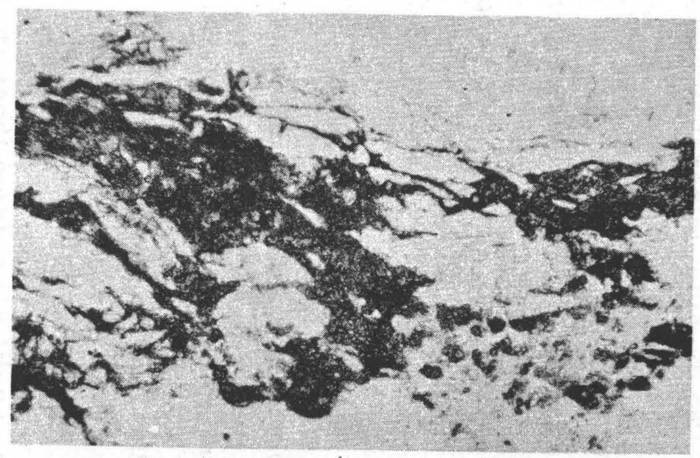


Fig. 13. --Photomicrograph of irregular vein of sabugalite in gypsum, plane light (magnification 100X).

No uranium mineral is visible under the microscope in the mildly uraniferous zone of gypsiferous limestone and dolomite. Opal having a yellow green fluorescence as bright as that of autunite occurs in this zone but assays no more than 0.002 percent eU.

Semiquantitative spectrographic analyses of a mineralized and nonmineralized pair of gypsum samples suggest that uranium is accompanied by molybdenum. The nonmineralized sample contains less than 0.0016 percent molybdenum. The mineralized sample, whose uranium content is in the range 0.03-0.16 percent, contains molybdenum in the range 0.016-0.073 percent. The abundance of other elements in the mineralized sample is no different from those in the nonmineralized sample.

Origin

Uranium in the Chadron occurrences probably was emplaced from above by uranyl solutions rich in sulfate. Bethke's laboratory experiments (1953, p. 182) show that available sulfate ion concentration is a controlling factor in holding uranium in a uranyl solution. Bethke states that the uranyl ion uses the sulfate ion as a vehicle, so to speak, with which to move in ground water solution, and that any substance that can rob the uranyl ion of its sulfate ion vehicle will precipitate it as a uranium mineral. Calcium ions are effective robbers, and hence capable of causing precipitation of uranium.

These findings provide a possible explanation for the weak but extensive occurrences of uranium in the gypsiferous limestone-dolomite zone at the base of the gypsum sequence. A uranyl solution, rich in sulfate ion dissolved from the gypsum with which it was in contact, migrated downward through the gypsum sequence. As long as the concentration of sulfate ion remained high, the solution was able to carry uranium, but where the solution encountered calcium ions in limestone and dolomite at the base of the gypsum sequence, its content of sulfate ion was diminished and uranium was precipitated. The lost sulfate ions formed the abundant secondary gypsum previously noted in the limestone and dolomite zone. Precipitation of uranium was so diffuse that uranium minerals large enough to be visible under the microscope were not formed.

Where the sulfate-rich uranyl solutions encountered carbonaceous matter near the base of the gypsum sequence, this more effective precipitant of uranium could have produced the local but relatively rich concentrations of readily visible uranium minerals.

Autunite does occur in gypsum some feet away from carbonaceous matter, as illustrated by the clay that contains 0.43 percent U and 0.29 percent eU at locality 1a (fig. 3). Autunite is concentrated around rootlets of living plants and on late-formed chalcedony and opal pseudomorphs of satinspar veins. This fact indicates recent migration of uranium, which may explain the marked disequilibrium.

The source of the uranium in the downward moving solution is unknown. There are at least three possibilities: (1) weakly uraniferous volcanic ash in the part of the upper Brule that was removed by pre-Miocene erosion, or in the overlying Arikaree group of Miocene age; (2) high grade uranium deposits resulting from unrecognized Tertiary hydrothermal activity on the Chadron arch and now removed by erosion; (3) uranium salts precipitated in an unrecognized final stage of evaporation of the same lake that earlier had deposited gypsum. There is no reason to believe all the uranium came from a single source. Prospecting will, it is hoped, uncover evidence needed to evaluate these possibilities.

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