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National Uranium Resource Evaluation

CORTEZ QUADRANGLE COLORADO AND UTAH

U.S. Geological Survey
Golden, Colorado

Issue Date
September 1982

PREPARED FOR THE U.S. DEPARTMENT OF ENERGY
Assistant Secretary for Nuclear Energy
Grand Junction Area Office, Colorado

This report is a result of work performed by the U.S. Geological Survey, through an interagency agreement with the U.S. Department of Energy, as part of the National Uranium Resource Evaluation. NURE was a program of the U.S. Department of Energy's Grand Junction, Colorado, Office to acquire and compile geologic and other information with which to assess the magnitude and distribution of uranium resources and to determine areas favorable for the occurrence of uranium in the United States.

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NATIONAL URANIUM RESOURCE EVALUATION
CORTEZ QUADRANGLE
COLORADO AND UTAH

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U.S. GEOLOGICAL SURVEY
Golden, Colorado

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PREPARED FOR THE U.S. DEPARTMENT OF ENERGY
GRAND JUNCTION AREA OFFICE
UNDER CONTRACT NO. DE-A113-78GJ01686

This report has not been edited for conformance
with U.S. Geological Survey stratigraphic
nomenclature or resource classification.

This is the final version of the subject-quadrangle evaluation report to be placed on open file. This report has not been edited. In some instances, reductions in the size of favorable areas on Plate 1 are not reflected in the text.

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* This map, Geology, structure, and uranium deposits of the Cortez Quadrangle, Colorado and Utah, by D. D. Haynes, J. D. Vogel, and D. G. Wyant, is published as U.S. Geological Survey Miscellaneous Investigations Series Map I-629 and is available from the Branch of Distribution, U.S. Geological Survey, Box from the Branch of Distribution, U.S. Geological Survey, Box 25286, Federal Center, Denver, CO 80225.

ABSTRACT

Six stratigraphic units are recognized as favorable for the occurrence of uranium deposits that meet the minimum size and grade requirements of the U.S. Department of Energy in the Cortez $1^{\circ} \times 2^{\circ}$ Quadrangle, Utah and Colorado. These units include the Jurassic Salt Wash, Recapture, and Brushy Basin Members of the Morrison Formation and the Entrada Sandstone, the Late Triassic Chinle Formation, and the Permian Cutler Formation. Four areas are judged favorable for the Morrison members which include the Slick Rock, Montezuma Canyon, Cottonwood Wash and Hatch districts. The criteria used to determine favorability include the presence of the following (1) fluvial sandstone beds deposited by low-energy streams; (2) actively moving major and minor structures such as the Paradox Basin and the many folds within it; (3) paleostream transport directions approximately perpendicular to the trend of many of the paleofolds; (4) presence of favorable gray lacustrine mudstone beds; and (5) known uranium occurrences associated with the favorable gray mudstones.

Two areas of favorability are recognized for the Chinle Formation. These areas include the Abajo Mountain and Aneth-Ute Mountain areas. The criteria used to determine favorability include the sandstone-to-mudstone ratio for the Chinle Formation and the geographic distribution of the Petrified Forest Member of the Chinle Formation which is considered as the possible source for the uranium.

Two favorable areas are recognized for the Cutler Formation. Both of these areas are along the northern border of the quadrangle between the Abajo Mountains and the Dolores River Canyon area. Criteria used to outline these areas are the distribution of facies within the formation. Favorable facies are those which include the depositional environments that are transitional between fluvial and marine.

Two areas are judged favorable for the Entrada Sandstone. One area is in the northeast corner of the quadrangle in the Placerville district and the second is along the eastern border of the quadrangle on the southeast flank of the La Plata Mountains. The boundaries of these two areas were determined by geologic mapping.

INTRODUCTION

PURPOSE AND SCOPE OF STUDY

The Cortez $1^{\circ} \times 2^{\circ}$ Quadrangle, southwestern Colorado and southeastern Utah (Fig. 1), was studied to identify and evaluate areas and geologic formations that are favorable for the occurrence of uranium deposits of specific minimum size and grade. This study was conducted by the U.S.

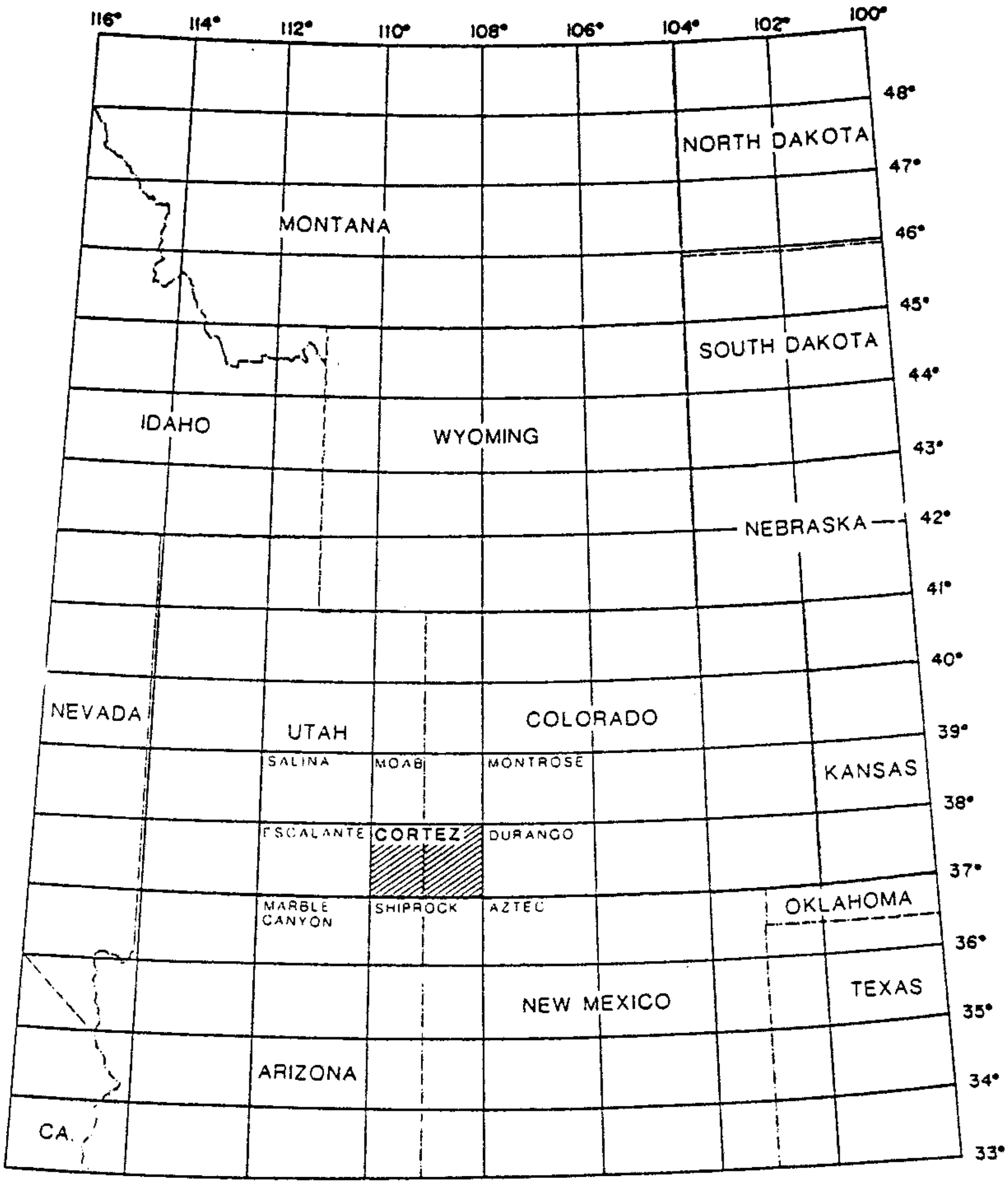

FIGURE 1.--Location of Cortez Quadrangle

Geological Survey (USGS) under contract to the Grand Junction Office of the U.S. Department of Energy (DOE) for the National Uranium Resource Evaluation (NURE) program.

This study of the Cortez Quadrangle began in the Spring 1978 and was completed in Spring 1980. Field teams located and described occurrences, sampled units of interest, studied sedimentary structures and ran radiometric surveys during two field seasons. A large number of people were also involved in literature searches, data compilation, drafting and report writing. A total of about 4 man-years were invested in the study of which about 1 to 1.5 man-years were field work. Each individual who worked on a particular portion of the folio is given credit for their work on that section.

ACKNOWLEDGMENTS

Evaluation of the Cortez Quadrangle has required the support of many professional and technical personnel in the USGS. Compilation of the land status map was done by P. B. Mudgett; computer support was made available by C. W. Adkisson, R. R. Wahl, C. A. Phillips and T. M. Copley; and tables and appendixes were compiled, in part, by S. M. Condon and J. L. Cornellisson all of the USGS. Special thanks are given to B. A. Steele-Mallory who assisted in every aspect of folio preparation. R. B. O'Sullivan of the USGS assisted with the geologic index maps and J. J. Stevenson assisted with subsurface analysis. We also gratefully acknowledge the clerical support provided by Myrna Trotter and the drafting support provided by Mary Durrett.

PROCEDURES

Before field work was begun, a literature search was conducted to compile a table of all reported uranium occurrences (App. A). Locations of the occurrences are shown on Plate 2. The major emphasis of field work was on visiting and sampling these occurrences. Because of the large number of occurrences in this quadrangle only a selected number were visited. Occurrences selected were considered to be representative of a given mining area, and also provided good quadrangle and complete host rock coverage. An occurrence form (App. C microfiche) was completed for each visited occurrence. Information on location, mine workings, production (if available), stratigraphy, sedimentology, and mineralogy is included in each form. If a prospect was listed as an occurrence or anomaly in the literature but did not register a minimum radiometric reading of twice background when field checked, it was footnoted in Appendix A as not constituting a occurrence.

Grab samples were collected at occurrence sites from both mineralized and unmineralized portions of the host rock. Samples were also collected from potential uranium host rocks at localitites with no mineralization. All sampling localities are plotted on Plate 5. Those samples collected from a reported occurrence site are listed on the individual uranium occurrence forms. All samples were analyzed by emission spectroscopy for 43 elements and by delayed neutron activation for uranium and thorium. Analyses were performed by the USGS analytical laboratories in Lakewood, Colorado and Menlo Park, California under the supervision of H. T. Millard, Jr. and J. L. Seeley. The chemical data for each sample are listed in Appendix B.

The aerial gamma ray and magnetic survey was conducted in the fall of 1978 by Aero Service Division, Western Geophysical company of America (1979). Complete information on instrumentation, data surveying and specifications, processing and interpretation methods is included in Aero Service, (1979 Vl. 1). Anomaly, pseudocontour and interpretation maps, profiles and statistical data are included in Aero Service (1979 Vl. 2). The Aero Service interpretative map is Plate 3. An analysis of this map and other information pertinent to its interpretation is given in detail in the aerial radiometrics section of this folio. This data was not received until after the second field season, thus has not been field checked.

The hydrogeochemical and stream sediment reconnaissance (HSSR) survey samples were collected in the Cortez Quadrangle during the summers of 1976, 1977 and 1978 by private contractors for the Los Alamos Scientific Laboratory. Each water sample was analyzed for 13 elements including uranium, and each sediment-sediment sample was analyzed for 43 elements including uranium, thorium and vanadium. All chemical analyses were conducted by Los Alamos Scientific Laboratory and all analytical data are listed in the informal report for the Cortez Quadrangle (Warren, 1979). Warren's interpretation of the data and statistical information are also given in his informal report. The methods used to compute Plate 4 and the analysis of this map are described in detail in the hydrogeochemical and stream sediment reconnaissance analysis section of this folio. This data also was not received until after the final field season, and thus has not been field checked.

The subsurface analysis of the Cortez Quadrangle utilized available oil and gas test wells (App. D and Pl. 5A). A list of gamma-ray anomalies was also compiled from these logs (App. E). These studies were conducted primarily to determine the extent and thickness of the uranium host-rock units. Although subsurface cross sections are not included in this folio, the subsurface information including thickness and extent of favorable units was utilized in the discussions of areas favorable for uranium deposits.

Knowledge of the principal uranium-bearing horizons obtained through USGS research programs has been used extensively in this evaluation. These studies include research on the Permian by John A. Campbell, on the Triassic by Robert D. Lupe, and on the Jurassic by Fred Peterson.

GEOLOGIC SETTING

The Cortez Quadrangle is situated in the northern part of the Colorado Plateau physiographic province. This area has had a complex geologic history that has included both stable shelf, and subsiding basin depositional sites, uplifts, and reversals in land-sea positions and paleoflow directions.

The lower Paleozoic, Cambrian through Mississippian, is characterized by a stable shelf situated between a subsiding basin to the west in western Utah and Nevada and stable, often positive, areas to the east in Colorado. The sea that occupied the western basin flooded across the stable shelf to and sometimes across the stable areas in Colorado a number of times. These transgresisons and regressions were often separated by long periods of nondeposition and/or erosion. Deposition in this epicontinental sea resulted in the formation of thin stratigraphic sequences of sandstone and limestone that thin to the east.

The upper Paleozoic, Pennsylvanian through Permian, is characterized by uplift of several structural elements in Colorado, a subsiding basin in eastern Utah and southwestern Colorado, and shelf to basin extending into western Utah and Nevada. The northwest-southeast trending Uncompahgre Uplift located in southwestern Colorado and extending into east-central Utah was the major source for sediment. Southwest of this uplift the subsiding Paradox Basin was flooded by the western sea. A few thousands of meters of marine shale, limestone, and evaporites that complexly interfinger with continental and marginal marine arkosic sediment next to the uplift were deposited in this basin during the Pennsylvanian Period. The resulting sedimentary rocks are the Hermosa Formation. (Fig. 2) The Uncompahgre was again uplifted in Early Permian time and the western sea retreated but subsidence continued such that a few thousands meters of predominantly continental fluvial, with some marginal marine, sediments filled the eastern part of the basin. This smaller Permian basin, called the Uncompahgre, was filled by sediment deposited on very large fluvial fans. The resulting sedimentary rocks are the Rico and Cutler Formations. The shelf and basins to the west were still sites of marine deposition. Uplift and erosion of the region brought to a close the Paleozoic depositional history.

Diapiric "salt" structures began to form perhaps as a result of the thick Permian deposits over the Pennsylvanian evaporites. Northwest-southeast folds and faults associated with salt intrusion probably started forming in Late Permian time and may have continued forming into Mesozoic time (Shawe, 1970). Movement on these structures affected sedimentation and may have influenced the formation of some uranium deposits (Butler and Fisher, 1978).

The lower Mesozoic, Triassic and Jurassic, is characterized by a return to a stable shelf in the region, but one on which deposition was thin and predominantly in continental environments with only a few marginal-marine incursions from the west. The initial Mesozoic deposition was in marine environments in which the Moenkopi Formation was formed. The Moenkopi truncates Late Permian structures and may not have been deposited over some of

SYSTEM	SERIES	STRATIGRAPHIC UNIT	LITHOLOGY		DESCRIPTION[1]
TERTIARY	Oligocene	San Juan Formation*		1	1. Grayish-green to purple andesitic tuffs and tuff breccias, in part water-laid; 400 ft
TERTIARY	Eocene	Telluride Conglomerate*		2	2. Pale-red sandstone, siltstone, claystone, and arkosic conglomerate; contact metamorphosed around stocks; 900 ft
TERTIARY	Eocene	San Jose Formation		3	3. Gray, green, and red shale; grayish-yellow, friable to well-cemented sandstone and conglomeratic sandstone; sparse, thin beds of pale-gray silicified tuff; 1000 ft
TERTIARY	Paleocene	Nacimiento Formation*		4	4. Gray, brown, green, and red shale; yellowish-gray to brown, friable, crossbedded, medium-grained, conglomeratic sandstone; 0-1000 ft
CRETACEOUS AND TERTIARY	Upper Cretaceous and Paleocene	Animas Formation*		5	5. Interbedded olive-green to reddish-brown breccia, conglomerate, tuffaceous sandstone, lithic tuff, and shale; composed of andesitic debris and siliceous pebbles; 0-300 ft
CRETACEOUS	Upper	Kirtland Shale*: upper member		6	6. Olive to greenish-gray shale; sparse lenses of friable, locally conglomeratic, fine-grained sandstone; 350 ft
CRETACEOUS	Upper	Kirtland Shale*: Farmington Sandstone Member		7	7. Cliff-forming, grayish-orange to olive arkosic sandstone lenses separated by thin shale partings; 350 ft
CRETACEOUS	Upper	Kirtland Shale*: lower member		8	8. Olive to greenish-gray chloritic shale; sparse lenses of fine-grained sandstone; 350 ft
CRETACEOUS	Upper	Fruitland Formation		9	9. Dark, chloritic shale; yellowish-brown or gray, locally carbonaceous, crossbedded sandstone; coal; 500 ft
CRETACEOUS	Upper	Pictured Cliffs Sandstone		10	10. Yellowish-orange to light-gray, crossbedded, fine- to medium-grained, well-sorted, quartzose, cliff-forming, marine sandstone; 250 ft
CRETACEOUS	Upper	Lewis Shale		11	11. Gray, marine, clay shale; thin platy beds of fine-grained sandstone near top and base; 1400-1800 ft
CRETACEOUS	Upper	Mesaverde Group: Cliff House Sandstone		12	12. Yellowish-orange to yellowish-brown, fine- to medium-grained, crossbedded marine sandstone and gray shale; 400 ft
CRETACEOUS	Upper	Mesaverde Group: Menefee Formation		13	13. Yellowish-gray and brown crossbedded sandstone, gray, and brown claystone and shale, coal seams; nonmarine; 350-800 ft
CRETACEOUS	Upper	Mesaverde Group: Point Lookout Sandstone*		14	14. Upper part: yellowish-gray to brown, cliff-forming, massive, crossbedded marine sandstone Lower part: alternating thin beds of yellowish-gray sandstone and gray shale; total thickness 400 ft
CRETACEOUS	Upper	Mancos Shale		15	15. Gray to dark-gray, soft, fissile, sparsely fossiliferous, marine clay shale; thin calcareous sandstone and sandy, clayey limestone ledges in lower 500 ft; 2000-3000 ft
CRETACEOUS	Upper	Mancos Shale: Juana Lopez Member		16	16. Thin-bedded, brown, sandy, fossiliferous limestone and dark-gray shale; present in southeast area; forms cuesta 500 ft above base of Mancos Shale; 25-50 ft
CRETACEOUS	Lower(?)	Dakota Sandstone*		17	17. Yellowish-brown to gray, quartzitic sandstone and conglomeratic sandstone; less abundant gray claystone, carbonaceous shale, and friable sandstone; local coarse basal conglomerate; marine near top; fluvial near base; 10-225 ft
CRETACEOUS	Lower	Burro Canyon Formation*		18	18. Light-gray and light-brown, fluvial, quartzose sandstone and conglomerate; lenticular, greenish-gray, commonly nonbentonitic siltstone, shale, and mudstone; thin gray limestone and chert near top; 150 ft

*Favorable for uranium deposition
**Uranium deposits
~ Unconformity
[1] Stratigraphic column compiled from Haynes and others (1972)

FIGURE 2. GENERALIZED PARTIAL STRATIGRAPHIC COLUMN FOR THE CORTEZ 1°X2° QUADRANGLE, UTAH AND COLORADO

Compiled by K. J. Franczyk

SYSTEM	SERIES	STRATIGRAPHIC UNIT[1]		LITHOLOGY	DESCRIPTION[1]
JURASSIC	Upper	Morrison Formation**	Brushy Basin Member	19	19. Variegated gray, pale-green, reddish-brown or purple bentonitic mudstone; a few lenses of green and red-chert pebble conglomeratic sandstone; 150-700 ft
JURASSIC	Upper	Morrison Formation**	Westwater Canyon Member	20	20. Yellowish- and greenish-gray, fine- to coarse-grained, arkosic sandstone; interbedded grayish sandy shale and mudstone; 180 ft
JURASSIC	Upper	Morrison Formation**	Recapture Member	21	21. Reddish-gray, white, and brown, fine- to medium-grained salt and pepper sandstone; interbedded reddish-gray siltstone and mudstone; 200 ft
JURASSIC	Upper	Morrison Formation**	Salt Wash Member	22	22. Pale-gray to reddish-brown, fine- to medium-grained fluvial sandstone; interbedded greenish-gray mudstone; thin limestone locally near base; 0-550 ft
JURASSIC	Middle	San Rafael Group	Bluff Sandstone	23	23. Light-gray to light-brown, fine- to medium-grained, eolian, crossbedded quartz sandstone; 20-300 ft.
JURASSIC	Middle	San Rafael Group	Summerville Formation	24	24. Thin, evenly bedded, reddish-brown or gray siltstone, shale and fine-grained sandstone; marginal marine origin; 60-200 ft
JURASSIC	Middle	San Rafael Group	Entrada Sandstone[3]: Moab Member	25	25. White, medium-grained, crossbedded or flat-bedded, well-sorted sandstone
JURASSIC	Middle	San Rafael Group	Entrada Sandstone[3]: Slick Rock Member	26	26. White or reddish-orange, massive, fine- to medium-grained eolian crossbedded quartz sandstone
JURASSIC	Middle	San Rafael Group	Entrada Sandstone[3]: Dewey Bridge Member	27	27. Reddish-brown, flat-bedded, locally contorted earthy siltstone and flat-bedded white sandstone; total formation thickness 70-440 ft
JURASSIC	Middle	San Rafael Group	Carmel Formation	28	28. Dark reddish-brown to grayish-red, thin-bedded, silty shale, siltstone and silty sandstone of estuarine or tidal flat origin; 100 ft
JURASSIC AND TRIASSIC(?)		Glen Canyon Gp	Navajo Sandstone	29	29. White-yellow-pale-orange, fine-grained, well-sorted, crossbedded, eolian quartz sandstone; 0-400 ft
TRIASSIC (?)	Upper(?)	Glen Canyon Gp	Kayenta Formation*	30	30. Gray or grayish-orange-red, irregularly bedded fluvial sandstone and siltstone with less abundant mudstone, conglomerate, and limestone; 0-200 ft
TRIASSIC (?)	Upper(?)	Glen Canyon Gp	Wingate Sandstone	31	31. Reddish- to grayish-orange, fine-grained, cross-bedded, quartzose, well-cemented, eolian sandstone; 250-450 ft
TRIASSIC	Upper	Chinle Formation** (west) / Dolores Formation (east)	Upper part; Moss Back Member[2] and lower part	32	32. Chinle Formation: Upper part: brown crossbedded limy or dolomitic sandstone or pelletal conglomerate; underlain, generally unconformably by limy and tuffaceous mudstone, shale, and shaly sandstone; 500 ft. Moss Back Member and lower part:[2] Moss Back - pale, vari colored, crossbedded quartzose sandstone and conglomeratic sandstone; gray-green or red massive mudstone lenses; 50-100 ft; lower part - lenses of crossbedded sandstone and conglomeratic sandstone interbedded with mudstone; 200 ft
TRIASSIC	Upper	Dolores Formation (east)		33	33. Dolores Fm: Bright-red to reddish-orange, fluvial siltstone, sandstone, and shale; few thin layers of limestone-shingle conglomerate; 400-850 ft
TRIASSIC	Middle(?) and Lower	Moenkopi Formation		34	34. Upper part contains brown to reddish-brown shaly siltstone, thin ripple-marked sandstone and thick, massive sandstone; lower part contains Hoskinni Member, intercalcated thin and commonly contorted beds of reddish-brown, fine-grained silty sandstone and dark reddish-brown shaly siltstone; 0-350 ft
PERMIAN		Cutler Formation*	Cutler Formation (undifferentiated)	35	35. Grayish- to purplish-red, fluvial, micaceous, arkosic sandstone, siltstone, and conglomerate; 4000 ft in northeast
PERMIAN		Cutler Formation*	De Chelly Sandstone Member	36	36. Light-brown to pale-reddish-brown, eolian, cross-bedded, fine- to medium-grained quartz sandstone; 0-400 ft
PERMIAN		Cutler Formation*	Organ Rock Tongue	37	37. Reddish-brown siltstone; fine-grained sandstone; 250-650 ft
PERMIAN		Cutler Formation*	Cedar Mesa Sandstone Member	38	38. Yellowish-gray to reddish-orange, medium- to coarse-grained sandstone and alternating bed of dusky-red siltstone; grades south and south east ward into evaporite, siltstone, silty shale and friable sandstone; 500-1200 ft
PERMIAN		Cutler Formation*	Halgaito Tongue	39	39. Reddish-brown, shaly siltstone; very fine-grained silty sandstone; thin, lenticular beds of non-fossiliferous limestone near base
PENNSYLVANIAN	Middle and Upper	Rico Formation		40	40. Light-gray, fossiliferous, cherty marine limestone; varicolored fine- to medium-grained fluvial sandstone and partly gypsiferous siltstone; 300-550 ft
PENNSYLVANIAN	Middle and Upper	Hermosa Formation*		41	41. Gray, fossiliferous, cherty marine limestone and dolomite; gray and light-brown, fine-grained, micaceous, crossbedded sandstone and siltstone; dark-gray shale; gypsum; sandy shale; minor quartzose conglomerate; 1800->5000 ft

*Favorable for uranium deposition

**Uranium deposits

~ Unconformity

[1] Stratigraphic column compiled from Haynes and others (1972)

[2] Moss Back Member and lower part includes Monitor Butte and Shinarump Member equivalents

[3] Entrada Sandstone differentiated into members in western and central areas, remaining area undifferentiated

FIGURE 2A. GENERALIZED PARTIAL STRATIGRAPHIC COLUMN FOR THE CORTEZ 1°X2° QUADRANGLE, UTAH AND COLORADO (CONTINUED)

Compiled by K. J. Franczyk

them, suggesting movement on the "salt" structures. Streams which originated in Colorado flowed westward across this area following retreat of the Moenkopi sea into marine basins in Nevada. The Chinle Formation was formed by these streams. Volcanos existed to the west and northwest and ash accumulated with the Chinle stream deposits. Eolian deposition prevailed across the shelf for much of the remainder of the lower Mesozoic time with stream or marginal-marine sequences forming between eolian sequences. The principal stratigraphic units (Fig. 2) formed at this time include the Wingate Sandstone (eolian), the Kayenta Formation (fluvial), the Navajo Sandstone (eolian); Carmel Formation (marginal-marine), Entrada Sandstone (eolian); and Summerville Formation (marginal-marine).

In the Jurassic the depositional pattern and transport directions across the shelf changed from dominantly east to west, to west to east with the inception of Cordilleran orogenic activity to the west. The streams that deposited the Morrison Formation, the Burro Canyon, and fluvial parts of the Dakota Formation originated in uplifts in Nevada and flowed northeastward, or eastward across the area in Late Jurassic and early Cretaceous time. Volcanos again existed to the west and northwest and ash is common in Jurassic and Cretaceous strata.

The upper Mesozoic, Cretaceous, is characterized by a subsiding basin to the east and uplift to the west of the Colorado Plateau. The basin was flooded by a sea which spread westward across the area. The Plateau was the site of deposition of several hundreds of meters of complexly interfingering marine shales, and continental sandstones and shales as a result of numerous transgressions and regressions. In Late Cretaceous time the sea regressed to the east as the uplift, folding, and faulting of the Laramide orogeny began.

Late Cretaceous and Early Tertiary deformation occurred all around the Colorado Plateau, but major mountain building did not occur on the Plateau. The effect of the Laramide orogeny on the Plateau was to produce broad upwarps, basins, and monoclines, to reactivate some older structures, and to produce faults.

The early Tertiary, Paleocene through Oligocene, history of the Plateau includes erosion of the highlands and fluvial and lacustrine sedimentation in the adjacent basins. The deposition of the very extensive lacustrine Green River Formation occurred across much of the northern part of the Plateau during this time. Later Tertiary, Miocene and Pliocene, as well as Quaternary history include erosion of the early Tertiary deposits such that only isolated remanants are left except in the Uinta Basin in the north, and in the high plateaus along the western border of the Plateau and into the adjacent Basin and Range province.

Tertiary history of the Plateau also includes some igneous activity. In Late Miocene or Early Pliocene intrusions of stocks and laccoliths occurred in a number of places. These diorite and monzonite porphyry intrusions formed the La Plata, Rico, Sleeping Ute, La Sal, Henry and Navajo Mountains in this part of the Plateau. Volcanic activity also occurred in a few areas, with basaltic flows present in Grand Mesa and on the high plateaus along the western border of the Plateau and in the adjacent Basin and Range area. These volcanics are largely Early to Middle Tertiary in age, but some may be Quaternary.

Block faulting occurred in the adjacent Basin and Range province and along the western border of the Colorado Plateau. This high-angle faulting is also Middle Tertiary, largely Miocene in age.

The Quaternary history of the Plateau includes local alluvial and colluvial and some eolian deposits, and some glacial deposits in the mountainous areas. Erosion was the predominant modifier of the Plateau during the Quaternary as it is at the present.

The map showing the geology, structure and uranium deposits of the Cortez Quadrangle was published in 1972 (Haynes, and others, 1972, Plate 10). The structure of the area is characterized by broad, simple folds and minor faulting. The Monument upwarp dominates the far western portion of the map with its eastern flank marked by the steep eastward dipping Comb Monocline. The Blanding basin is east of the Comb Monocline in the south-central part of the quadrangle, and the Sage Plain terrace is north of the Blanding basin along the north-central border. The Mesa Verde basin is in the southeastern part, and the Dolores anticline and Disappointment syncline are major structures in the northeast. A number of smaller anticlines and synclines are superimposed on all of these larger folds. Domes, associated with Tertiary laccolith and stock intrusions, are present along the eastern border and form the La Plata and Rico Mountains. The Sleeping Ute Mountains in the south-central and Abajo Mountains in the northwest part of the quadrangle are also domal structures associated with Tertiary laccolith and stock intrusions.

Faulting is not a common geologic feature in the Cortez Quadrangle. Some high-angle faulting is associated with the doming produced by the Tertiary intrusives. High-angle faulting, often forming grabens, is common along the northern border of the area.

The stratigraphic sequence exposed in the Cortez Quadrangle ranges in age from Precambrian to Quaternary (Fig. 2). Precambrian and Lower Paleozoics are exposed in only one small area in the Rico dome along the Dolores River in the northeast corner of the area. Upper Paleozoic rocks are exposed in the western part of the quadrangle in the Monument upwarp and in the east around the Rico and La Plata domes. Mesozoic rocks are exposed in the central part of the area and are largely Jurassic and Cretaceous in age. Tertiary and Quaternary deposits cap older sequences in many places, but are concentrated in the central part of the quadrangle. Although a number of stratigraphic units contain some uranium only four are considered favorable including the Permian Cutler Formation; the Triassic Chinle Formation; and the Jurassic, Morrison and Entrada Formations (Pls. 1A,1B and 1C).

AERIAL RADIOMETRIC SURVEY ANALYSIS

Aero Service Division of Western Geophysical Company of America conducted the airborne gamma-ray spectrometer and magnetometer survey of the Cortez Quadrangle during the fall of 1978. Complete information on instrumentation and proceedures used for data gathering is contained in Aero Services, Volume I (1979). East-west traverse spacing throughout the quadrangle was 4.8 Kilometers (3 miles) and north-south tie lines were flown 17.3 Kilometers (12 miles) apart.

The major portion of data editing consisted of a data quality check and a data corrections program. The data quality check eliminated data which did not meet certain reliability criteria. The data corrections program applies background and cosmic correction factors, normalizes the terrain clearance and determines the statistical adequacy. Complete descriptions of these processes are given in Aero Services Volume I (1979).

Aero Service compiled an uranium anomaly interpretation map of 177 anomalies. A table which gives a brief description of each anomaly and its associated geologic formation is in the Aero Service, Volume I (1979). These anomalies have been classified into four catagories by Aero Service: 1) outstanding anomalies on both anomaly maps and profiles, 2) outstanding anomalies on anomaly maps and readily recognizable on profiles, 3) strong anomalies on anomaly maps, recognizable on profiles, and anomalies taken from profiles, 4) anomalies based on statistical evidence only (anomaly maps), which are generally more regional in character. Only those anomalies in catagories 1, 2 and 3 are shown on Plate 3.

There are distinct areas of anomaly clustering on Plate 3. These areas occur along the southern and northern extent of Comb Ridge and in the Cretaceous Mancos Shale in the northeastern portion of the quadrangle. A linear pattern of anomalies occur through Montezuma Canyon and into the Blanding basin. Some prominent anomalies occur around the Slick Rock mining area.

Areas with numerous uranium occurrences are also outlined on Plate 3. Anomalies which occur in or near these areas may result from mine workings. This is particularly true in the Slick Rock area and Montezuma Canyon areas. Some of the anomalies along northern Comb Ridge may also be the result of mine workings.

There are isolated anomalies in the southeastern area of the quadrangle associated with Cretaceous and some Jurassic units. Because of the sparsity of anomalies and lack of known uranium mineralization in the Cretaceous the significance of the anomalies may be negligable. The cluster of anomalies in the northeastern area associated with the Mancos Shale occur in the faulted, folded area immediately west of numerous Tertiary intrusives. This area requires further, in-depth field examination.

The anomalies across the northern area of Comb Ridge occur continuously across Pennsylvanian-Permian units through Jurassic units. Numerous isolated uranium occurrences are located in the Morrison Formation along the eastern edge of Comb Ridge. The extent to which those anomalies reflect a high radioactive zone across Comb Ridge, or merely reflect lithologic change across the numerous formations exposed over such a short distance, is unknown. Further field investigation is needed in this area.

The cluster of anomalies at the southern extent of Comb Ridge is not associated with any known uranium occurrences. Anomalies in the Cedar Mesa Sandstone Member of the Cutler Formation occur with or near Tertiary volcanic breccias. Anomalies in the Rico and Hermosa Formations occur immediately north of those in the Cutler Formation. One of these anomalies also occurs near a Tertiary volcanic breccia. All of these anomalies warrant further investigation.

In the Blanding Basin area there are a few fairly widespread anomalies in the Morrison Formation. This is an area of gentle folds with only a few isolated known uranium occurrences. However since the Morrison Formation is mineralized to the north, at Montezuma Canyon the area should be examined in greater detail.

Several important factors place strict limitation on the initial interpretation of airborne gamma-ray anomalies. In an airborne gamma-ray survey the radiation measured emanates primarily from the upper 46 cm (18 inches) of surficial material. In addition anomalies which meet the statistical criteria may not result from true concentration of uraniferous minerals but from the following: differential surface cover (soil or vegetation) within a lithologic unit, local weather conditions, facies variation within a geologic unit, and differential weathering of rocks within a geologic unit. Another factor is that anomalies which lie across geologic units may indicate an anomalous sample relative to one of the units, and are not a true indication of a radioactivity difference within a unit. All initial anomalies can only be verified by further field investigation. As this data was not available until after the second field season, anomalies have not been field checked.

HYDROGEOCHEMICAL AND STREAM-SEDIMENT RECONNAISSANCE SURVEY ANALYSIS

Hydrogeochemical and stream sediment reconnaissance (HSSR) data compiled by Los Alamos Scientific Laboratory (Warren 1979) were analyzed to determine water and stream-sediment samples with anomalous uranium concentrations. These anomalous samples were plotted on the interpretive map of HSSR data (Pl. 4). A total of 598 water and 1657 stream-sediment samples collected throughout the quadrangle were analyzed. However, this data was received after NURE field work was completed and anomalous areas determined from the HSSR samples were not field checked.

The following procedure was used to determine anomalous uranium concentrations. The Cortez Quadrangle was divided into sampling areas by drainage systems. Mean uranium concentration (in ppm), standard deviation and variance was determined using stream-sediment samples within each area. Uranium divided by conductivity was calculated for all water samples. This ratio was used to determine the mean, standard deviation and variance for water samples. Samples with either extremely high uranium and uranium/conductivity values were not used in the statistical study.

The mean uranium concentrations in stream sediments for the drainage areas ranged from 2.01 to 3.37 ppm and the standard deviation and variances did not exceed 1. The highest average uranium values occur in the eastern and northeastern quadrangle area and the lowest in the western and southwestern area. Los Alamos report (Warren, 1979) notes this decrease to the southwest strongly parallels a decrease in annual precipitation, thus attributes this trend predominately to climate control. The mean uranium concentrations of sediment samples from the analysis area were not significantly different; therefore, a mean and standard deviation for the entire quadrangle was determined. Two standard deviations above the mean were used as the lower limit of anomalous values for water and the sediment samples. This lower limit for sediment samples is 5.0 ppm and 5.0 for the uranium/conductivity x1000 values of water samples. All anomalous samples are plotted on Plate. 4.

Some anomalous clusters and single anomalous samples, predominately in the western portion of the quadrangle, coincide with active mining areas such as White Canyon, Montezuma Canyon and Slick Rock and/or uranium occurrences. Mining contamination may account for many of these anomalous samples. However, some samples were collected upstream from known mining operations and might reflect uranium mineralization.

Numerous anomalous water samples occur in the Cretaceous sediments in the southeast. The Los Alamos report interpreted these anomalies not to reflect uranium mineralization but rather reflect a long hydrologic residence in shale-rich units and/or evaporative concentration.

The Dolores River drainage system in the eastern part of the quadrangle contains igneous and sedimentary rocks. Anomalous water and sediment samples there may reflect either the igneous rocks, which normally have slightly higher average uranium content, or uranium mineralization of the Culter, Chinle or Morrison Formations. All of these formations are known to be mineralized in other areas of the quadrangle or elsewhere on the Colorado Plateau.

Anomalous samples in the Blanding basin not associated with uranium occurrences are sediment samples from the Morrison Formation, and well and spring water samples whose uranium enrichment may be associated with the Morrison. The Los Alamos report, (Warren, 1979) suggests that this is a favorable setting for the occurrence of uranium.

Other isolated anomalous samples are commonly associated with the Morrison, Dakota and Burro Canyon Formations or shale-rich Cretaceous units. The extent to which these samples reflect uranium mineralization is unknown without more study of these areas.

ENVIRONMENTS FAVORABLE FOR URANIUM DEPOSITS

DEFINITION OF FAVORABILITY AND CRITERIA USED FOR EVALUATION

All rocks within the quadrangle to a depth of 1500 m (5000 ft) have been evaluated and classified as either favorable or unfavorable to contain a specific endowment of uranium. The following (DOE) guidelines were used to catagorize any stratigraphic unit as favorable: 1) the presence of known uranium occurrences; 2) radiometric anomalies detectable by hydrogeochemical or, radiometric surveys; 3) the potential host rocks possess geologic and geochemical characteristics similar to known uranium productive environments; and 4) is evidence, based on the above criteria, for the potential to contain uranium deposits that total at least 100 tons U_3O_8 at a minimum average grade of 0.01 percent. The classification of a unit as favorable does not imply the presence of a 100-ton deposit but implies a potential to contain 100 tons U_3O_8. Likewise the classification as unfavorable does not imply the absence of such deposits, but implies that the evidence does not support the potential to contain such deposits.

The principal geologic criteria used in evaluating each stratigraphic unit: inlcude the following: (1) the depositional environment of the host rock, especially those factors which control facies distribution and host-rock geometry; (2) the mineralogy, texture, and diagensis of potential hosts; (3) the ability of the host unit to transmit solutions; (4) and the presence of possible reductants for uranium precipitation.

The units classified as favorable are discussed in order of decreasing favorability. Areas designated as favorable are shown on Plates 1A, 1B and 1C. These areas are labeled for reference on the plates and if possible are listed in order of favorability. Boundaries of favorable areas shown by dashed lines indicate approximate extent in the subsurface. Solid-line boundaries were established by outcrop patterns. Boundaries of favorable areas are placed to include mineralized areas and adjacent areas in which geologic and geochemical characteristics are similar.

FAVORABLE AREAS FOR URANIUM DEPOSITS IN THE SALT WASH MEMBER OF THE MORRISON FORMATION (CLASS 240, SUBCLASS 244)

The Salt Wash Member of the Morrison Formation of Late Jurassic age is considered one of the most favorable units for uranium deposits in the Cortez Quadrangle (Pl. 1). Since World War II approximately 31.7 million kg (70 million lbs.) of U_3O_8 have been produced from this member throughout the

Colorado Plateau and approximately 5,383,000 kg (11,884,000 lbs.) of U_3O_8, or about 17 percent of all Salt Wash production, have been mined from this member in the Cortez Quadrangle (Butler and Fischer, 1978). All of this production has come from the southwestward continuation of the Uravan mineral belt in the middle of the quadrangle. One district has produced more than 906,000 kg (2,000,000 lbs.) of U_3O_8. In decreasing order of production the three uranium-producing districts are the Slick Rock South, Cottonwood Wash, and Montezuma Canyon districts. Uranium deposits in the Salt Wash Member best fit recognition criteria for Class 240 (sandstone) and subclass 244 (nonchannel-controlled peneconcordant deposits) proposed by Austin and D'Andrea (in Mickle and Mathews, 1978) and Mathews and others (1979).

The Morrison Formation crops out in numerous places in the quadrangle except in the western quarter where it was removed by erosion, and the extreme southeast corner areas where it is underground. Maximum depths of overburden above the base of the Salt Wash Member is 2,840 m (9,320 ft) in the southeast part of the quadrangle and 0-1,200 ft (0,370 m) in the middle of the quadrangle. Throughout most of the region Morrison strata are horizontal on gently folded, although along the flanks of comb monocline and some of the salt anticlines the beds dip about 20° or more; near some of the intrusive masses in the Abajo and Ute Mountains the beds dip steeper. Faults cut Morrison strata in some parts of the quadrangle but there are many other places where the member is unbroken by faults.

Salt Wash strata were first evaluated for their potential of containing significant uranium deposits that meet DOE minimum criteria regardless of the 1,520 m (5,000 ft) depth limitation. A large part of the middle of the quadrangle, divided into three contiguous areas, was found to be favorable for meeting minimum classification standards and these areas were then evaluated with regard to the maximum depth limitation. The maximum depth of overburden above the base of the Salt Wash in areas that are classified as favorable for containing significant uranium deposits is only about 1,200 ft (3,700 ft). Thus all three areas in the quadrangle that are considered favorable for containing one or more significant uranium deposits in the Salt Wash Member have less than 1,520 m (5,000 ft) of overburden. In this report, significant uranium deposits are defined as uranium deposits containing, a total of at least 100 tons of U_3O_8, of which the ore grade is at least 0.01 percent U_3O_8, and the ore occurs in a more or less compact configuration that could be considered minable in an engineering sense if it were economically possible to mine ore of that low grade.

Areas in the quadrangle where uranium deposits occur or that are considered favorable for their presence are sparsely populated. Most of the land is under the jurisdiction of the the U.S. Bureau of Land Management, the U.S. National Park Service, and the U.S. Department of Agriculture. A comparatively small amount of the land is either privately owned or belongs to the State (Pl. 12). Most of the land is used for mining, grazing, or recreation.

Stratigraphy

The Morrison Formation of Late Jurassic age consists predominantly of interbedded grayish-brown sandstone and red to gray mudstone in the Cortez Quadrangle (Fig. 3). The formation is 453-650 ft (138-198 m) thick in the quadrangle according to Huff and Lesure (1965) and Ekren and Houser (1965).

The Morrison Formation consists of three stratigraphic units: the Tidwell unit at the base, the Salt Wash Member in the middle, and the Brushy Basin Member at the top. The Salt Wash and Brushy Basin Members have been known and studied for several decades whereas the Tidwell unit has only recently been recognized as a new unit in the formation lying unconformably on the Summerville Formation (Fig. 3; Peterson, 1980). Previous workers included strata here placed in the Tidwell in the uppermost part of the Summerville Formation.

The Tidwell unit is about 12-30 m (40-100 ft) thick and is composed of red and greenish gray mudstone and smaller quantities of gray sandstone and limestone. Locally, some of these beds contain slightly radioactive red and yellow chert blebs, nodules, or concretions termed welded chert by geologists and sunset agate by rockhounds.

The Salt Wash Member averages about 276 ft (84 m) in thickness in the Cortez Quadrangle and the thicknesses range from a minimum of about 50 ft (15 m) near Bluff, Utah to a maximum of about 650 ft (198 m) in the Ute Mountains. Sandstone percentages range from 50 to 70 percent and the average for the quadrangle is about 62 percent. Sandstone beds greater than about 3 m (10 ft) thick are generally considered as having more potential for containing significant uranium deposits than thinner beds. In most of the quadrangle, the measured sections average about 6 sandstone beds 3 m (10 ft) or more in thickness and the range is from 2 to 8 in the measured sections that were available. The maximum thickness of individual sandstone beds is 38-60 ft (12-18 m) and the average thickness of sandstone beds greater than 10 ft (3 m) thick is 30 ft (9 m). For the various sections, the average thickness of beds greater than 10 ft (3 m) ranges from 19-38 ft (5-12 m).

The Salt Wash Member consists of interbedded sandstone and mudstone. The sandstone is light gray and weathers grayish brown. Generally it is fine grained, and is crossbedded and horizontally laminated. Pebbles are scattered throughout some of the sandstone and consist predominantly of brown, black, and gray chert although a small quantity are red or gray quartzite or pink to light-gray, fine-grained extrusive igneous rock. At a few places, mudstone beds may be locally missing between sandstone beds and sandstone may occur for a thickness of 46 m (150 ft) or more. However, on close inspection continuous surfaces can be distinguished that mark horizons where the mudstone beds probably were present but were scoured out by the processes that deposited the overlying sandstone bed. Because of this scouring, sandstone thicknesses greater than about 15 to 18 m (50-60 ft) may be deceptive and may not represent a single persistent depositional event. Conglomerate lenses composed largely of chert pebbles are scarce and largely restricted to the top

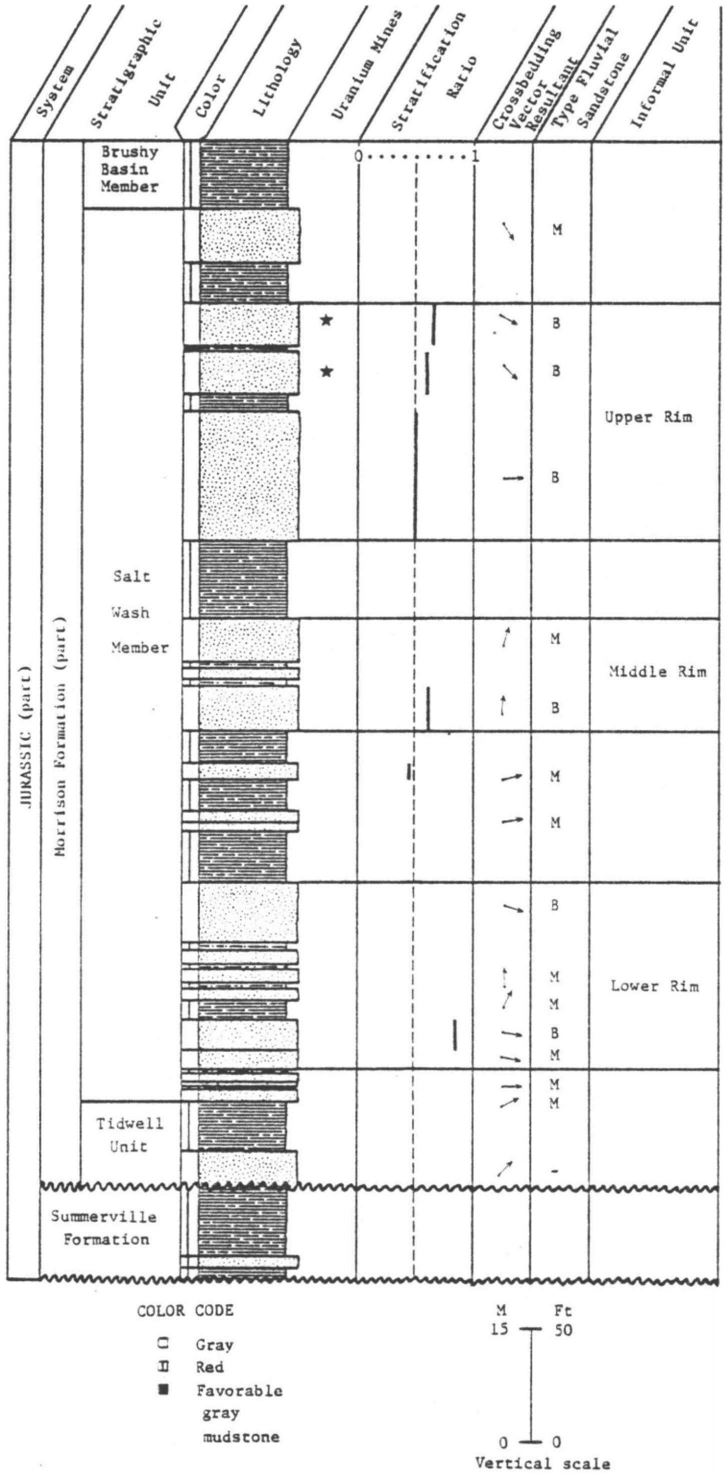

Figure 3.--Measured section of rocks in La Sal Creek canyon showing sedimentologic characteristics of fluvial sandstone beds in the Salt Wash Member of the Morrison Formation. Interpretation of type of fluvial sandstone bed; B, braided stream; M, meandering stream. Stratification ratio = P/(P+H) where P = thickness of planar crossbedded sets and H = thickness of horizontally laminated sets measured in closely spaced sections. Crossbedding dip vector resultants determined by methods of Reiche (1938). Location shown in Figure 4

of the Salt Wash or base of the Brushy Basin Member.

Sandstone beds in the Salt Wash Member consist of very fine- to medium-grained, crossbedded and horizontally laminated, sandstone locally containing well-rounded pebbles of black, gray, and brown chert less than about 13 mm (0.5 in.) in diameter. Most of these beds are light to medium gray or grayish-brown but they often appear dark reddish brown owing to wash from overlying mudstone strata of that color. In a detailed petrographic study of Salt Wash sandstones, Cadigan (1967) reported silicified tuff and felsite fragments and altered ash (mostly shards and clay) from these beds. The sandstone contains an average of about 8.6 percent feldspar and kaolinitic clays thought to be alteration products of originally feldspathic minerals (Cadigan, 1967). Associated siltstones were reported by the same author to contain 16.8 percent feldspar or nearly twice as much as occurs in the sandstones. Fluvial sandstone is poorly to moderately sorted but sandstone deposited in marginal lacustrine and deltaic environments generally is poorly to well sorted and eolian sandstone typically is well sorted. The sandstone is fairly porous and permeable (Phoenix, 1956; Jobin, 1962) but this does not appear to be a significant factor that influenced mineralization (Motica, 1968).

Mudstone beds are moderate reddish brown to greenish gray and laminated to very thin bedded or structureless. Most of these beds are discontinuous; they were either cut out by fluvial processes associated with deposition of overlying sandstone beds or they grade laterally into sandstone beds. It cannot be determined how much of the greenish-gray mudstone in the Salt Wash Member is the result of bleaching of originally red mudstones or was originally greenish gray, but in many cases the boundary between red and gray in the same mudstone bed is sharp and cuts across the bedding, indicating that one of the colors is a product of later alteration. In many of these cases gray mudstone lies in a zone several inches (several cm) to about 3 ft (1 m) thick beneath sandstone beds and extends parallel to the irregular and scoured or channelized basal surface of the sandstone bed. In these situations the red-gray color boundary cuts across bedding in the mudstone and the gray color of the mudstone is related to bleaching caused by fluids within the sandstone. Chemical analyses from the same laminae on either side of the red-gray color boundary indicate that the bleaching results in an overall loss of iron from the mudstone. Organic carbon may be higher or lower in the gray mudstone as compared with red mudstone in the same laminae, and it is tentatively concluded from this relationship that leaching of iron from these mudstone beds was not caused directly by organic matter dissolved in the fluids.

There are four main types of mudstone in the Salt Wash Member and Tidwell unit. These are (1) red mudstone that is either calcareous or noncalcareous and does not swell appreciably when moistened, (2) gray mudstone that also may be calcareous or noncalcareous and does not swell appreciably when moistened, (3) Botryococcus-bearing mudstone that commonly is calcareous, does not swell appreciably when moistened, and contains visible carbonized plant fragments, and (4) favorable gray mudstone that generally is not calcareous but does contain significant quantities of swelling clays and also contains minute carbonized plant fragments. The favorable gray mudstone is referred to as such because it is intimately associated with uranium-bearing sandstone beds and because the presence of this lithology is a favorable indication of nearby ore deposits.

Chemical analyses indicate that red mudstone and gray mudstone lacking plant debris contain little organic carbon. As shown in the accompanying table, these lithologies average 0.25-0.27 percent organic carbon whereas Botryococcus-bearing mudstone and favorable gray mudstone contain an average of 0.78 and 0.58 percent organic carbon, respectively.

Mean	Range	Number of Samples	Mudstone type
0.78	0.35-1.22	8	Botryococcus-bearing
0.58	0.03-2.88	39	Favorable gray
0.27	0.09-0.36	15	Red
0.25	0.03-0.39	4	Gray

The two different types of gray mudstone containing carbonized plant fragments can be distinguished readily in most cases because the favorable mudstone generally is bentonitic and swells readily, whereas Botryococcus-bearing mudstone lacks or only contains small quantities of swelling clays. In addition, carbonized plant fragments in favorable gray mudstone strata generally require a 10X hand lens to see and are too small to be identified with the naked eye, being about 0.5 mm (1/50 in.) or less in length. In contrast, plant fragments in Botryococcus-bearing mudstone commonly can be seen and identified with the naked eye, being as much as 25 mm (1 in.) long. Other features that serve to distinguish these mudstones are discussed in Peterson (1980) and Peterson and Turner-Peterson (1980). The presence of carbonized plant debris indicates that these mudstones could not have been red or oxidized at any time in their history and that the gray color is their original color rather than an alteration phenomenon.

The Salt Wash has been informally divided into several parts by various workers. Many geologists refer to the more conspicuous and cliff-forming sandstone beds as rims and the member is often thought of as containing three rims, each composed of about 1-4 sandstone beds (Fig. 3). The lower and upper rims are fairly continuous but sandstone beds in the middle rim generally are lenticular and not as continuous as those in the lower and upper rims. By far, the majority of the uranium deposits in the quadrangle are in the upper rim which has been well explored by drilling in many areas. The lower rim contains few ore deposits. The lower rim appears to offer considerable promise as a relatively unexplored potentially uraniferous unit in the quadrangle. Sandstone beds in the middle rim are difficult to assess but appear to have little potential for containing significant uranium deposits, although the presence of scarce radioactivity anomalies some of these beds suggests that it could be more productive than it has thus far proven to be.

The Salt Wash interfingers with the underlying Tidwell unit and with the overlying Brushy Basin Member, and there is no evidence that either contact is an unconformity. Scouring commonly occurs at the base of fluvial sandstone beds and this has led some workers to conclude that the lower contact of the Salt Wash is an unconformity. In many places it can be demonstrated that the lowest sandstone bed of the member pinches out into red mudstone beds of the Tidwell unit and there is no evidence of continuity of the basal surface of the sandstone bed through the mudstone as would be expected if that surface was an unconformity.

Depositional Facies

The Salt Wash Member and Tidwell unit contain rocks deposited in several environments that are considered different depositional facies. Although exceptions exist, a general sequence of these facies progresses from high on the alluvial plain and closer to the source region, to the distal part of the alluvial plain and into a lacustrine environment that lay relatively farther from the source region. These facies and their major lithologies are described briefly in succeeding paragraphs; an expanded discussion about them can be found in a report by Peterson (1980).

Alluvial-plain facies. This facies consists largely of crossbedded sandstone beds deposited by braided and meandering streams, and it also contains smaller quantities of red and gray mudstone strata deposited between the major stream courses in an overbank flood-plain environment. Uranium deposits in the Cortez Quadrangle commonly occur in fluvial sandstone beds that are closely associated with favorable gray mudstone beds.

Marginal lacustrine and deltaic facies. This facies consists largely of horizontally laminated sandstone beds deposited at or near the shoreline of shallow lakes on deltas and beaches or in shallow-water lacustrine environments. Because of similar lithologic features, rocks deposited in these environments are not readily distinguished from each other. The marginal lacustrine and deltaic facies differs from the nearshore lacustrine and mudflat facies by containing more sandstone and less mudstone. The marginal lacustrine and deltaic facies was deposited at or near the shoreline during high-water stages of the lakes whereas the nearshore lacustrine and mudflat facies was deposited farther offshore during high-water stages or on extensive mudflats during low-water stages of the lakes. Some of the uranium deposits in the quadrangle occur in sandstone beds included in this facies where favorable gray mudstone beds are nearby.

Nearshore lacustrine and mudflat facies. Red mudstone beds interbedded with smaller quantities of thin sandstone and gray mudstone beds are included in this facies. Desiccation cracks about 2.5 to 7.5 cm (1-3 in.) deep in some of these beds indicate subaerial exposure on mudflats at low-water stages of the lakes. Also included in this facies are sublacustrine bars and distributary-channel sandstone beds. No uranium deposits have been found in this facies.

Offshore lacustrine facies. This facies is divided into the following three subfacies: (1) calcareous mudstone that is noncarbonaceous but contains thin limestone beds, (2) Botryococcus-bearing carbonaceous mudstone, and (3) favorable gray mudstone that is also carbonaceous but lacks the lacustrine alga Botryococcus. The first two types are found in offshore parts of lakes that were present during deposition of the Tidwell unit, whereas favorable mudstone beds were deposited in small lakes or ponds that formed in the Salt Wash part of the lower sequence.

Calcareous mudstone beds deposited in offshore lacustrine environments consist of laminated to very thin bedded or structureless, gray to greenish-gray mudstone that is moderately to highly calcareous and that lacks or only contains small amounts of swelling clays. Although fossils are scarce, a small suite of ostracodes and charophytes was recovered from the Tidwell unit of the Henry Basin of south-central Utah and near Uravan, Colorado. Ostracodes and charophytes identified by R. M. Forester (in Peterson, 1980) suggest a shallow fresh-water lake or pond environment. Thin gray algal limestone beds as much as a 30 cm (1 ft) thick occur interbedded with calcareous mudstone in many places. Carbonaceous plant debris was not found in these beds. Small desiccation cracks 2.5-7.5 cm (1-3 in.) deep in some of these beds indicate that the lakes dried up intermittently. No uranium deposits have been found in beds of this subfacies.

The Botryococcus-mudstone subfacies is dark gray to gray or grayish green, finely laminated to very thin bedded, moderately to highly calcareous, and lacks or contains only small quantities of swelling clays. Thus far this mudstone has only been found at the top of the Tidwell unit near the town of Uravan, Colorado, and in the Henry Basin about 65 km (40 mi) west of the quadrangle. The Tidwell is poorly exposed in the Cortez Quadrangle and this lithology may be more common than presently known. Botryococcus-mudstone beds grade laterally into beds of the calcareous mudstone subfacies. Fossils in this subfacies include carbonized plant fragments as much as several centimeters long and palynomorphs including the alga Botryococcus, an excellent indicator of lacustrine environments (R. H. Tschudy, oral commun., 1978). Small desiccation cracks 2.5 to 7.5 cm 1-3 in.) deep are also present and indicate brief periods of subaerial exposure.

The presence of Botryococcus and carbonized plant materials indicate reducing lacustrine environments where conditions in the bottom muds were conducive to preservation of palynomorphs and carbonization of plant debris. Preservation of the plant fossils in these beds contrasts markedly with the red and gray mudstone or calcareous gray mudstone deposited in overbank, mudflat, nearshore, and offshore lacustrine environments where oxidation or other processes evidently destroyed any organic matter that may have been originally present in these rocks. This indicates that plant materials could be preserved in at least some parts of the lacustrine environment. In the Henry Basin where this subfacies has been studied more thoroughly, *Botryococcus*-bearing mudstone beds tend to occur in synclines. Evidently active subsidence in these areas during deposition produced conditions favorable for depletion of oxygen in the bottom muds and for preservation of plant materials. *Botryococcus*-bearing mudstone strata are neither uraniferous nor related spatially to uranium deposits, even though the mudstone and associated sandstone beds may contain abundant carbonized plant matter.

Favorable mudstone beds often contain appreciable quantities of swelling clays and are dark gray to gray or greenish gray, finely laminated to very thin bedded, and slightly calcareous to noncalcareous. They are closely associated with fluvial or marginal lacustrine and deltaic sandstone beds, generally lying directly above or below them or a short lateral distance from them. Microscopic fossils found in these mudstones include a varied palynomorph suite notably lacking *Botryococcus*. Megascopic fossils and trace fossils are rare and include fern pinnules, small carbonized twigs, comminuted bits of carbonized plant debris, and small smooth-sided horizontal burrows.

Thin beds of gray to brown, very fine to fine-grained sandstone as much as 0.6 m (2 ft) thick commonly are interbedded with these mudstones. Fine laminations, very thin bedding, or ripple cross-laminations in these beds indicate deposition by gentle currents. Sandstone-filled mudcracks also occur in favorable mudstone beds and indicate brief periods of desiccation when the lakes in which they were deposited were temporarily dry.

None of the fossils from these beds is diagnostic of a lacustrine depositional environment, although it is a reasonable inference and their preservation strongly suggests it. Fossils such as palynomorphs and carbonized plant fragments are not preserved in mudstone beds deposited in the well oxygenated overbank flood-plain, nearshore lacustrine, or mudflat environments although these fossils may have been originally deposited with these beds. It would seem unlikely, therefore, that the favorable mudstone beds were deposited in those environments. On the other hand, the presence of palynomorphs and carbonized plant debris indicates oxygen-deficient conditions were present and, by comparison with the *Botryococcus*-bearing mudstone beds, these conditions most likely existed at the bottom of lakes. A more detailed description of this mudstone and the features that serve to distinguish it from *Botryococcus*-bearing mudstone is given in Peterson (1980).

Uranium rarely occurs concentrated in favorable gray mudstone strata but it is often found in ore-grade quantities in sandstone beds lying adjacent to this lithology.

Eolian Facies. Eolian sandstone beds are scarce and thus far were only found in the lower rim of the Salt Wash in the canyon of the San Miguel River about 16 km (10 mi) southeast of Norwood and northwest of Bluff, Utah. Uranium concentrations have not been found in this facies.

Paleotectonics

The central and eastern parts of the Cortez Quadrangle includes the Paradox Basin, which lies between the Monument uplift along the west edge of the quadrangle and the Uncompahgre uplift several km (several mi) east of the quadrangle. The Paradox Basin is known to have started subsiding as a structural downwarp at least as far back as Pennsylvanian time when considerable thicknesses of salt were deposited in it. Subsequent upward movement of the salt occurred along northwest-trending lines of structural weakness in basement rocks, producing several northwest-trending anticlinal zones for which the region is geologically famous. The Paradox Basin and the salt anticlines within it were active tectonic features during deposition of the Morrison Formation, and influenced Morrison sedimentation patterns in the quadrangle (Shaw and others, 1968; Cater, 1970; Butler and Fischer, 1978).

Regional Deposition

Since the work of Lupton (1914) a concept of Salt Wash deposition gradually evolved that suggests this member was deposited by braided streams on a broad alluvial fan which covered most of the central and southwestern parts of the present-day Colorado Plateau. The thicker and most proximal part of the fan lay in south-central Utah, and the streams that deposited the fan flowed from source regions farther southwest and rapidly covered southern Utah (Craig and others, 1955; Mullens and Freeman, 1957). Although many facets of this hypothesis are still believed to be valid, recent studies indicate that the Salt Wash consists of coalescing alluvial-plain complexes deposited in an arid to semi-arid climate. Deposition was by streams that gradually advanced across the Colorado Plateau from multiple source regions that lay to the southwest and west (Peterson, 1980).

Uranium Deposits

Most of the uranium ore deposits in the Salt Wash of the Cortez Quadrangle are in the upper rim of that member. The lower rim contains significantly fewer deposits and ore deposits are scarce in sandstone beds of the middle rim.

The relationship of ore deposits to the various lithologies has been summarized well by Stokes (1952) for the Thompson district farther north, but his description applies equally to the Salt Wash throughout the Cortez Quadrangle:

> "In general, the thicker, more continuous sandstone lenses are more likely to contain uranium-vanadium deposits than are the discontinuous ones.. Mudstone is barren except where it occurs as thin partings or lenses within the sandstones, or lies at contacts of mineralized sandstones or in the form of rounded pellets, which may be more or less widely scattered or in local thin conglomerates.

> Fine-grained sandstones, siltstones, and limestones are rarely mineralized in the Morrison formation but sandstone with calcareous cement is apparently not unfavorable for mineralization. Most of the ore is contained in medium- and coarse-grained sandstone... Ore does not appear to have been confined to sandstone with any particular type of bedding or original sedimentary structures...

There are four types of ore deposits in the Salt Wash Member, (1) tabular, (2) roll, (3) log replacement, and (4) trash pocket. These have been described briefly by several authors as indicated in the following discussion:

> "The flat-lying tabular deposits may occur as single layers as much as 3 feet thick, or as several thinner superposed layers separated by barren sandstone. Locally several layers join and form a composite layer as much as 12 feet thick. These layers generally are thicker in some places and thinner in others in conformation with bedding planes inherent in the sandstone lenses or with surfaces of mudstone layers separating sandstone lenses. The layered deposits are extremely varied in size. They range from isolated ore bodies covering a few tens of square feet and containing a few tons of ore to clusters of ore bodies that are generally interconnected by thin layers of weakly mineralized sandstone or mudstone; these ore bodies cover areas as much as 600 feet long and 300 feet wide and contain as much as 20,000 tons of ore. Where these bodies occur in closely spaced clusters, from 10,000 to 50,000 tons of ore can be produced from a single mine. The orientation and indicated or inferred limits of these deposits...parallel the average direction of roll axes and trends of sedimentary structures." (Carter and Gualtieri, 1965)

The tabular ore bodies are as much as 20 ft (6 m) thick and average about 3 ft (1 m) thick according to measurements in mines, outcrops, and in drill holes (Shawe and others, 1959; Carter and Gualtieri, 1965).

> "Rolls are layered ore bodies of a great variety of forms that curve sharply across the sandstone bedding. They most commonly display rough C and S shapes in cross section, usually with some irregularity in the limbs. Many rolls are C-shaped but the C is turned on its side and the outside roll surface is either convex upward or downward. Less abundant are the more complex 'socket' and 'mirror-image' rolls described by Shawe (1956). In plan, the rolls are elongate or linear bodies which may be straight but more commonly are curved to some degree." (Carter and Gualtieri, 1965)
>
> "Typically, the curving plane or roll surface is crescent or C-shaped in cross-sections normal to the long axis. Cross-sections of S-shape are also common, and the variations may be visualized as the progressive stages in the deformation of the letter S from the normal upright position to a straight line, provided that the top and base of the letter are straight and remain essentially parallel." (Stokes, 1952)
>
> "Roll ore bodies in Slick Rock uranium-vanadium deposits range from

several inches to more than 5 feet wide, a foot or so to more than 15 feet high, several feet to several hundreds of feet long, and contain a few tons to a few thousands of tons of ore. They commonly are near and parallel to the edges of, and within, elongate sandstone lenses, and are oriented with the concave side of the roll toward the center of the lens." (Shawe and others, 1959)

"Log replacement and trash-pocket ore bodies are considerably smaller but of higher grade than other ore bodies. Logs contain very high grade material and are as much as 30 feet long and 1 to 2 feet in diameter."

The trash pockets are podlike accumulations of poorly sorted sandstone, fragments of carbonaceous matter, and mudstone or clay galls that are partly impregnated with, and in part replaced by, uranium and vanadium minerals. These pockets are rarely more than a few feet long, are a foot or two thick, and are of various shapes. Some pockets are circular in plan and appear to represent accumulations deposited by small whirlpools or eddies in Salt Wash streams; others are elongate and fill minor channel scours. The direction of elongation of such bodies generally agrees with directions determined by cross-stratification measurements in subjacent sandstone beds." (Carter and Gualtieri, 1965).

Huff and Lesure (1965) recognized that the ore deposits commonly are zoned according to differences in color, uranium content, and the amount of vanadium contained in each.

"Many of the ore deposits in the Montezuma Canyon area have three distinct zones called here the ore zone, the brown zone, and the gray zone. The ore zone is the olive-gray sandstone impregnated with uranium-vanadium minerals, just described. The brown zone is an iron-stained porous sandstone commonly containing abundant carbonaceous material or abundant plant fragments. The gray zone is a light-gray sandstone tightly cemented with carbonate and commonly freckled with limonitic specks. These zones are most easily recognized in deposits that range from 10 to 20 feet in length.

In homogeneous well-sorted sandstone the ore zone typically is a continuous smoothly curved rounded or ellipsoidal layer or "shell," that completely envelops the brown zone and is in turn completely enveloped by the gray zone... The rounded ends or sides of the ore zone form the characteristic ore rolls that have been described elsewhere on the Colorado Plateau... Mudstone layers, logs, and concentrations of organic cebris create local irregularities in the shape of the ore zone. The ore layer commonly is from 1/4 to 2 feet thick. It is thinnest at the top or bottom of the shell and is particularly thin where close to a mudstone bed. It is thickest where it forms the side or margin of the ore shell. The boundary between the ore zone and the iner brown zone is sharp, but the boundary between the ore zone and the outer gray zone is gradational.

Samples of the ore zone, the brown zone, and the gry zone were collected from 13 typical mines. Analyses of samples of the ore zone from these 13 deposits ranged from 0.001 to 1.54 percent U_3O_8 and from 0.5 to 7.35 percent V_2O_5.

The brown zone, which is inside the ore layer or shell, is a limonite-stained porous sandstone, ranging from grayish orange to moderate brown depending on the iron content. Most of the quartz sand grains in the brown zone are etched or corroded; some have discontinuous authigenic quartz overgrowths. In most of the deposits the carboante content of the brown zone is very low. The brown zone commonly has a high organic content consisting of carbonized plants or many iron-stained molds of tiny plant fragments. Chemical analyses of samples of the brown zone from the 13 deposits indicate a range in U_3O_8 content of 0.001 to 0.024 percent and in V_2O_5 content of 0.015 to 0.55 percent.

The gray zone, which is outside the ore layer or shell, is a gray sandstone tightly cemented with calcite. It is generally a very light gray or white and characteristically has abundant small limonite spots or freckles. Where the quartz sand grains are in contact, they generally are etched and have sutured grain boundaries; where not in contact many grains have authigenic quartz overgrowths. Calcite, which commonly fills all interstices in the sandstone, locally forms single skeleton crystals 3 to 5 inches in diameter. Carboized plant fragments are present in some of the deposits in the gray zone. The gray zone has a gradational boundary with the ore zone, and grades imperceptibly into the country rock. Chemical analyses of samples of the gray zone from the 13 deposits indicate a range in U_3O_8 content of <0.001 to 0.058 percent and in V_3O_5 content of 0.06 to 0.54 percent.

The three zones can be identified and mapped within many of the uranium-vanadium deposits. At the Lucky Boy mine... the ore shell is a single flattened northwest-trending ellipsoid more than 120 feet long and aboout 40 feet wide. In some of the other large mines, however, the zonal pattern is not as simple. In the Strawberry mine at least four ore shells enclosing separate brown zones locally coalesce forming a complicated intergrowth of zones. Nowhere, however, does one zone occur without the corresponding other two zones. These more complicated patterns may represent overlapping of the zones during mineralization."

Stokes (1952) noted that smaller ore bodies tend to be higher in grade than larger ones in the Thompson district. This generalization appears to be valid elsewhere for Salt Wash ore deposits but it may be more apparent than real because of mining economics and practices. High-grading can be practiced more readily in a small operation whereas economics dictate that this practice cannot ordinarily be followed in large operations.

The concept of an assay wall or abrupt limit to the ore deposits is important and needs to be investigated more, not only for resource assessment but for exploration and development as well. This concept was mentioned briefly by Johnson and Thordarson (1966) in their study of ore deposits in the Chinle Formation (Upper Triassic) and Morrrison Formation in the central part of the Colorado Plateau including the Sage Plains district in the Moab Quadrangle:

> "In general the uranium deposits have rather well-defined limits, and ore-grade material commonly extends to or nearly to the edge of mineralized ground. In some mines or parts of mines the limit of mining is controlled by an assay wall, and in other places mining limits are controlled by a thinning of the ore layer, but generally the ore bodies are not surrounded by large masses of low-grade mineralized rocks. Some deposits of marginal or submarginal grade are known, however, and a few of these may be moderately large..."

Overall, uranium deposits in the Salt Wash tend to be fairly small. Nearly 70 percent of them in the Moab Quadrangle contain less than about 9,000 kg (20,000 lbs) U_3O_8 and 93 percent contain less than about (91,000 kg (200,000 lbs) U_3O_8 (Butler and Fischer, 1978). Similar percentages probably apply to the Cortez Quadrangle. Large deposits are rare and only one or two in the Cortez Quadrangle contain 910,000 to 2,720,000 kg (2-6 million lbs) U_3O_8. The lenticular and discontinuous nature of the orebodies may be partly due to the nature of the original ore-forming processes, but it is undoubtedly enhanced by leaching above the water table and especially in the outcrops.

Uraninite and coffinite have been identified as primary ore minerals coating sand grains and filling pore throats or cells in carbonized plant fragments. It has not yet been determined if some of the uranium occurs as urano-organic complexes disseminated in structured and unstructured carbonaceous matter (carbonized plant debris and materials thought to have been humate, respectively). Although the ore deposits contain mineralized carbon plant fragments, the ore also fills pore spaces in sandstone between the plant fragments, and also occurs in areas where no megascopic structured plant fragments are present. Carnotite and tyuyamunite are the most common secondary ore minerals in the Salt Wash.

The approximate average thickness of ore-bearing sandstone beds in the region is considered to be about 6 m (20 ft), although locally this thickness is about 10 m (30 ft).

The ratio of vanadium to uranium (that is, V_2O_5:U_3O_8) averages 5.5:1 and ranges from 2.5:1 to 7.7:1 in the quadrangle, based on production or other values given by Chenoweth (1975) and Austin and D'Andrea (in Mickle and Mathews (1978). Such relatively large values are often considered to indicate that movement of uranium for considerable distances may not have occurred during redistribution of primary ore bodies that lay above the water table. For this reason, Wyoming-Texas type roll deposits (subclasses 241 and 242) are not considered in evaluating the uranium potential of the Salt Wash Member of the Cortez Quadrangle. Uravan-type roll deposits that are completely enclosed in reduced ground (not classified in Austin and D'Andrea, in Mickle and Mathews, 1978, but best included in subclass 244) have been shown to be closely related to sediment transport directions in the host sandstone beds by Stokes (1952) and Carter and Gualtieri (1965). They are closely related to tabular ore deposits and are considered to have formed by the same ore-forming processes and at essentially the same time by moving ground waters (Shawe, 1956).

There is no evidence to suggest that Uravan-type roll deposits moved considerable distances from their associated tabular deposits and therefore Uravan-type rolls are considered a variation of the peneconcordant tabular uranium deposits that are typical of Salt Wash ore bodies. Available vanadium-uranium ratios for the various districts in the quadrangle are shown below:

7.7:1 Slick Rock South
6.2:1 Cottonwood Wash
2.5 Montezuma Canyon

Welded chert, the limestone concretions in which it occurs, as well as some of the enclosing mudstone strata of the Tidwell unit locally have anomalous concentrations of uranium and have several times background radiation count. However, uranium content in these rocks is low and maximum uranium values determined from samples are 0.033 percent in the mudstone, 0.001 percent in the limestone and 0.010 percent in the chert. The uranium in this zone is not in sufficiently large bodies to meet the minimum requirements for classification as favorable for uranium deposits.

Resource Assessment Guides

Recognition Criteria. Uranium deposits in the Salt Wash Member of the Morrison Formation in the Cortez Quadrangle are best classified as nonchannel-controlled peneconcordant deposits (Subclass 244) according to the classification by Austin and D'Andrea (in Mickle and Mathews, 1978) and Mathews and others (1979), based on their recognition criteria: (1) The tectonic setting for the Morrison Formation was a platform. (2) Adjacent highlands eroded to provide the sediments. (3) The host rock for the deposits is clean quartzose sandstone containing scattered carbonaceous material and is medium to coarse grained; it was deposited on a large, low gradient, "wet" alluvial fan; the host rocks are blanket-like sandstone beds; and the ore occurs in distinct trends that may mark the former position of major drainages. (4) Associated rocks are siltstones and mudstones which provide local permeability control; the mudstones within and above host units may have been derived largely from devitrified and argillized tuffs which may have been a source of uranium. (5) Alteration is indicated by bleaching of host and underlying rock units due to reduction of pigmenting Fe-oxides. (6) Observed primary uranium-bearing minerals are uraninite and coffinite, whereas secondary uranium-bearing minerals are carnotite, and tyuyamunite. (7)

Associated elements are V, Mo, Se, and Pb.

The description of sandstone-type uranium deposits by Austin and D'Andrea (in Mickle and Mathews, 1978) contains an excellent summary of many features relating to Salt Wash ore deposits. However, the accompanying recognition criteria (Mathews and others, 1979, p. 15) are either so vague or so specific that they could not be used to evaluate the uranium potential of any region in which the Salt Wash occurs. The following paragraphs are a discussion of the problems with the recognition criteria; the numbers refer to the specific criteria numbered in the preceding paragraph. To illustrate the lack of applicability of this list, an asterisk (*) follows the numbers of the recognition criteria that apply equally to nonmarine Upper Cretaceous rocks of the Colorado Plateau that are known to contain very little uranium.

(1)* Tectonic setting as a platform: Applies to the entire Morrison Formation.

(2)* Adjacent highlands: Although this is primarily a matter of definition, the "adjacent" highlands were a considerable distance from the site of deposition in the Cortez and adjoining quadrangles. The rock types and fossils in Morrison chert pebbles indicate that the source must have been off the Colorado Plateau and therefore at least 400 km (250 mi) to the southwest and at least 320 km (200 mi) to the west. The best estimate is that the source regions lay about 640 km (400 mi) in these directions. In addition, it is difficult to see how distance from the source region has anything to do with favorability for uranium deposits.

(3a)* Host-rock lithology: By far the majority of Salt Wash sandstone beds are "clean" in the sense of containing little clay matrix, according to detailed petrographic studies by Cadigan (1967). Scattered carbonaceous materials commonly are present in or near the ore deposits, but the same materials also occur in nonuraniferous sandstone strata associated with Botryococcus-bearing mudstone beds.

(3b)* "Wet" alluvial fan: Applies to the entire Salt Wash and equally to many other widespread fluvial deposit in other nonuraniferous formations.

(3c)* Blanket-like sandstone: Applies to many of the sandstone beds in the Salt Wash and other nonuraniferous formations. Ore in distinct trends: In the Salt Wash "individual ore bodies...may or may not be elongate parallel to the sedimentary-structure trend" (McKay, 1955, p. 277).

(4)* Associated siltstones and mudstones provide permeability control: These lithologies occur throughout the Salt Wash and in many other non-uraniferous fluvial sequences. Mudstones may have been derived from tuffs which may have been the source of the uranium: Applies to the entire Salt Wash. It is commonly thought that bentonitic mudstone strata of the Brushy Basin Member of the Morrison were the source of the uranium in the Salt Wash Member. This may well be true for those ore deposits lying directly beneath the Brushy Basin in the uppermost sandstone beds of the Salt Wash. However, it is difficult to apply this concept to ore-bearing sandstone strata that occur at the base of the Salt Wash where uranium-bearing fluids would have had to pass from the Brushy Basin downward through many relatively impermeable mudstone beds. Another consideration is that sandstone beds interbedded with mudstone tend to act as conduits through which fluids pass laterally, not vertically.

(5)* Alteration indicated by bleaching of host and underlying rock units: By far the majority of Salt Wash sandstone beds are white to gray or buff which are the "alteration" colors listed by Austin and D'Andrea (in Mickle and Mathews, 1978). The presence of sandstone lenses having these "alteration" colors and embedded within red mudstone that has a greenish-gray alteration halo surrounding the sandstone lens suggests that the alteration was caused by fluids originally within the sandstone rather than by fluids that seeped into the sandstone at a later time. This also suggests that the "altered" sandstone beds probably never were red. In addition, many of the sandstone beds in the Salt Wash that are well removed from any known ore deposits are bordered by a greenish-gray alteration halo or band in adjacent red mudstone beds. Although the cause of this alteration is not known, alteration resulting in white, gray, or buff sandstone and greenish-gray bands or halos in adjoining mudstone is common to the entire Salt Wash and is not restricted to those parts of the member that contain uranium. McKay (1955) noted that the majority of Salt Wash uranium deposits in the northern part of the Uravan mineral belt occur where altered greenish-gray mudstone directly underlying ore-bearing sandstone is 1.5 m (5 ft) or more thick. Where altered mudstone is thin or missing, ore deposits are scattered, low in grade, or missing. It is not known if some of these altered greenish-gray mudstone beds actually contain unaltered favorable gray mudstone that was overlooked because of the fine size of carbonized plant fragments within them. However, based on the assumption that these mudstone beds are indeed altered from originally red mudstone beds, McKay's (1955) finding suggests either that alteration was more intense near the ore deposits as compared to elsewhere in the Salt Wash where similar but thinner altered mudstone beds occur, or that mudstone alteration associated with the ore deposits was at a different time and by another process. Unfortunately, the detailed studies necessary to determine how the alteration occurred have not been done and, whatever the process or processes involved, the final result is greenish-gray mudstone that appears to be the same throughout the Salt Wash, regardless of whether it is associated or not associated with ore-bearing sandstone beds.

(6) Uranium-bearing minerals: Too specific and cannot be readily used as a guide to whether an area known to contain some uranium may contain significant quantities of that element nearby.

(7) Associated elements: Too specific if the elements are already known to be associated with uranium; too uncertain if uranium is not known to be present. Considerable effort has been devoted to finding pathfinder elements that might be used to indicate where undiscovered uranium deposits could occur. Most of these efforts have been disappointing.

Sand-Shale Ratios. An hypothesis that deals with prediction but not with theories of origin proposes that uranium deposits tend to occur in areas where certain "optimum" sand-shale ratios or sandstone percentages are present. Usually these values are about 1:1 or 50 percent. The "optimum" ratios or percentages are determined from areas where known uranium deposits occur. An evaluation of sandstone percentages elsewhere in the Salt Wash (Peterson, 1980; Peterson and others, 1980) indicates that these values occur throughout such a large region that they must be regarded with suspicion. Another drawback that is an inherent part of this method is that processes related to sandstone and mudstone beds well above and below the ore-bearing bed are considered capable of exerting some sort of influence on mineralization processes in the one or two beds that do contain uranium. The manner in which these unknown processes could influence the ore-bearing process is not even vaguely understood and therefore is not considered usable. For these reasons, then, sand-shale ratios or sandstone percentages are not considered useful in classifying land for potential uranium content in the Salt Wash Member of the Morrison Formation.

Carbonized Plant Debris. Carbonized plant debris (the so-called carbonaceous trash) commonly occurs in the ore deposits, but preservation of this material in certain sandstone strata that also contain uranium appears to be largely a consequence and not necessarily a cause of mineralization. That the plant debris is not concentrated in scours or cutoff channels in the Salt Wash has been demonstrated in many outcrops and mines. Instead, it is scattered about within or near ore-bearing parts of the sandstone bed and is locally concentrated along some of the bedding laminae. Petrified logs are locally present in many of the sandstone beds of the Salt Wash, either within the ore deposits or well removed from them, indicating that plant debris was originally present throughout the sandstone beds but it was only preserved by carbonization in or near the orebodies. Anoxic fluids must have been present in and around the ore bodies in order to allow preservation of the plant matter by carbonization. However, the chemical nature of those fluids is unknown and they could have been any of several different types depending on which theory of origin is applied to the ore deposits. In addition, nonuraniferous sandstone strata containing carbonized plant debris are associated with *Botryococcus*-bearing mudstone strata that lack evidence of having once contained uranium. This suggests (1) that anoxic conditions necessary for carbonization can occur in other places than within ore-bearing sandstone beds, (2) that uranium concentration is not necessarily caused by the plant debris (although it may be enhanced by the plant matter), and (3) that fluids with different chemical characteristics, some of which are capable of fixing uranium and some of which are not, may be conducive to carbonization of plant materials. For these reasons, preservation of plant debris by carbonization is viewed as a subsidiary process that occurred soon after depositiona and probably along with the primary mineralizing process. As far as resource assessment guides are concerned, the location of carbonized plant debris in sandstone beds cannot be predicted from sedimentologic criteria related to depositional processes of fluvial sandstone beds, and sandstone strata containing this material must be further evaluated for the presence of nearby beds of favorable gray mudstone or unfavorable _Botryococcus_-bearing mudstone.

Theories of origin as ore guides. Several theories have been proposed to explain the origin of uranium ore deposits in the Salt Wash Member. The most commonly mentioned ones are the following: (1) Fluid interface theory in which any one of several types of fluids capable of reducing uranium is assumed to be locally present in the sandstone bed and uranium is introduced by actively moving ground water; the reducing fluid precipitates uranium along a horizontal interface, producing a tabular orebody. (2) Hydrogen sulfide theory in which H_2S is thought to be generated by anaerobic bacteria living on plant matter incorporated in the sandstone bed, or else H_2S is thought to be derived from deeper formations and migrates upward through fault zones and into the ore-bearing sandstone bed; the H_2S-bearing fluid then reduces uranium carried into the bed by ground water. (3) Trash pile theory in which abundant plant debris is thought to accumulate in pockets in sandstone beds and later adsorbs or precipitates uranium carried in by ground water. (4) Shallow water-table theory in which a shallow water-table is thought to occur in the distal part of an alluvial fan and plant debris incorporated in sandstone that is below the water table is preserved, whereas plant matter incorporated in sandstone that is above the water-table is destroyed by oxidation and other degradation processes; the plant matter or H_2S produced by anaerobic bacteria in sandstone beds below the water-table then reduce uranium carried into the sandstone stratum by moving ground water. (5) Lacustrine-humate model in which solubilized humic and fulvic acids in the bottom muds of small lakes are thought to be expelled by seepage or compaction into adjacent sandstone beds where they are fixed as a tabular humate body; uranium carried into the sandstone bed by ground water is then fixed by adsorption or other processes in the humate body.

Each of these theories have strong and weak points, but the first three listed above do not lend themselves to predicting the location of ground favorable for undiscovered uranium deposits whereas the last two theories cited above do have the capability of prediction. Thus, a combination of the lacustrine-humate model and the shallow water-table theory appear to be most applicable to the Salt Wash in the Cortez Quadrangle.

Resource Evaluation Criteria. For purposes of discussion it is convenient to refer to the long arcuate trend of uranium mining districts in southeastern Utah and southwestern Colorado as the greater Uravan mineral belt (Fig. 4). The belt includes the following districts progressing around from its northwest end: Tidwell (SalinaQuadrangle); Thompson, West Gateway, East Gateway, La Sal, Martin Mesa, Uravan, Bull Canyon, Slick Rock North, and Sage Plains North (Moab Quadrangle); Slick Rock South, Montezuma Canyon, and Cottonwood Wash (Cortez Quadrangle). The boundaries between the various districts were largely determined by historical precedent or for convenience at quadrangle boundaries.

The greater Uravan mineral belt is concave to the west and is interpreted as the distal facies of an alluvial fan complex by Shawe (1962) and succeeding workers (Fig. 5). North, east, and southeast from the distal alluvial fan facies Salt Wash sandstone beds become "more thinly and evenly bedded and more fine-grained, as if they accumulated under conditions of standing water" (Fischer, 1974). These thinly and evenly bedded sandstone beds are included in the marginal lacustrine and deltaic facies (or marginal lacustrine and minor fluvial facies) described earlier in this report. The distal alluvial-fan facies also would have had a shallow water table owing to proximity to widespread lacustrine environments farther north, east, and southeast (Butler and Fischer, 1978). This would have been conducive to preservation of plant debris by carbonization in fluvial sandstones and formation of small shallow scattered lakes and ponds suitable for deposition of favorable gray mudstones in active synclines, abandoned fluvial channels, and interfluvial flood basins.

The location of the greater Uravan mineral belt in the distal alluvial fan facies characterized by low energy streams is similar to relationships in the Henry Mountains mineral belt farther west (Peterson and others, 1980). This suggests that the five evaluation criteria developed and used there to evaluate the uranium potential of the Salt Wash Member can also be used in the greater Uravan mineral belt.

From the standpoint of resource assessment, a helpful feature related to the ore deposits in the greater Uravan mineral belt is that they are closely associated with favorable gray lacustrine mudstone strata in many places. A close spatial association of favorable gray lacustrine mudstone and ore-bearing sandstone has also been shown stratigraphically and geographically in south-central Utah (Peterson, 1980) and was an important feature used in evaluating the uranium resource potential in the Escalante Quadrangle (Peterson and others, 1980). An important corollary also demonstrated in that report is that favorable mudstone beds have not been found outside uranium-bearing areas.

Favorable gray lacustrine mudstones have also been found in the greater Uravan mineral belt in the following districts: Tidwell (Salina Quadrangle); Thompson, East Gateway, Uravan, La Sal, and Slick Rock North (Moab Quadrangle); Slick Rock South Montezuma Canyon, and Cottonwood Wash (Cortez Quadrangle). In addition, geologists with private companies working in the

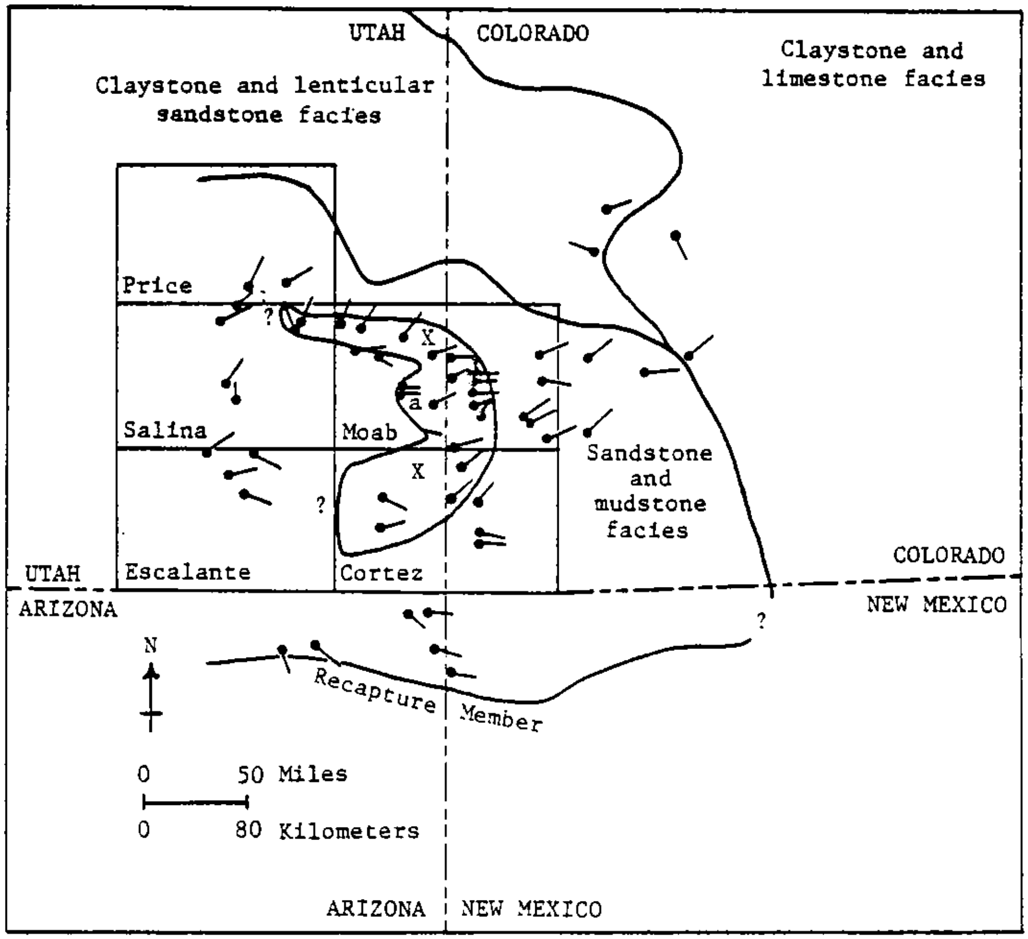

Figure 4.--Map of middle part of Colorado Plateau showing lithofacies in the Salt Wash Member of the Morrison Formation (modified from Craig and others, 1955). Dots indicate points of measurement and lines extend from dots in direction of crossbedding dip vector resultants. Five quadrangles under evaluation by the NURE program are also indicated. X = interpreted distal alluvial plain depositional facies from Figure 5. that also includes lenticular favorable gray mudstone beds and numerous uranium deposits in the Salt Wash Member. a = location of measured section in Figure 3.

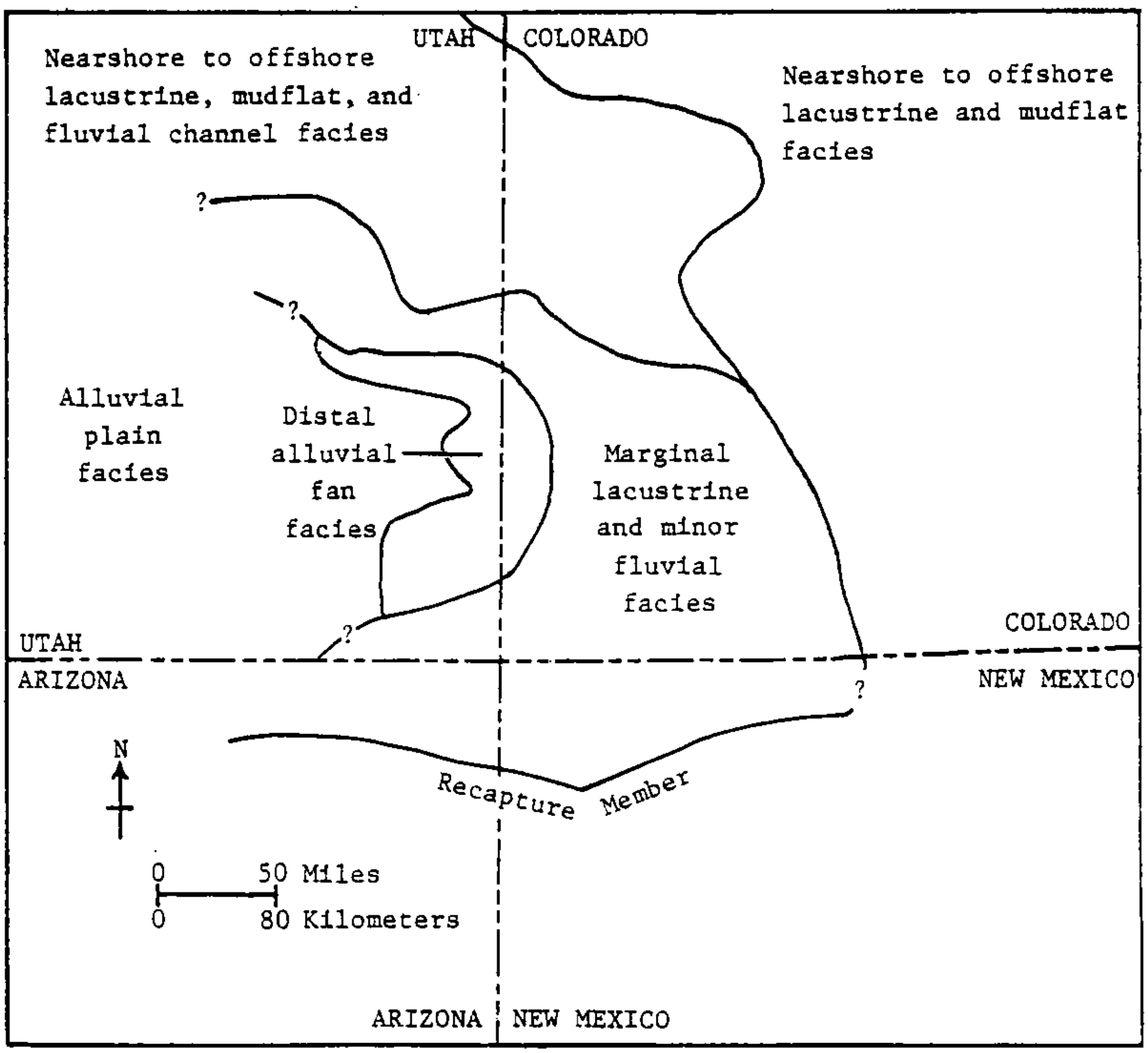

Figure 5.--Map of middle part of Colorado Plateau showing interpreted depositional facies in the Salt Wash Member of the Morrison Formation. Modified from Craig and others (1955) and Shawe (1962)

region also reported that the mudstones occur in many places in the mineral belt.

The close association of ore-bearing sandstone and favorable gray mudstone suggests that techniques which can predict the location of these mudstone beds may also predict, in a broad way, the location of ore deposits in nearby sandstone beds. The techniques that may accomplish this goal were developed in south-central Utah and involve an evaluation of the sedimentologic and paleotectonic history of the region. Unfortunately, some of the detailed sedimentologic studies that are needed for a thorough evaluation of the Cortez Quadrangle using these techniques have not been made. However, an adequate amount of information is available to give a reasonable evaluation of the uranium potential of the quadrangle.

An important factor that apparently contributed to the formation of lakes in certain parts of the Paradox Basin where favorable gray mudstones were deposited is the lower energy regime of streams in the distal part of the alluvial complex that lay in area. A rough approximation of stream energy can be obtained from stratification ratios in fluvial sandstones. Stratification ratios in braided-stream sandstone beds range from zero to one and tend to be high in the downstream as well as lateral parts of alluvial deposits in south-central Utah (Peterson, 1980; Peterson and others, 1980, Fig. 7). A downstream increase in stratification ratios has been found in the present-day Platte-South Platte River system and in Silurian, Jurassic, and Cretaceous fluvial systems (Smith, 1970; Gilbert and Asquith, 1976; Peterson, 1980). By comparison with these ancient and modern fluvial systems, high stratification ratios averaging 0.61 and ranging from 0.44 to 0.86 in Salt Wash braided-stream sandstone beds in the greater Uravan mineral belt (Fig. 3) suggest relatively low-energy regimes where the rate of sediment transport by streams was reduced and the possibility of ponding in actively downwarped areas was increased. The lack of favorable gray mudstone beds in the proximal facies of the Salt Wash alluvial-plain complex apparently resulted from the inability of growing structures to pond the higher energy streams that were present in most of that region.

An indication that ponding occurred in actively subsiding synclines during deposition of the Salt Wash in south-central Utah was shown by Peterson (1980, Figs. 13-15). The belts or patches containing favorable gray lacustrine mudstone in that region coincide with several synclines, and the conclusion from this relationship is that active synclines played a contributing role in determining where the lakes formed, especially where fluvial energy regions were low.

The relationship of stream transport directions to the trend of folds also appears to have played a partial role in determining if and where the lakes would form. Crossbedding studies indicate that Salt Wash streams flowed nearly at right angles to the trend of folds in south-central Utah (Peterson, 1980). In this setting, the anticlines appear to have acted as slight barriers to sedimentation and retarded stream flow into the next syncline downstream for a sufficient length of time to allow small lakes or ponds to form in those synclines. Similar relationships occurred during deposition of the Salt Wash in many parts of the greater Uravan mineral belt. Owing to the predominant northwest trend of most of the folds in the region, Salt Wash streams flowed more or less at right angles to folds in the northern half of the mineral belt but apparently flowed directly down the axes of some of the synclines in the southern half of the mineral belt. However, even in the southern part of the region the streams were deflected by growing folds (Johnson and Thordarson, 1966). In addition, Salt Wash streams moved east to northeast across the Cottonwood Wash and Montezuma Canyon districts and nearly perpendicular to the Monument uplift which is known to have been active during Late Jurassic time (Huff and Lesure, 1965; Johnson and Thordarson, 1966; Peterson, 1980). Interpretation of depositional patterns in the Salt Wash by Young (1978) suggests that folds throughout the region were actively moving during deposition of the Salt Wash and influenced the course of paleostream pathways.

It has often been assumed that paleostream pathways can be determined from percent-sandstone maps in which the streams are interpreted to have flowed most of the time through areas where sandstone percentages are highest. This interpretation could not be supported by evidence from the Salt Wash in south-central Utah (Peterson, 1980). For this reason, maps of sandstone percentages were not used in attempting to determine paleostream pathways in the Cortez Quadrangle. More reliable crossbedding studies by previous workers (Craig and others, 1955) indicate the streams flowed generally eastward down the Salt Wash alluvial-fan complex and radiated outward from the apex of the fan which was located just north of the western part of the Cortez Quadrangle (Fig. 4).

Thus, three interrelated factors caused ponding that resulted in formation of lakes in which the favorable gray lacustrine mudstone beds were deposited: (1) low fluvial energy regimes, (2) actively moving folds, and (3) orientation of fold axes at large angles to paleostream transport directions. An analysis of the interrelationship of these three factors may result in delineating areas likely to contain favorable gray mudstone strata and, by association, undiscovered uranium deposits. Two additional factors, (4) presence of favorable gray mudstone beds, and (5) presence of uranium deposits associated with the favorable gray mudstone beds, also are helpful but are of limited value in areas where the mudstone beds and associated uranium deposits are not exposed at the surface and where subsurface information is scant or lacking. Classification of land in the Cortez Quadrangle for the potential of containing one or more significant uranium deposits is based primarily on the previously mentioned five criteria because the recognition criteria have not proven useful in this context. For purposes of discussion and land evaluation these five criteria are hereafter referred to as <u>evaluation criteria</u>, as contrasted with DOE recognition criteria discussed earlier.

In the final analysis, present knowledge can only suggest that certain lands appear to be favorable for containing significant undiscovered uranium deposits and that other lands do not appear to be favorable for containing significant uranium deposits. There is no way, presently known, of guaranteeing that land classified as favorable for containing significant uranium deposits by these or any other criteria will contain one or more deposits of at least 0.01 percent U_3O_8 grade and totaling at least 100 m tons (110 short tons) of U_3O_8 in a minable configuration, or that land classified as unfavorable will not contain uranium deposits exceeding that minimum size, grade, and configuration. In addition, boundaries between favorable and unfavorable ground cannot be considered precisely located and, for the most part, these boundaries should be considered as approximate midpoints of zones several kilometers (of miles) wide. The science of resource prediction and projection simply has not progressed far enough to allow greater precision than this.

Although the five evaluation criteria are part of the lacustrine-humate model of Turner-Peterson (1979) and Peterson and Turner-Peterson (1980), these criteria deal solely with favorable gray mudstone beds and not with the geochemical and hydrologic theory of origin of the ore deposits proposed by that model. Thus, one need not accept the theory of origin proposed in the lacustrine-humate model in order to classify land for its uranium potential. Instead, one need only accept (1) that favorable gray mudstone beds are closely associated with ore deposits in known uraniferous areas, (2) that this association can be used elsewhere, and (3) that prediction of areas favorable for containing undiscovered uranium deposits can be accomplished by predicting areas where favorable gray mudstone strata should occur. By keeping the two concepts of mudstone-uranium association and theory of origin separated, any alternative theory of origin can be used as long as it is compatible with the mudstone-uranium association. Thus, the basic principles described in previous paragraphs and used to classify land for its uranium potential need not be altered if one prefers another theory of origin.

Resource Assessment

The Salt Wash Member of the Morrison Formation was examined throughout the Cortez Quadrangle for the potential of containing one or more significant uranium ore deposits of a total of 100 m tons (110 short tons) U_3O_8 or more, in a minable configuration, and with an average ore grade of at least 0.01 percent U_3O_8. It was found that none of the three areas classified as favorable for containing significant ore deposits has more than 1,520 m (5,000 ft) of overburden (Pl. 1A).

Classification is based primarily on the five evaluation criteria discussed in the previous section and for reasons also given in that section. Only peneconcordant tabular-type ore deposits (Subclass 243) are considered in the evaluation of this quadrangle because Uravan-type roll deposits (Granger and Warren, 1979), which are completely enclosed in reduced ground, do not show evidence of having moved from the tabular ore-bodies, with which they are associated (Shawe, 1956). Wyoming-Texas type roll deposits (Granger and Warren, 1979) have not been found in the quadrangle and, as discussed in a previous sections, need not be considered.

For convenience, all three areas can be considered as one for purposes of classification; the only reason they are distinguished is for ease in resource calculation and for purposes of discussion in preceding sections. The areas are contiguous and, as previously noted, the boundaries were determined by historical precedent.

Areas A-1 to A-3, Greater Uravan mineral belt. These lands include the following areas shown on Plate 1A:

Area A-1, Slick Rock South district
Area A-2, Montezuma Canyon district
Area A-3, Cottonwood Wash district

The greater Uravan mineral belt lies within the distal alluvial-fan facies of the Salt Wash Member that is considered most favorable for the presence of significant uranium deposits. The southeastern, eastern, and northern boundaries are the boundary between the distal alluvial-fan facies and the marginal lacustrine and minor fluvial facies farther east (Fig. 5). The western boundary is the eroded edge of the Salt Wash in the Cortez Quadrangle. As thus defined, the favorable part of the quadrangle contains (1), relatively low fluvial energy regimes, (2), paleofolds that were actively moving during deposition of the member, (3), paleofolds that were oriented at large angles to paleostream transport directions in parts of the region, (4), favorable gray mudstone beds, and (5), uranium deposits associated with the favorable gray mudstone beds. All of the favorable areas have less than 1,520 m (5,000 ft) of overburden.

Parameters of interest in the three favorable areas (Pl. 1A) in the Cortez Quadrangle evaluated for uranium potential in the Salt Wash Member are given in the following table:

Area Code	Area (Km^2)	Depth (m)	Thickness (m)	Volume (Km^3)
A-1	998	0-200	6	5.99
A-2	2,097	0-200	6	12.58
A-3	906	0-200	6	5.44
Total All Areas	4,001	0-200	6	24.01

Other areas. Other than the three favorable areas already discussed, the remaining areas in the quadrangle that are underlain by the Salt Wash Member are considered unfavorable for one or more of the following reasons: (1) the fluvial sandstone beds were deposited by high-energy streams, (2) the areas are not in synclines that were actively subsiding at the time of deposition of the Salt Wash Member, (3) paleostream transport directions tend to be parallel to the paleofolds, (4) favorable gray mudstone beds are not present, and (5) the areas contain either no known uranium occurrences or the uranium that is present is of such low tenor and tonnage that it cannot reasonably be considered as indicating any potential for significant quantities of uranium resources.

Favorable area for uranium deposits in the Recapture Member of the Morrison Formation (Class 240, Subclass 244).

The Recapture Member of the Morrison Formation of late Jurassic age contains small quantities of uranium in the Cortez Quadrangle. Uranium occurs in one area in the west-central part of the quadrangle that is considered favorable for containing moderate to relatively large quantities of additional uranium resources.

The Recapture consists of fine- to medium-grained sandstone beds interbedded with red to gray mudstone. The member contains a variety of lithologies deposited in several depositional environments. The various depositional facies included within the member are: an alluvial plain facies containing braided and meandering stream sandstones and overbank flood plain red and gray mudstones; a marginal lacustrine and deltaic facies consisting of distributary channel sandstones, deltaic sandstones, beach and shallow water sandstones, and minor red or gray mudstones; a nearshore lacustrine and mudflat facies that is composed largely of red mudstones but that also includes gray mudstones and thin sandstones; and an offshore lacustrine facies containing gray mudstones and minor thin sandstones. For a more thorough descrition of the depositional facies in the closely related Salt Wash Member see Peterson (1980).

The uranium deposits in the Recapture Member of the Morrison Formation in the Cortez Quadrangle are classed as nonchannel-controlled peneconcordant deposits (Subclass 244, Austin and D'Andrea, in Mickle and Mathews, 1978) based on the following recognition criteria: 1) the tectonic setting for the Morrison Formation was a platform; 2) the "adjacent" highlands that provided the sediments were at least 400 km (250 mi) to the south; 3) the host rock for the deposits (a) is "clean" quartzose sandstone containing scattered carbonaceous material and is fine- to medium-grained, (b) deposited on a large, low-gradient alluvial plain, and (c) forming blanket-like sandstone bodies; 4) the associated rocks are mudstones and siltstones that provided permeability control; 5) the source of the uranium most likely was tuffaceous material incorporated in the sediments as they were deposited (Waters and Granger, 1953); 6) the hsot sandstone is in a reduced state; 7) the primary uranium minerals are uraninite and coffinite whereas the oxidized minerals are carnotite and tyuyamunite; 8) associated elements are V, Mo, Se, and Pb.

As noted earlier, the recognition criteria have not proven useful for classifying land for uranium potential, and the Recapture meets many of these recognition criteria throughout a large part of the quadrangle. However, in the southern part of the Cottonwood Wash district, within the area that is already classified as favorable for uranium deposits by the Salt Wash Member of the Morrison Formation (Area A-3), the Recapture contains several uranium deposits. It is not known if Recapture uranium deposits in this area are associated with favorable gray mudstones although the member meets one of the other favorable criteria mentioned under the discussion of the Salt Wash Member; that is, deposition in the low-energy distral facies of an alluvial plain facies (Craig and others, 1955).

Parameters of interest in the favorable southern part of Area A-3 in the Cortez Quadrangle evaluated for having uranium potential in the Recapture Member:

Area Code	Area (Km^2)	Depth (m)	Thickness (m)	Volume (Km^3)
A-1	97.	0-200.	6.	0.58

Other areas in the quadrangle underlain by the Recapture Member of the Morrison Formation are considered infavorable because they lack organic matter, the sandstone beds are too thin or lenticular, or they lack uranium occurences.

Favorable Areas for uranium deposits in the Brushy basin Member of the Morrison Formation (Class 240, Subclass 244).

The Brushy Basin Member of the Morrison Formation of Late Jurassic age contains small quantities of uranium in the Cortez Quadrangle. Uranium occurs in one area in the quadrangle that is considered favorable for containing moderate additional quantities of additional uranium resources.

The Brushy Basin consists mainly of red and gray bentonitic mudstone and smaller quantities of fine- to medium-grained sandstone, pebbly sandstone, and conglomeratic sandstone beds. The member contains a variety of lithologies deposited in several depositional environments. The various depositional facies included within the member are: braided and meandering stream sandstones and overbank flood plain red and gray mudstones; a marginal lacustrine and deltaic facies consisting of distributary channel sandstone, deltaic sandstones, beach and shallow water sandstones, and red or gray mudstones; a nearshore lacustrine and mudflat facies that is composed largely of red mudstones but that also includes gray mudstones and thin sandstones; and an offshore lacustrine facies containing gray mudstones and minor thin sandstones. For a more thorough description of the depositional facies in the closely related Salt Wash Member of the Morrison see Peterson (1980).

The uranium deposits in the Brushy Basin Member of the Morrison Formation in the Cortez Quadrangle are classed as nonchannel-controlled peneconcordant deposits (Subclass 244, Austin and D'Andrea, in Mickle and Mathews, 1978) based on the following recognition criteria: 1) the tectonic setting for the Morrison Formation was a platform; 2) the "adjacent" highlands that provided the sediments were at least 400 km (250 mi) to the southwest and west; 3) the hsot rock for the deposits (a) is "clean" quartzose sandstone containing scattered carbonaceous material and is fine- to medium-grained, (b) deposited on a low-gradient alluvial plain, and (c) forming channel-like sandstone bodies; 4) the associated rocks are red and gray mudstoens that provided permeability barriers; 5) the source of the uranium most likely was tuffaceouos material incorporated in the sediments as they were deposited (Waters and Granger, 1953); 6) the host sandstone is in a reduced state; 7) the primary uranium minerals are uraninite and coffiite whereas the oxidized minerals are carnotite and tyuyamunite; 8) associated elements are V, Mo, Se, and Pb.

As noted earlier in this report, the recognition criteria have not proven useful in classifying land for uranium potential, and the Brushy Basin meets many of these recognition criteria throughout a large part of the quadrangle. However, in Area A-4 the member contains several uranium deposits. It is not known if the Brushy Basin uranium deposits in this area are associated with favorable gray mudstone beds of the type described earlier in this report or if other types of favorable gray mudstones, deposited in environments so alkaline that all organic matter in them was solubilized, are present (Peterson and Turner-Peterson, 1980).

Area A-4 (Hatch district). The favorable area includes a fairly large mine for the Brushy Basin but it is doubtful that other deposits of similar size farther east could be mined because of the expense of constructing a long shaft or tunnels through barren ground to get to the orebodies. Also, Brushy Basin uranium deposits are extremely spotty and difficult to predict in the subsurface, owing to the considerable lack of knowledge of this member. Thus, prediction of uranium potential for areas not presently known to contain uranium cannot be made. The southern and eastern boundaries of the favorable area are drawn at 1.6 km (1 mi) behind the outcrop or at the 100 m (300 ft) depth line. The western and northern boundaries are the eroded outcrop edge of the Brushy Basin Member.

Parameters of interest in Area A-4 that is favorable for containing one or more significant uranium deposits in the Brushy Basin Member area:

Area Code	Area	Depth	Thickness	Volume
	(Km^2)	(m)	(m)	(Km^3)
A-4	28	0-100	6	0.17

Other areas in the quadrangle underlain by the Brushy Basin Member of the Morrison Formation are considered unfavorable because they lack organic matter, the sandstone beds are too thin or lenticular, or they lack uranium occurrences.

Recommendations

Improvements in evaluating the uranium potential of the Morrison Formationin the Cortez Quadrangle can best be accomplished by making more detailed sedimentologic, stratigraphic, and paleotectonic studies of the various members of the Morrison Formation in the region. Most workers are of the opinion that mineralization was early and occurred shortly after deposition of the host beds. This suggests that the chemical and hydrologic conditions that were necessary for mineralization to proceed were largely if not entirely governed by the chemical and hydrologic conditions that prevailed at the sites of deposition and were therefore influenced by the nature of the depositional environments. Because movement on growing folds influenced the nature and distribution of the depositional environments, which in turn influenced mineralization, studies of paleotectonics must also be included with studies of stratigraphy and sedimentology.

Specifically, more studies of stream energy as determined from bedding parameters are needed, as are studies of the relationship of paleostream flow paths to growing structures, as determined by crossbedding. Most of the folds are known to have been moving during Morrison deposition but measurement of closely spaced sections could help to indicate which parts of synclines subsided faster, and this could have considerable significance as to where the favorable gray mudstone beds and associated uranium deposits might occur. Although all parts of the Morrison should be examined in detail, the lower rim of the Salt Wash offers the greatest potential for undiscovered uranium deposits and could well become an entirely new exploration zone in a region that has already been well explored but largely for younger strata at the top of the Salt Wash. Preliminary studies suggest that the lower rim was deposited in an alluvial-fan complex similar to that of the upper rim, but the lobate outline of the lower rim appears to have been shifted laterally south several km (several mi) from that of the upper rim and the most favorable parts of the lower rim have been shifted accordingly. Studies outlined above should help to delineate the outline of the distal alluvial-fan facies of the lower rim and allow projection into the subsurface where the most favorable ground in this rim should occur. These studies should also extend into adjoining areas such as the Shiprock and Price Quadrangles where relationships to the five evaluation criteria are, at present, poorly understood

Most of the geochemical studies to date were poorly conceived and yielded little information of value to quadrangle assessment, yet geochemical studies have much to offer if carefully thought out. Most of the ore bodies are above the water table and have suffered a certain degree of leaching that makes interpretations of their geochemistry difficult. Instead of sampling numerous deposits that lie above the water table, only a few carefully selected ore bodies should be examined which lie below the water table and show evidence of never having been leached or otherwise altered. Those ore bodies selected for detailed work should be few in number but should be examined in as great detail as is reasonably possible. These studies must also be accompanied by detailed petrographic, clay-mineral, alteration, and microprobe studies to determine mineral phases, paragenesis, and where the uranium resides. The resulting data cannot help but place considerable constraint on theories of origin. Once this is accomplished, the surviving theories of origin should be tested as completely as possible to enhance their potential for resource evaluation and prediction of areas favorable for undiscovered ore deposits.

Detailed hydrologic studies are needed to determine the movement of underground water, both with respect to flow of fluids during ore formation and with respect to flow of fluids after uplift when the ore deposits are above the water table and subject to leaching.

FAVORABLE AREAS IN THE CHINLE FORMATION, CLASS 240, SUBCLASS 243 (Lupe)

Method for Determining Favorability for Uranium Deposits in the Chinle Formation

The Chinle Formation is favorable for Sandstone-type uranium deposits. Most of these deposits have been classified as Subclass 243, channel-controlled, peneconcordant deposits (Austin and D'Andrea, *in* 1978 Mickle & Mathews, p. 108). The recognition criteria for those deposits include the following: (1) the existence of potential host rocks on the continental platform immediately above an unconformity and within, or near, "channels" incised into relatively impermeable rocks; (2) the potential host rocks are coarse-grained, arkosic to quartzose sandstones and conglomerates with mixtures of siltstone and mudstone that contain carbonaceous material; (3) known deposits in the quadrangle have favorable mineralogy (uranium associated with vanadium, copper, zinc, and lead minerals) and alteration features (oxidized iron and copper minerals); and (4) an adjacent, bentonitic unit (the Petrified Forest Member of the Chinle) that was a potential uranium source rock.

These criteria (except the third one), which relate to aspects of uranium geology on many scales and, have been consolidated into two observable, regionally scaled features in this report. These two features are (1) the distribution of potential host rocks, which is inferred from the distribution of sandstone-to-mudstone ratios, and (2) the distribution of potential uranium source rocks, the Petrified Forest Member of the Chinle.

This consolidation of criteria into two features enhances the ability to predict favorable areas. Favorability can be predicted in areas where the specific recognition criteria of Austin and D'Andrea (*in* Mickel & Mathews, 1978) are not observable, especially in the subsurface. This method closely follows that described by Lupe (1977a, b).

The use of these two features is based on the hypothesis that the primary geologic features that controlled the uranium mineralization resulted from sedimentation of the host rocks. If the sedimentation process is known (that is, if the distribution of depositional products is known), then the distribution of features controlling favorability will also be known. It is important, therefore, to understand the depositional history of the Chinle.

The Chinle Formation was deposited throughout the Colorado Pateau in Late Triassic time in a variety of continental environments. The average formation thickness ranges from 150-1,200 ft (50 to 400 m) and is comprised of six members. In ascending order, these members are the Shinarump, Monitor Butte, Moss Back, Petrified Forest, Owl Rock, and Church Rock. The basal Shinarump is present in the Salina and Escalante Quadrangles but missing in the Price, Moab, and Cortez Quadrangles. This basal unit is composed of sandstone and conglomerate that totals as much as 50 (20 m) thick. It is overlain by the Monitor Butte Member, a thinly-bedded muddy, silty, and sandy unit, 30 to 200 ft. (10 to 60 m) thick. The sandstones and conglomerates of the Moss Back, which may be as much as 120 ft. (40 m) thick, unconformably overly the Monitor Butte. These three lower units, the Shinarump, Monitor Butte, and Moss Back, comprise the ony favorable part of the Chinle and will be discussed in greater detail below.

The remaining units of the Chinle are the Petrified Forest, Owl Rock, and the Church Rode Members. The Petrified Forest is a bentonitic mudstone and siltstone unit that reaches a maximum thickness of 800 ft. (250 m) in Utah. It is conformably overlain by non-bentonitic siltstones and mudstoens of the Owl Rock, which is in turn conformably overlain by the non-bentonitic mudstones and siltstones of the Church Rock.

Deposition of the Chinle began abruptly and energetically after a long period of nondeposition and erosion that lasted most of Middle Triassic time. This period of nondeposition and erosion is marked by an unconformity above the fine-grained relatively impermeable rocks of the Lower Triassic Moenkopi Formation. This unconformity extends throughout the Colorado Plateau and because of the close spatial relationship between uranium deposits and the unconformity, it is possible that the unconformity may have had influence on the mineralization process. High-energy, coarse-grained, fluvial sediments coursed westward from the Ancestral Rockies of Colorado. High-energy deposition did not continue however. As transport energy decreased, a lower energy flow regime produced finer grained fluvial, overbank, and lacustrine deposits. The result of this evolution was a single cycle of Chinle deposition--a vertical sequence of coarse-grained rocks overlain by finer grained rocks. Two more cycles followed. Of the three Chinle cycles, the lower part of the first cycle is where most uranium has been found.

Uranium is associated with the sedimentation process in the following way: when the initial high-energy pulse began in the east, braided streams carrying coarse-grained sediments prograded westward. In advance of these prograding streams, fine-grained sediments were carried toward the sea that existed in Nevada (Silberling and Wallace, 1969). These distal fine-grained sediments were deposited in low energy environments, including lower-energy stream channels, overbank sites, and in lakes. As the prograding, coarse-grained fluvial sediments extended farther west they were deposited over some of these distal, fine-grained sediments. The result was a vertical juxtaposition of fine- and coarse-grained sediments that apparently was critical for uranium mineralization. Lenses of interbedded sandstones, some conglomerates, siltstones, and mudstones that contained abundant carbonaceous material were overlain by regionally extensive, coarse-grained sediments. The carbonaceous material was abundant because plants thrived in these low-energy environments that existed at or near the water table. Burial of this plant material at or below the water table allowed it to be preserved and to serve as potential reductants for dissolved uranium. These lenses of carbonaceous sandstone, siltstone, and mudstone, protected in pockets of impermeable rocks, are favorable host rocks.

Above these favorable host rocks is a regionally extensive, coarser grained rock body that was an aquifer, and therefore, a potential conduit for uranium-bearing solutions. Thus, with a potential conduit above rocks that had the necessary attributes of a favorable host rock, a favorable environment for mineralization existed. This juxtaposition of conduit over potential host rocks did not exist everywhere, however. Streams issuing from the Ancestral Rockies occupied favored corridors as they flowed westward. In some areas the lower part of the Chinle is entirely sandstone and in other areas it is entirely mudstone and siltstone. Moreover, in many places the prograding high-energy fluvial systems eroded previously deposited fine-grained sediments. Only in areas between highest sandstone abundance and highest mudstone abundance did a favorable juxtaposition exist.

Sandstone or mudstone abundance is based on sandstone-to-mudstone ratios for the entire formation. This use of information from the entire formation to imply the lithologic characteristics of only the basal part is justified by a relationship discovered through study of the entire formation. The geographic location of sites of abundant sandstone or mudstone deposition remained the same throughout Chinle time. Distribution of sandstone-to-mudstone ratios for the entire formation therefore reflects those for any part, including the basal, ore-bearing part (Lupe, 1977b).

Plate 7 shows the distribution of sandstone-to-mudstone ratios for the quadrangle. These ratios were interpreted from geophysical data from well logs, which are regionally distributed (Pl. 5A). The ratio distribution generally shows a decrease in sandstone from east to west, away from the source. Furthermore, the location of linear areas of more abundant sandstone, which were the corridors of high energy transport, are generally oriented east-west. Westward, these corridors become less distinct and eventually are no longer present. Favorable areas are areas of intermediate sandstone-to-mudstone ratios Pl. 7. These areas exist off the flanks and beyond the western ends of corridors of higher energy deposition, but not in areas of lowest or highest energy deposition. Not all intermediate zones were considered favorable; factors which preclude some of these intermediate areas from being favorable will be discussed below.

It is important to note the spatial relationship between the distribution of sandstone in the Chinle and the distribution of known uranium deposits. Most significant uranium deposits exist in the areas of intermediate amounts of sandstone adjacent to and beyond the western ends of the corridors. This relationship adds support to the use of sandstone-to-mudstone ratios in predicting the regional location of favorable host rocks in unexplored areas.

An additional important constraint on the distribution of favorable ground is the distibution of uranium source beds. The most obvious potential source rocks are the bentonitic rocks of the Petrified Forest Member of the Chinle (Fig. 2). These rocks exist higher in the formation. The Petrified Forest Member contained abundant rhyolitic tuff (Waters and Granger, 1953). Devitrification of this tuff probably occurred soon after deposition. If processes described for devitrification and dissolution of uranium from other rhyolitic tuffs (Zielinski, 1979) acted on to the Petrified Forest, the uranium would have been available for mobilization by ground water and subsequent precipitation.

The Petrified Forest Member of the Chinle is not present everywhere in the quadrangle.. Its distribution (Stewart, and others, 1972, Pl. 4) is shown on Plate 7. Favorable ground is extended approximately 30 km beyond the extent of the Petrified Forest on this plate beame uranium deposits are present. Ground water probably was responsible for carring uranium laterally to areas beyond the distribution of the Petrified Forest.

<u>Area B-1, Abajo Mountain Area</u>

The Abajo Mountain area is in the northwest corner of the quadrangle, and lies around the laccolithic Abajo Mountains on the northeast flank of the Monument Uplift. Geographically, it is bounded by a line between Morticello, Utah, and Dove Creek, Colorado, on the east; Blanding, Utah, on the south; Elk Ridge and Deer Flats on the west; and the map boundary on the north. In the Moab Quadrangle (Campbell and others, 1980), Area B-1 joins with this area. Deposits predicted for the Chinle in Area B-1 are of Subclass 243, channel-controlled peneconcordant deposits (Austin and D'Andrea <u>in</u> Mickle and Mathews, 1978, p. 108).

Area B-1 is closely related to a corridor in which the deposition of sandstones was more abundant. The area lies off the flanks of this corridor, extending partially into areas of dominantly fine-grained rocks, and beyond the end of this corridor, where the corridor fades out into finer-grained rocks.

Numerous uranium deposits have been found in this area, including those of the Elk Ridge Mining district, which contains the Hideout, King Edward, Notch, and Pay Day mines. The orebodies average 0.25% U_3O_8 and have had ore production ranging from a few tons to more than 15,000 tons (Lewis and Campbell 1965, p. 37). These tabular orebodies are typically in the lowest part of the Chinle, in sandstone, conglomerate, and siltstone beds that are interbedded with mudstones in the so-called mudstone unit of Lewis and Campbell (1965, p. 36). Although ore bodies are tabular, in detail they do vary in shape, locally cutting across bedding and assuming the shape of a roll. These mineralized rocks contain abundant carbonaceous material and some asphalitite, and are dominantly cemented by calcite. Unlike many Chinle deposits elsewhere, however, the host rocks of these deposits are not necessarily confined to "channels" that incised underlying impermeable rocks (Lewis and Campbell, 1965, p. 40).

Metals found associated with uranium are iron, copper, lead, zinc, vanadium, cobalt, and molybdenum. The ore minerals are usually unoxidized with oxidized minerals only found within 30 to 50 m (98-165 ft.) of the surface. The chief unoxidized minerals are uraninite, chalcopyrite, and bornite, with small amounts of galena and sphalerite (Lewis and Campbell, 1965, p. 38).

Area B-1 contains 8.55 km^3 (2.1 mi^3) of favorable host rock, based on an area of 1710 km^2 (660 mi^2) and a typical host rock thickness of five meters (16 ft.).

Except for the usual scattering of state school lands, the federal government owns nearly all land in Area B-1. The bulk of those federal lands is administered by the U.S. National Forest Service in the Manti-La Sal National Forest. The Bureau of Land Management administers lands surrounding the forest; and the U.S. National Park Service administers Natural Bridges National Monument, which lies in the south part of the area. Blanding and Monticello, two towns of significant size for this part of rural Utah, lie in or near Area B-1.

Area B-2, Aneth-Ute Mountain Area

Area B-2, the Aneth-Ute Mountain area, lies in the south-central part of the quadrangle (Pl. 1B) on the extreme northwest flank of the San Juan Basin. It is an elongate area, bounded on the east by Sleeping Ute Mountain and on the west by Aneth Field. McElmo Creek flows westward through the middle of the area, toward the San Juan River. Deposits predicted for the Chinle in Area B-2 are of Subclass 243, channel-controlled peneconcordant deposits, of Austin and D'Andrea (1978, p. 108).

No occurrences or deposits are known in the Chinle in Area B-2. The Chinle in the area is entirely subsurface and has not been subject to intense exploration. However, the Chinle in the area does have favorable characteristics similar to those described earlier. Specifically these favorable characteristics are: the distribution of sandstone abundance as related to a corridor of sediment transport, and the distribution of the Petrified Forest Member as the most likely source for uranium in Chinle deposits (Pl. 7).

Deposits which may exist in the Aneth-Ute Mountain area would most likely have the same characteristics as known deposits in Area B-1.

The Aneth-Ute Mountain area contains 5.83 km^3 (1.4 mi^3) of favorable host rock. This volume is based on a typical host rock thickness of five meters and an area of 1165 km^2 (450 mi^2).

Most land in the Aneth-Ute Mountain area is federally owned, but, a significant portion is also Indian land. The southwestern part of the area is Navajo land and the eastern part is on the Ute Mountain Indian Reservation. The federally owned land is mainly BLM land with a part administered by the National Park Service including Hovenweep and Yucca House National Monuments. The states of Utah and Colorado own scattered school sections. The small, oil-patch town of Aneth lies in area B-2.

FAVORABLE AREAS IN THE CUTLER FORMATION, CLASS 240, SUBCLASS 244 (CAMPBELL)

The lower Permian (Wolfcampian) Cutler Formation contains a number of uranium occurrences, and several mines, within 19 km (12 mi.) of the northern border of the Cortez Quadrangle, at Lisbon Valley, Utah in the Moab Quadrangle (Campbell, and ohters, 1980). A very similar stratigraphic and structural setting to Lisbon Valley exists at several places under the Sage Plain terrace, and at the northern end of the Dolores anticline (Pl. 10) in the Cortez Quadrangle. The Cutler Formation is thus considered favorable for the occurrence of uranium in the Cortez Quadrangle.

The structural setting at Lisbon Valley consists of an anticline produced by salt intrusion. Movement on the anticline occurred during, or just after, deposition of overlying units and thus some units thin or are missing over the structure. The Dolores anticline is a very similar structure over which the Triassic Moenkopi Formation is absent. Other similar structrual settings occur along the northern border of the Cortez Quadrangle.

The Cutler Formation along the northern border of the Cortez Quadrangle consists of similar lithologies, deposited in similar environments to the Cutler at Lisbon Valley (Campbell, and others, 1980). Fluvial arkosic sandstones and shales were deposited in association with marine sandstones, shales, and limestones and some eolian sandstones. Sand-shale ratios for the complete sequence are about 1: 3, to 1: 4 (Campbell and Steele-Mallory, 1979a). The depositional environment of the fluvial portions of the Cutler was a large, low-gradient wet, fluvial fan, (Campbell, 1980). The association with marine units and the sedimentary structure in the arkosic sandstones suggest some are fluvial-distributary in origin (Campbell and Steele-Mallory, 1979a). These fluvial-distributary sandstone are 3-7 m (10-23 ft) thick, are most common in the upper 200 m of the Cutler, and are the most favorable host units for uranium.

The ore in the Culer at Lisbon Valley occurs in tabular zones within somewhat bleached arkosic sandstones. The tabular zones are located at the base, at the top, or close to pinchouts of the sandstone bodies. Tabular zones are as much as 1 m (3 ft) thick. Mineable ore zones are tens of meters wide and as much as several kilometers long. Ore grade drops toward the middle of sandstone bodies.

Uranium ranges from less than 0.05 to 1.0 percent and averages 0.30 percent in these tabular zones (Campbell and Steele-Mallory, 1979b). Vanadium ranges from 0.001 to 0.7 percent and averages 0.17 percent for these deposits. Other elements present include: Ba, Be, Co, Cr, Cu, Ga, La, Mn, Nb, Ni, Pb, Sc, Se, Sr, Y, Yb, and Zr (Campbell and Steele-Mallory, 1979b). Neither organic material or pyrite is common, and no relationship was found between organic carbon and ore. The uranium minerals of these deposits include very little uraninite, coffinite, uranophane, and carnotite. Most of the uranium is associated with iron oxides rather than in discrete uranium minerals (Campbell and Steele-Mallory, 1979b). Host-rock mineralogy includes quartz, feldspar, and biotite with calcite as a cement and some clay and iron oxide as a matrix (Campbell and Steele-Mallory, 1979a).

The variety of depositional environments of the Permian host rocks does not allow these deposits to be placed exclusively in any of the sandstone uranium-deposit classification subclasses listed by Austin and D'Andrea (in Mickle and Mathews, 1979). Many of the sedimentary environments that characterize each of the subclasses are present in the Permian deposits. These deposits are perhaps best clasified as nonchannel-controlled peneconcordant deposits.

Because of the apparent relationship between fluvial-distributary facies, marine facies and uranium occurrences, the distribution of these facies was used to outline areas of favorability based on mapping by Campbell (1979, 1980). Two favorable areas for the Cutler Formation, area C-1 and C-2, are shown on Plate 1-C. The western boundary of favorable area C-1 (Pl. 1-C) occurs at the eastern boundary of the Cedar Mesa Sandstone Member of the Cutler Formation as mapped (Plate 10). The Cedar Mesa is predominantly marine and eolian in origin with minor fluvial sandstones. The eastern boundary of area C-1 is the approximate maximum eastward extent of the marine-fluvial transition facies of the Cedar Mesa interval. Distributary-fluvial channel sequences should be common in this area. The eastern boundary of favorable area C-2 is the eastern edge of the dominantly meandering stream depositional facies of the Cutler. East of that boundary streams that deposited the Cutler were predominantly braided.

The southern boundary of both C-1 and C-2 areas are arbitarly drawn, due to the lack of outcrop and good subsurface data. The meandering stream facies boundary trends to the southeast toward Durango, Colorado and the marine facies boundary trends southwest toward Bluff, Utah. In addition, the fluvial sandstones are becoming finer grained and less numerous in the section toward the southwest. Favorability for Lisbon Valley-like uranium deposits should gradually decrease to the south. Favorable areas C-1 and C-2 extend northward into the Moab Quadrangle (Campbell, and others, 1980).

Area C-1

Area C-1 includes about 932 km^2 (360 mi^2). The average thickness of favorable rock is about 5 m (15 ft.), this area contains about 4.7 km^3 (1.0 mi^3) of favorable ground. The depth to the favorable portion of the Cutler Formation ranges from about 610 to 760 m (2000-2500 ft.). The favorable part of the Cutler in this area is the upper 200 m of the Formation (810-960 m deep). The zone in the range 960 m, to 1,500 m (2,500-5,000 ft), is considered unfavorable.

Area C-1 covers the high plateau area east of Monticello, Utah at the foot of the Abajo Mountains. The land status is predominately privately owned with minor amounts of U.S. Bureau of Land Management or U.S. Forest Service controled land.

Area C-2

Area C-2 includes about 559 km^2. (216 mi^2.). The average thickness of favorable rock is about 5 m (15 ft.) thus area C-2 contains about 2.8 km^3 (0.6 mi^3) of favorable ground. The depth to the favorable portion of the ranges from 0 m in the Dolores river Canyon to 610-760 m (2,000-2,500 ft) on either side of the Canyon. The favorable part of the Cutler in this area is the upper 200 m of the formation (810-960 m deep). The zone in the range 960 m to 1,500 m (2,500-5,000 ft), is considered unfavorable. Area C-2 is cut by the Dolores River Canyon and includes the highland areas on each side of the River. Three U.S. Department of Energy withdrawal areas are included in the northwestern corner and the Dolores River is classed as wild and scenic river (Pl. 12). The remainder is San Juan National Forest, U.S. Bureau of Land Management controlled or private land. The Dominquez-Escalante National Trail passes through portions of both areas (Pl. 12).

Areas in the Entrada Sandstone, Class 240, Subclass 244 (Campbell)

The Jurassic Entrada Sandstone is the host for low grade uranium-vanadium deposits along the east side of the Cortez Quadrangle. Production of vanadium, with uranium as a byproduct, occurred in the Placerville district in the northeast corner of the quadrangle, and in the Graysill district just to the east of the east-central boundary of the quadrangle in the Durango Quadrangle. In addition a large low-grade uranium-vanadium area has been mapped south-east of the La Plata Mountain along the southeastern border of the quadrangle (Haynes and others, 1972, Plate 10).

In the Cortez Quadrangle three units of the Entrada Sandstone are mapped (Pl. 10). The basal unit is the Dewey Bridge Member which consists of reddish-brown flat-bedded locally contorted earthy siltstone and some flat-bedded white sandstone. The middle unit is the Slick Rock Member which consists of white or reddish- or yellowish-orange thick, massive, fine- to medium-grained, crossbedded quartz sandstone. This unit erodes to prominent sounded cliffs. The sedimentary structures present are large sweeping cross-beds interbedded with the horizontal bedded units. The cross-bedding and texture of the sandstone suggests an eolian origin. The upper Moab Sandstone Member consists of white medium-grained crossbedded or flat-bedded well-sorted sandstone. The cross-bedding suggests that this unit is also eolian in origin. All these members are recognized in the west and central parts of the quadrangle but not in the east. All members together range from 21 m (70 ft) to 134 m (440 ft) thick and thin to the east.

In the east and northeastern part of the quadrangle the Entrada Sandstone is a medium- to fine-grained, white, massive, well sorted quartz sandstone. The large sweeping crossbeds interbedded with thin horizontal bedded units suggest an eolian origin. The Entrada ranges from about 11 to 31 m (35-100 ft) thick in this area.

The uranium-vanadium deposits in the Entrada occur as one or more layers or undulant tabular bodies in the upper 9 m (30 ft) of the sandstone. A chromium rich clay layer is commonly a few feet below the ore layers and extends about 1.6 km (1 mile) west of the ore belt (Fisher, 1955). The mineralogy of the ore consists largely of vanadium-bearing clays, such as roscolite and the uranium is present in an unrecognizable mineral form (Fisher, 1955). Minor amounts of the secondary uranium mineral carnotite are sometimes present on the outcrops. Organic material, as well as pyrite, are very rare constituents of the host sandstone or in the ore zones. Ore belts are 1 to 1.5 kilometers (0.6 to 1 mile) wide and about three kilometers (5 miles) long (Fischer, 1968). Ore grade averages about 2% V_2O_5 and about 0.05 to 0.1% U_3O_8. Production from the Placerville area has been about 240,000 tons of vanadium ore from which about 240,000 to 480,000 pounds of U_3O_8 has been recovered as a byproduct (Fischer, 1968).

The origin of the deposits is not understood (Fisher, 1968). They were emplaced after the Entrada Sandstone was deposited but before regional deformation. The geometry of the deposits suggests that they formed under ground-water conditions. The western edge of the ore belt coincides closely with the western edge of the overlying lacustrine Pony Express Limestone Member of the Wanakah Formation, suggesting a geochemical environment associated with the formation of the Pony Express Limestone (Fischer, 1968). The ore layers are generally less than 0.3 m (1 ft.) thick but may range from 0.3 to 6 m (1-2^{o} ft.) thick (Fisher, 1955). These deposits do not fit many aspects of the DOE recognition criteria, or classification scheme (Austin and D'Andrea <u>in</u> Mickle and Mathews, 1978, 1979). They are perhaps best classified as non-channel-controlled penedoncordant deposits, subclass 244.

<u>Area C-3 and C-4</u>

Two areas of favorability for the Entrada are shown on Plate 1-C as areas C-3 and C-4 and are included with the Permian favorable area. The boundaries of these Entrada areas were established by drawing lines around the areas mapped as low-grade deposits by Haynes and others (1972, Plate 10).

Area C-3 is about 10 sq. km in area (4 sq. mi.). The Entrada is about 21 m thick (68 ft.) on the average thus this favorable area contains about 0.21 km^3 (0.05) favorable ground. Area C-4 is about 8 sq. km. (3 sq. mi.) in area and contains about 0.17 km^3 (0.04 mi^3) favorable ground using the same average thickness for the Entrada.

Area C-3 is on the edge of the San Juan Mountains in the Uncompahgre National Forest. Area C-4 is on the east flank of the La Plata Mountains in the San Juan National Forest. Area C-4 is close to a Colroado Division of Wildlife withdrawal area.

ENVIRONMENTS UNFAVORABLE FOR URANIUM DEPOSITS

Unfavorable units are categorized and discussed by depositional environment. These depositional environments include fluvial, marginal-marine, marine, eolian, and lacustrine. All the igneous and metamorphic rocks are considered unfavorable in this quadrangle and are discussed together.

The criteria used in this report to designate units as unfavorable vary; however, the most important are included in the following: (1) lack of occurrences, or radioactive anomalies of quality or quantity; (2) rocks oxidized brown or red; (3) the lack of reductant, particularly organic material; (4) lack of porosity and permeability; (5) unsuitable lithology; and (6) lack of suitable source for uranium. Many of the unfavorable units fit one or more of the DOE recognition criteria for various subclasses of sandstone uranium deposits including tectonic setting, host rock lithology, depositional environment and geometry (Austin and D'Andre in Mickle and Mathews, 1978).

FLUVIAL DEPOSITIONAL ENVIRONMENTS

From oldest to youngest the fluvial formations that are classified as unfavorable are as follows: the fluvial portions of the Pennsylvanian through Permian, Hermosa, Rico and lower parts of the Cutler Formation,including the lower part of the Cutler below the base of the two favorable areas from about 960 to 1,500 m (315 to 5,000 ft); the Triassic Kayenta Formation; the Cretaceous Burro-Canyon, and fluvial parts of the Dakota Sandstone, Mesaverde Group, Fruitland Formation and Kirtland Shale; the Tertiary Animas, Nacimiento, San Jose Formations, Telluride Conglomerate and San Juan Formation.

The Hermosa, Rico and lower Cutler which contain a few scattered uranium occurrences, are composed of arkosic sediment derived from a crystalline source rock. These units are however, commonly oxidized, and generally lack any concentrated reductants. The Kayenta is also oxidized, lacks reductant, and contains very few occurrences or anomalies. The Cretaceous fluvial units contain scattered amounts of organic material that could have served as a reductant but have only a few occurrences, such as in the Memefee Formation of the Mesaverde Group in the southern part of the quadrangle (Pl. 2). The lack of sufficient concentrations of reductant is perhaps the reason for the small number of occurrences in Cretaceous units. The Tertiary units are composed predominantly of volcanic material derived from the San Juan volcanics. These volcanics are largely intermediate to basic in composition and not usually thought of a good source for uranium. These Tertiary units also lack reductants and contain very few known occurrences of uranium.

MARGINAL MARINE ENVIROMENTS

Sediments deposited in, or closely associated with, marginal marine environments are hosts for uranium deposits regionally. Favorable area C-1 (Pl. 1-C) in the Cutler Formation is one example. Similar facies exist in portions of the Pennsylvanian Hermosa and Permo-Pennsylvanian Rico Formations,in the northern and northeastern part of the quadrangle, and in the Cedar Mesa-Cutler marginal-marine facies in the subsurface east of Comb Ridge. These arkosic facies have had very little study but seem to lack sufficient concentrations of organic material which could act as a reductant. No occurrences are present in these rocks in the Cortez Quadrangle.

Additional marginal-marine deposits that are classified as unfavorable include the Triassic Moenkopi and Carmel Formations, the Jurassic Summerville Formation, and portions of the Cretaceous Dakota Sandstone. The first three lack necessary reductants, are not associated with any good uranium source rocks, and lack laterally continuous sandstone units that could have been conduits for uranium bearing solutions. Occurrences of uranium are rare in these formations. The Dakota Sandstone contains some organic concentrations and some volcanic ash that could have been a source for uranium, but contains few occurrences.

MARINE DEPOSITIONAL ENVIRONMENTS

Very few occurrences were found in rocks that were deposited in marine environments. Lithologies, such as limestone, shale, and quartz sandstone, found in these stratigraphic sequences are not usually hosts for uranium. Permeabilities in these lithologies, particularly the older Paleozoic sequences are often low. Organic matter that might be suitable as a reductant is not common in these rocks. For these reasons these units are classified as unfavorable.

Stratigraphic units that are included as unfavorable in this catagory are: the Cambrian Ignacio Quartzite; the Devonian Elbert Formation and Ouray Limestone; the Mississippian Leadville Limestone; marine portions of the Pennsylvanian Hermosa and Pennsylvanian-Permian Rico Formations. Cretaceous units which are considered unfavorable include marine portions of the Dakota Sandstone, the Mancos Shale, the Point Lookout and Cliff House Sandstones of the Mesaverde Group, the Lewis Shale and the Picture Cliffs Sandstone. The aerial radiometric survey (Pl. 3) shows higher radioactivity from Cretaceous shales than from other lithologies, suggesting very low-grade uranium concentrations.

EOLIAN DEPOSITIONAL ENVIRONMENTS

A few occurrences are found in sandstones that were deposited in eolian depositional environments. The most notable occurrence is in the Entrada Sandstone discussed under favorable environments, but a few occurrences are present in the DeChelly and Navajo Sandstones. Such occurrences are rare and are poorly understood. Eolian sandstones generally have good porosity and permeability but lack organic material in concentrations to be reductants for uranium. The lithologies of these units are predominantly quartz sandstones. They are not usually associated with volcanic material or first-cycle granitic material, which could be sources for uranium.

Sandstone units included as unfavorable are the DeChelly Sandstone Member of the Permian Cutler Formation, the Triassic Wingate and Navajo Sandstones; and the Jurassic Bluff-Junction Creek Sandstones. Also included is the Jurassic Entrada Sandstone in all areas of the quadrangle except Areas C-3 and C-4 (Pl. 1C).

LACUSTRINE DEPOSITIONAL ENVIRONMENTS

The Jurassic Brushy Basin and Recapture Members of the Jurassic Morrison Formation are partially lacustrine in origin. Some small, uranium occurrences are known from these units. Favorable areas are discussed elsewhere in this report (Areas A-3 and A-4). The remainder of the quadrangle where there units are present are considered unfavorable (see discussion of favorable areas in the Morrison Formation).

IGNEOUS AND METAMORPHIC ENVIRONMENTS

Igneous rocks occur in the Cortez Quadrangle as stocks, laccoliths, dikes, and sills of late Cretaceous to Tertiary age in the Abjao, Sleeping Ute, Rico, La Plata, and San Miguel Mountains. The rock types include quartz diorite porphry, monzonite, granodiorite, granogabbro, trachybasaltic and lamprophric rocks, and minor amounts of rhyolite and basalt. Intermediate composition rocks are the most common. Very few uranium occurrences are found associated with these rocks. The intermediate composition, intrusive form, and lack of occurrences of uranium lead to the unfavorable classification.

Metamorphic rocks occur around the various intrusions in contact zones, and in the very small exposures of Precambrian rocks in the Rico dome. There has been very little study of these rocks. Uranium occurrences have not been found in any of these metamorphic rocks thus they are classified as unfavorable. The Precambrian, cross-bedded, quartzite conglomerates of the Uncompahgre Formation exposed in canyons cut through the Rico Dome should be examined in more detail.

UNEVALUATED ENVIRONMENTS

No environments are left unevaluated above 1,500 m (500 ft), depth cutoff although many are in need of more detailed work. The lack of detailed formation gathered for the purpose of establishing favorability for uranium makes evaluation of some units difficult.

RECOMMENDATIONS TO IMPROVE EVALUATION

Evaluating stratigraphic units without complete basic, or frame-work, data on lithologic variation and associations, facies changes and sedimentary structures useful for intrepretation of depositional environments is difficult. Many units are well defined and described for mapping, but data necessary for evaluation as a uranium host have not been collected. Pockets of organic material maybe very local in occurrence and of little or no interest to the mapper but of prime importance to the uranium evaluator. Assignment of favorability and resource evaluation will be greatly improved as these basic data are collected.

Analysis of the paleotectonics associated with favorable host-rock formation and with events that occurred shortly after deposition would be of value. It has been suggested by Peterson (1980), and Butler and Fischer (1978) that tectonic events that occurred with, and shortly after deposition of the Salt Wash Member of the Morrison Formation and the Chinle Formation may well have controlled formation of some uranium deposits in these rocks. Such studies would require detailed surface and subsurface stratigraphic data.

Studies of the paleohydrologic conditions that existed at the time of deposition of host-rock sequences as well as just after deposition would also be of value. Relating the paleo flow patterns to possible source rocks for uranium and to potential traps should provide much improved predicion and evaluation of resources. Paleohydrology studies will require knowledge of the depositional systems and subsystems of potential host stratigraphic sequences.

Depositional systems studies of potential host-rock sequences detailing the changes in system characteristics and the resulting change in depositional facies would have value to resource studies. Such studies will allow the mapping of facies which are the most favorable for the occurrence of uranium deposits and a much improved method of outlining favorable areas as was done for the Rico and Cutler Formations (Campbell and others, 1980a).

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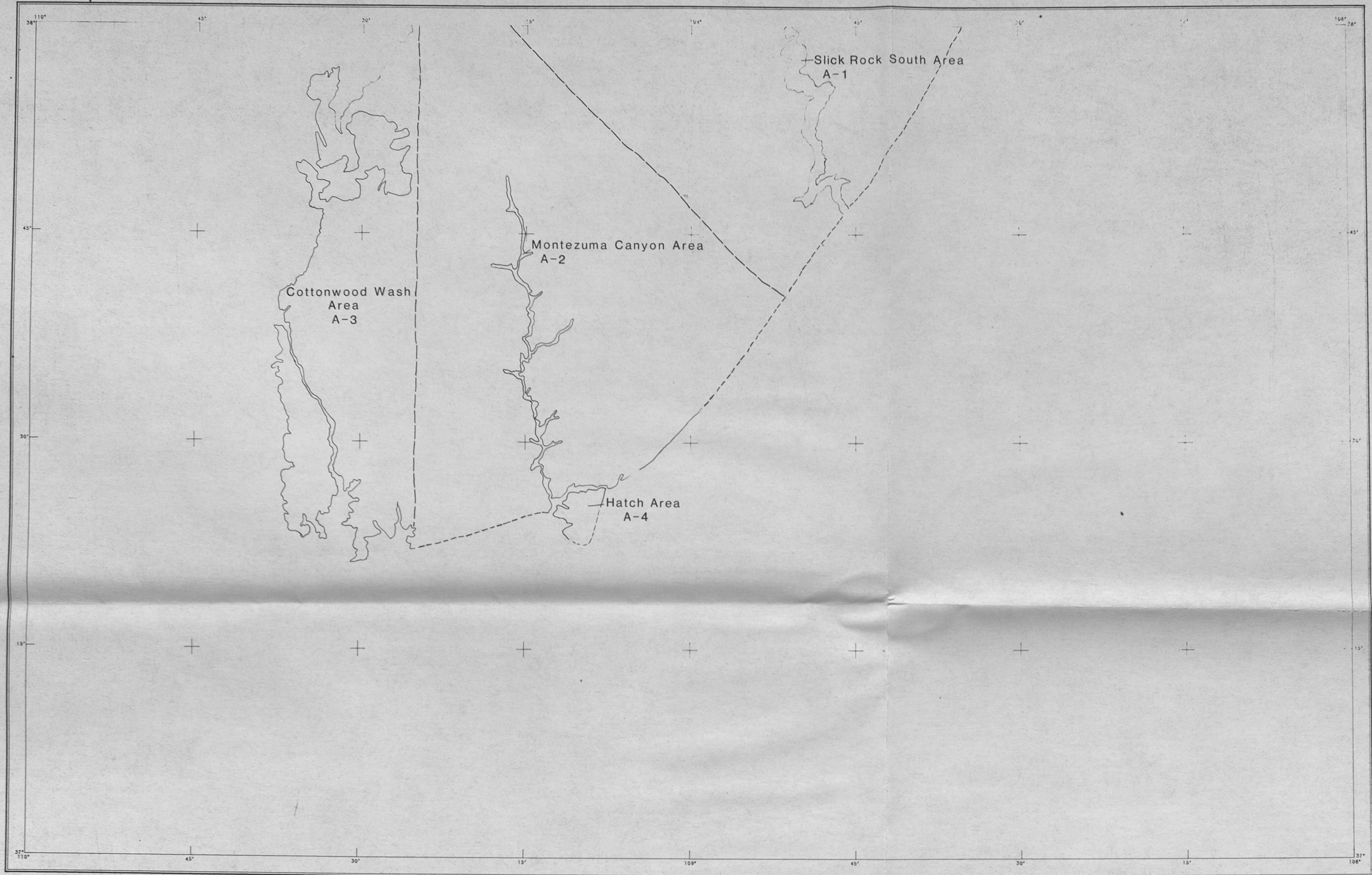


EXPLANATION

Outcrop boundary

Approximate subsurface boundary

Arbitrary boundary between favorable areas

URANIUM RESOURCE EVALUATION
ISSUED BY THE U.S. DEPARTMENT OF ENERGY

BASE MAP CONTROL FROM USGS

5 0 5 10 15 20 25 MILES

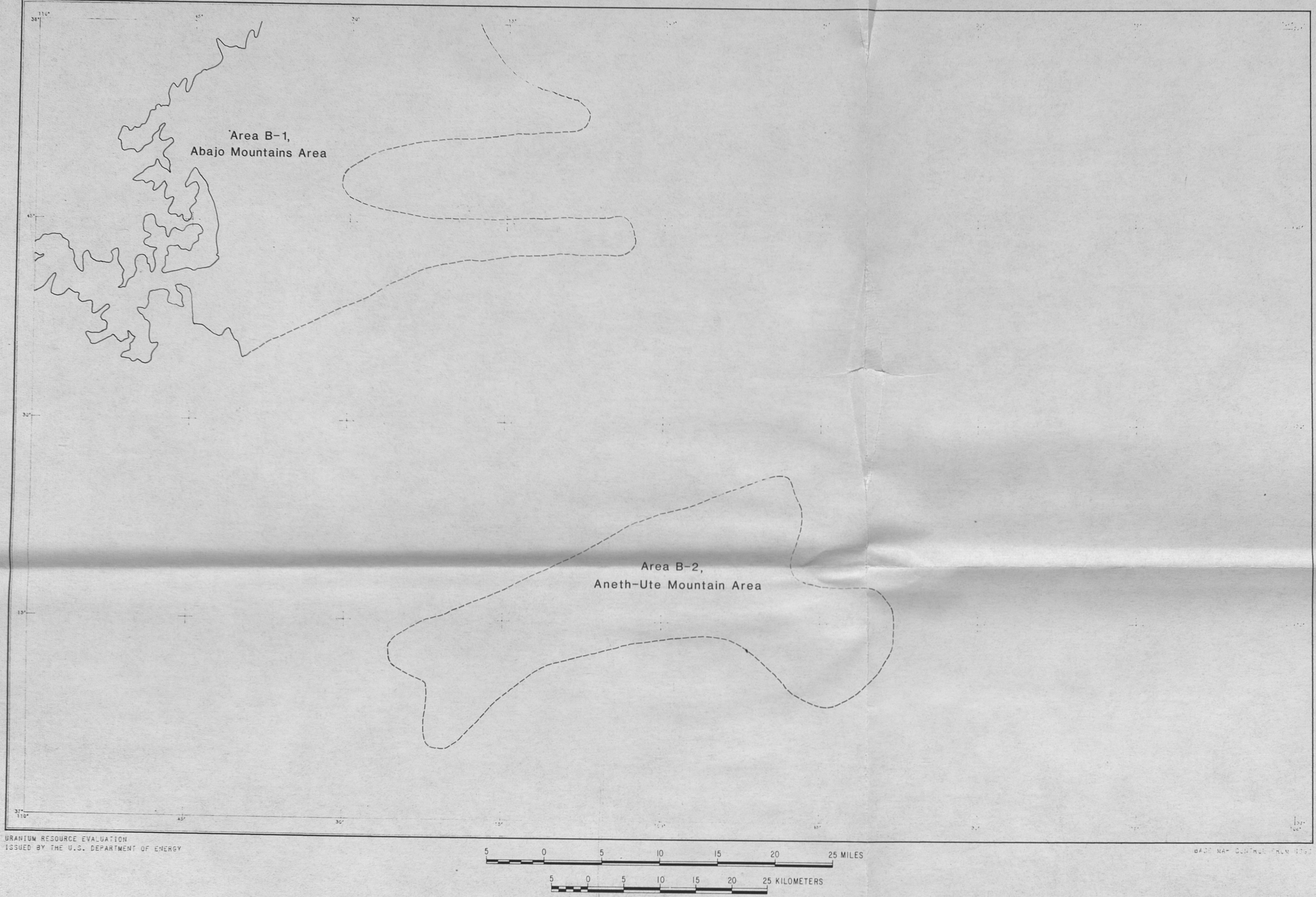
5 0 5 10 15 20 25 KILOMETERS

PLATE 1A.--AREAS FAVORABLE FOR URANIUM DEPOSITS IN THE MORRISON FORMATION

Compiled by
Fred Peterson, U.S. Geological Survey

Plate 1A.
1980

CORTEZ, COLORADO/ UTAH



URANIUM RESOURCE EVALUATION
ISSUED BY THE U.S. DEPARTMENT OF ENERGY

EXPLANATION

Outcrop boundary of favorable area

Subsurface boundary of favorable area

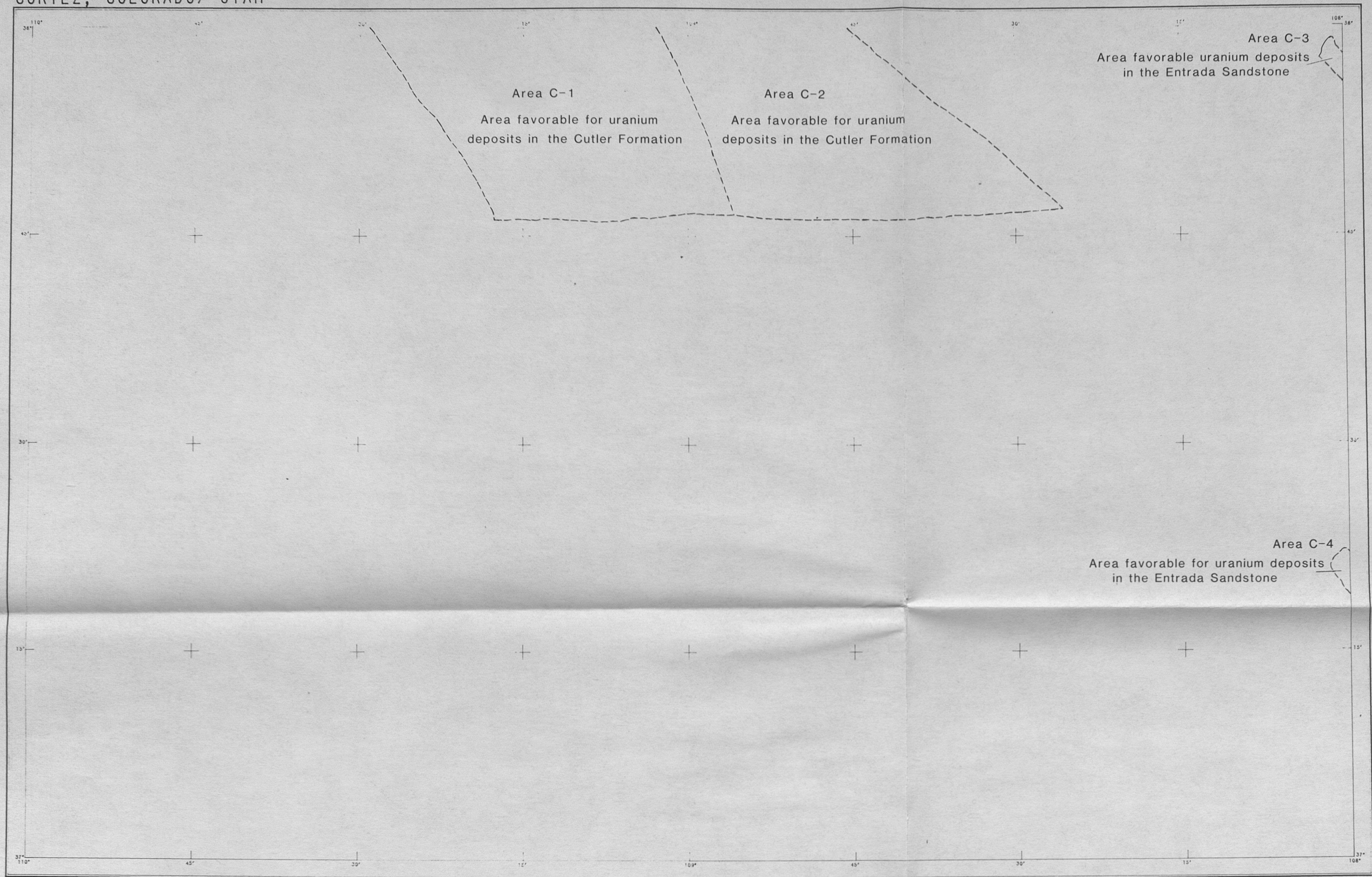
PLATE 1B.--AREAS FAVORABLE FOR URANIUM DEPOSITS IN THE CHINLE FORMATION

Compiled by

Robert Lupe, U.S. Geological Survey

Plate 1B.
1979

CORTEZ, COLORADO/ UTAH



EXPLANATION

Outcrop boundary of favorable area

Subsurface boundary of favorable area

URANIUM RESOURCE EVALUATION
ISSUED BY THE U.S. DEPARTMENT OF ENERGY

BASE MAP CONTROL FROM USGS

5 0 5 10 15 20 25 MILES

5 0 5 10 15 20 25 KILOMETERS

PLATE 1C.--AREAS FAVORABLE FOR URANIUM DEPOSITS IN THE CUTLER FORMATION AND THE ENTRADA SANDSTONE

Compiled by

John A. Campbell, U.S. Geological Survey

CORTEZ, COLORADO/ UTAH

URANIUM RESOURCE EVALUATION
ISSUED BY THE U.S. DEPARTMENT OF ENERGY

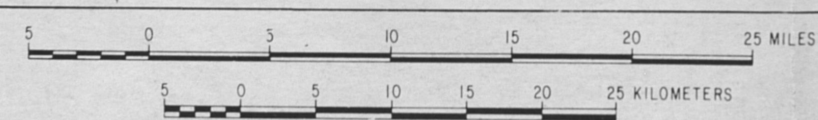
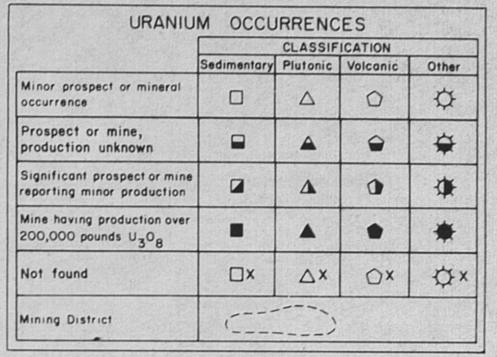


PLATE 2.—URANIUM OCCURRENCE MAP

Compiled by
Frank J. Hagar and Brenda A. Steele-Mallory, U.S. Geological Survey

EXPLANATION



Uranium occurrences visited

6	109	168	324
11	111	169	
14	116	191	
18	120	216	
28	124	260	
40	127	265	
45	132	280	
57	137	281	
59	140	290	
61	143	302	
66	144	311	
70	149	312	
92	153	313	
97	156	316	

Areas of crowded uranium occurrences

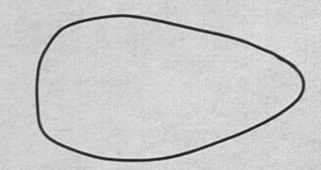
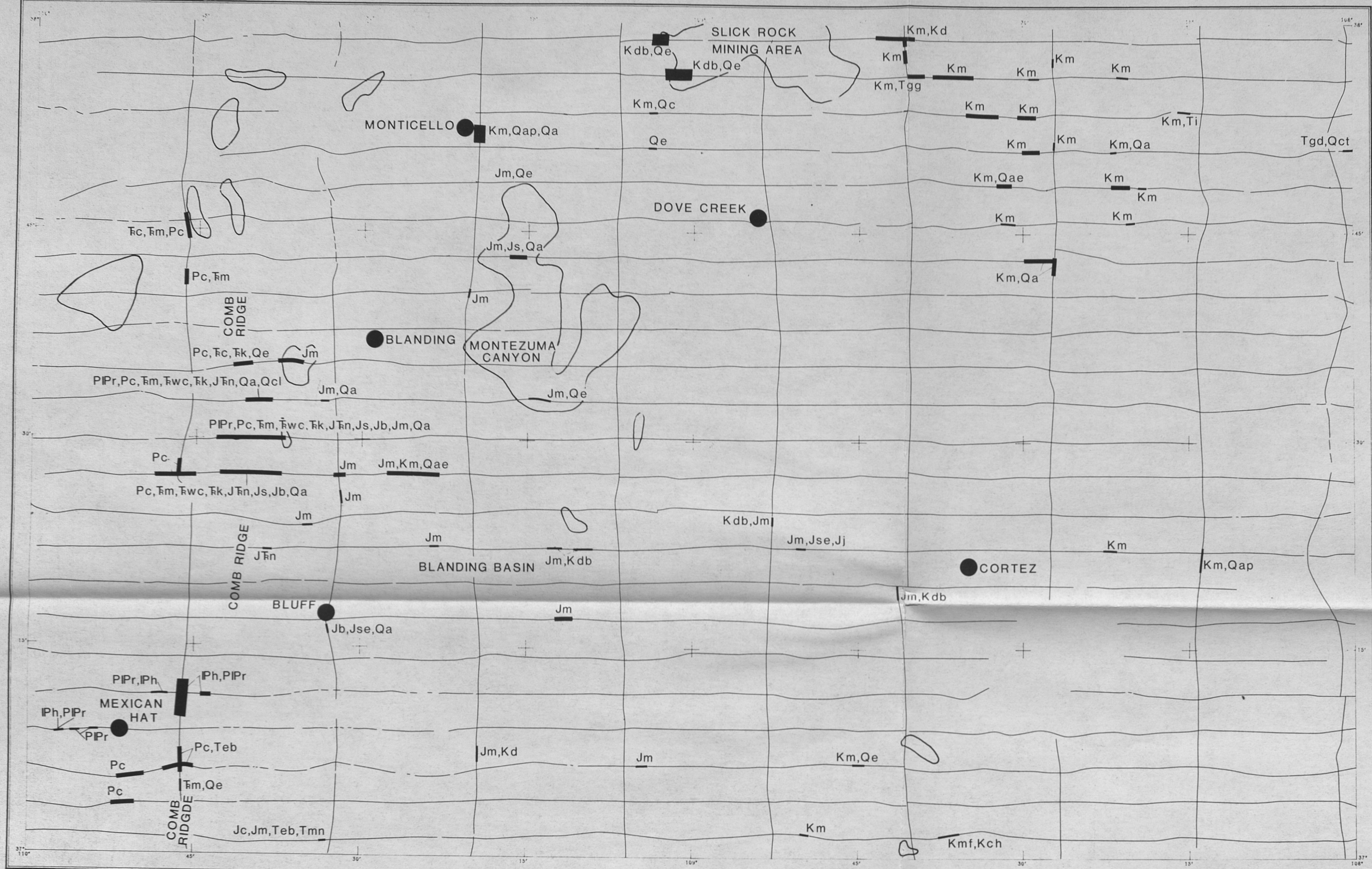


Plate 2.
1979

CORTEZ, COLORADO/ UTAH



URANIUM RESOURCE EVALUATION
ISSUED BY THE U.S. DEPARTMENT OF ENERGY

BASE MAP CONTROL FROM USGS

5 0 5 10 15 20 25 MILES

5 0 5 10 15 20 25 KILOMETERS

PLATE 3.--INTERPRETIVE MAP OF SELECTED AERIAL RADIOMETRIC URANIUM ANOMALIES

Compiled by
Karen J. Franczyk, U.S. Geological Survey

EXPLANATION

Flight lines

Area of three or more uranium occurrences

Cities and towns

Outstanding anomalies on both maps and profiles*

Outstanding anomalies on anolmaly maps, readily recognized on profiles*

Strong anolmalies on anomaly maps, recognizable on profiles; and anomalies taken from profiles*

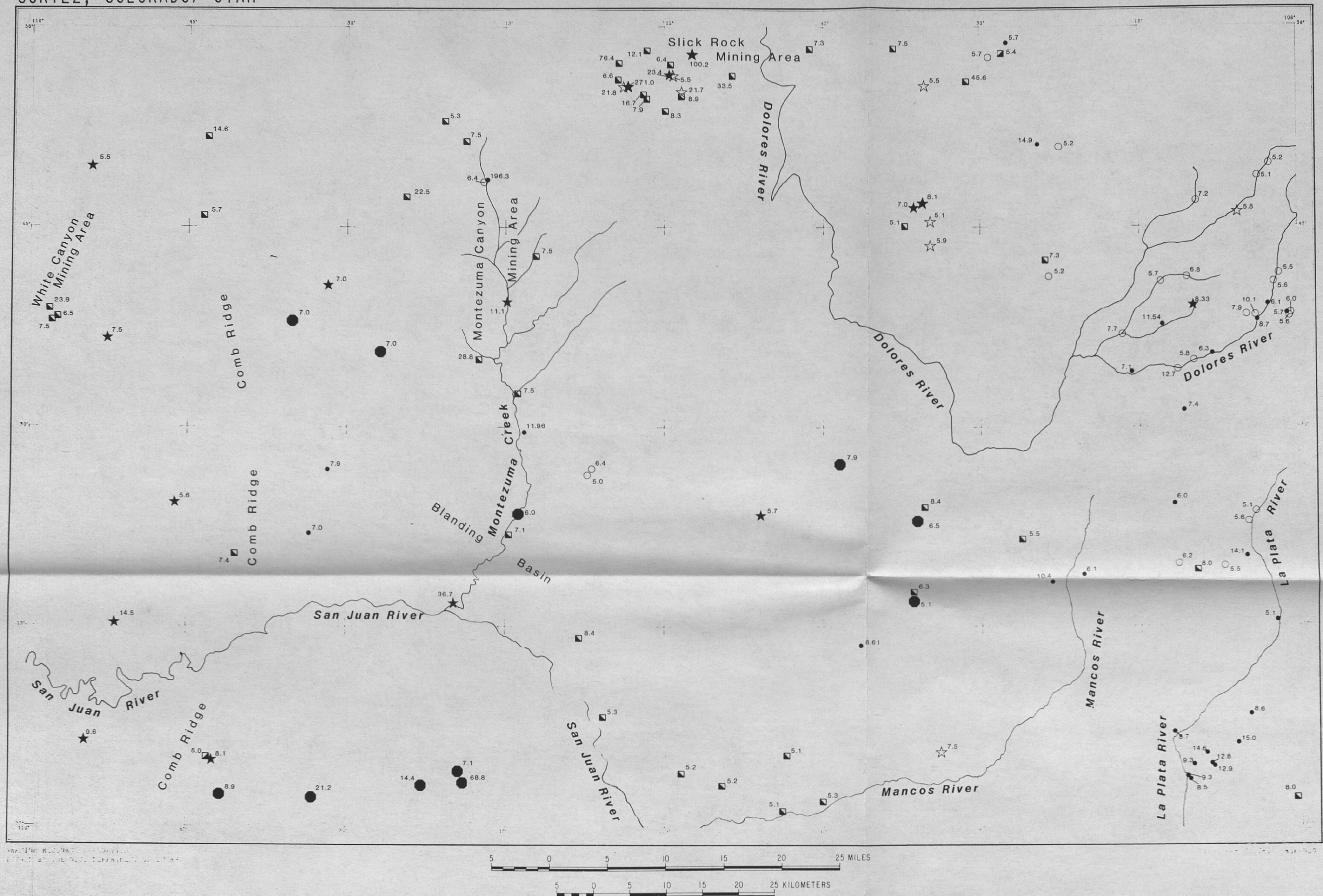
MAP SYMBOL	GEOLOGIC UNIT
Qe	Eolian deposits
Qa	Alluvial deposits
Qae	Alluvial and eolian deposits
Qc	Colluvial deposits
Qcl	Landslide debris
Qct	Talus deposits
Qap	Pediment gravels
Ti	Intrusives
Tgg	Granogabbro
Tgd	Quartz latite
Tmn	Minette
Teb	Explosion breccia
Kch	Cliff House Sandstone
Kmf	Menefee Formation
Km	Mancos Shale
Kdb	Dakota Sandstone and Burro Canyon Formation
Kd	Dakota Sandstone
Jm	Morrison Formation
Jb	Bluff Sandstone
Js	Summerville Formation
Jj	Junction Creek Sandstone
Jse	Summerville Formation and Entrada Sandstone
Jc	Carmel Formation
JTRn	Navajo Sandstone
TRk	Kayenta Formation
TRwc	Wingate Sandstone and Chinle Formation
TRc	Chinle Formation
TRm	Moenkopi Formation
Pc	Cutler Formation
PIPr	Rico Formation
IPh	Hermosa Formation

* Anomalies classified into these categories by Aero Service

Source of data : Aero Service Division, Western Geophysical Company of America, 1979, Aerial gamma ray and magnetic survey, Cortez NTMS, Colorado and Utah: U.S. Department of Energy Open-File report GJBX-144 '79, Vol. 1

Plate 3.
1979

CORTEZ, COLORADO/ UTAH



EXPLANATION

Sediment Samples

☆ Wet spring

○ Wet stream

◪ Dry stream

Water Samples

★ Spring

• Stream

● Well

Sediment samples shown are those with uranium values ≥ 5.0ppm

Water samples shown are those with values of (uranium/conductivity) x 1000 ≥ 5.0

Data from Los Alamos Scientific Laboratory Informal Report LA-7505-MS; Warren, R.G., 1979, Uranium hydrogeochemical and stream sediment reconnaissance of the Cortez NTMS Quadrangle, including concentrations of forty-three additional elements, U.S. Department of Energy Open-File report GJBX-77'79

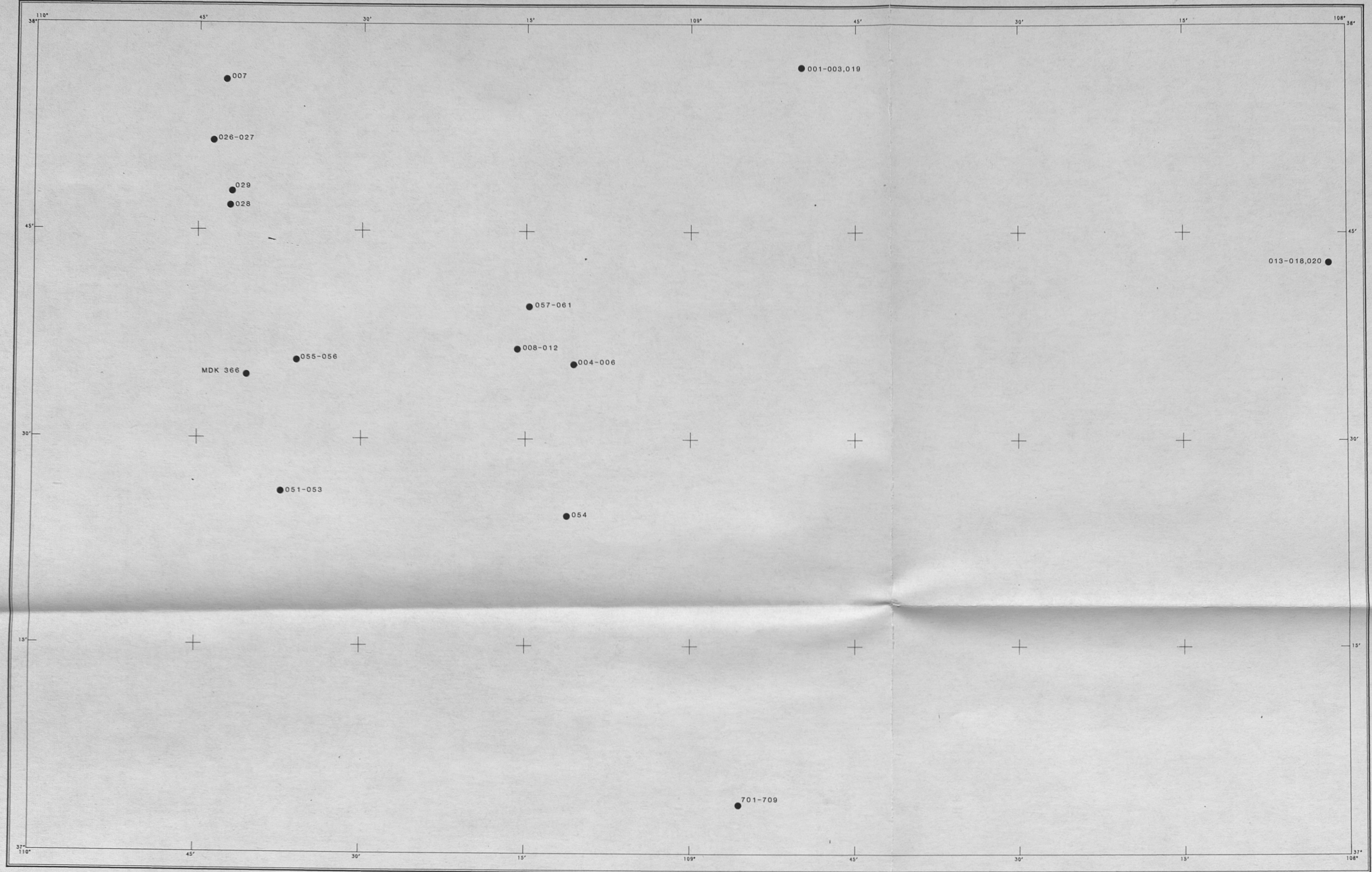
Sample analyses by Los Alamos Scientific Laboratory

PLATE 4.--INTERPRETIVE MAP OF HYDROGEOCHEMICAL AND STREAM SEDIMENT RECONNAISSANCE SURVEY

Compiled by

Karen J. Franczyk, U.S. Geological Survey

CORTEZ, COLORADO/ UTAH



URANIUM RESOURCE EVALUATION
ISSUED BY THE U.S. DEPARTMENT OF ENERGY

BASE MAP CONTROL FROM USGS

5 0 5 10 15 20 25 MILES

5 0 5 10 15 20 25 KILOMETERS

PLATE 5.—ROCK SAMPLE LOCALITY MAP

Compiled by
Joseph C. Cornellisson, U.S. Geological Survey

EXPLANATION

001-003● Sample locality and numbers where more than one sample was collected

All numbers are prefixed by MBM unless otherwise noted

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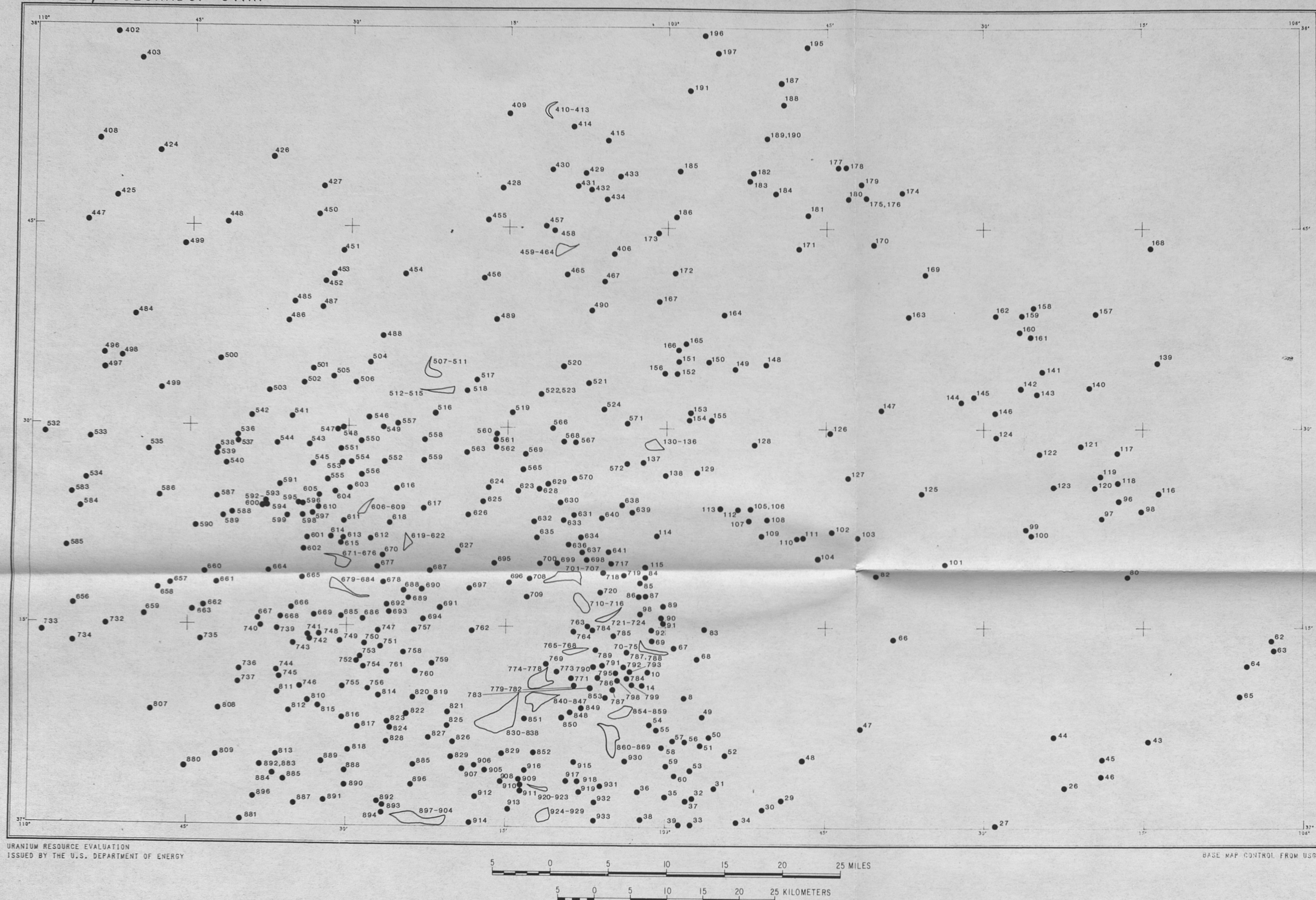

EXPLANATION

- Oil and gas well locations
- Area of crowded oil and gas wells

Location of wells shown in Appendix D.

PLATE 5A.--LOCATION MAP OF OIL AND GAS TEST WELLS

Compiled by

Compiled by John J.Stevenson and Karen J. Franczyk, U.S. Geological Survey

Plate 5A.
1979

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URANIUM RESOURCE EVALUATION
ISSUED BY THE U.S. DEPARTMENT OF ENERGY

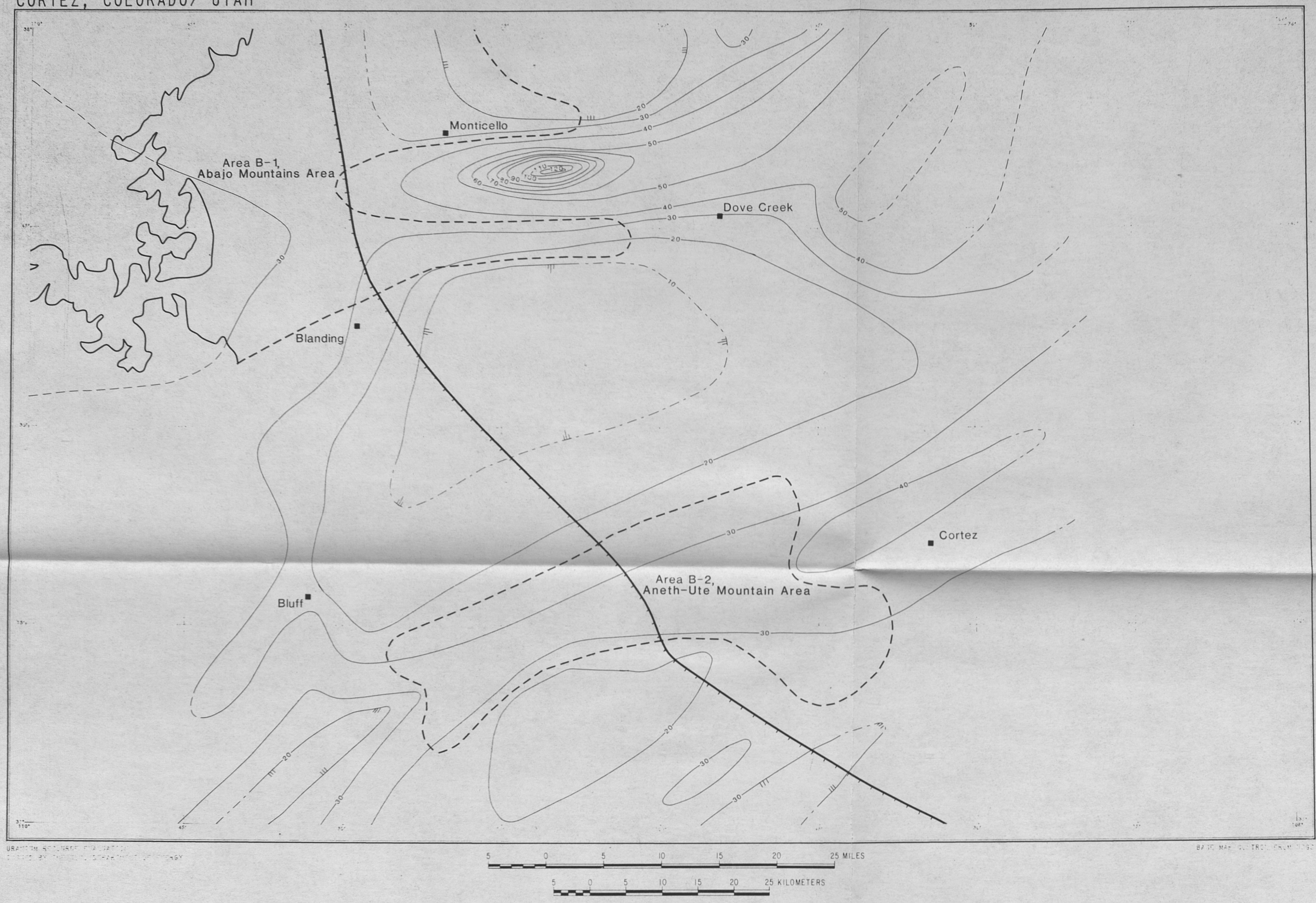
5 0 5 10 15 20 25 MILES

5 0 5 10 15 20 25 KILOMETERS

PLATE 6.--DRAINAGE MAP

Plate 6.
1979

CORTEZ, COLORADO/ UTAH



EXPLANATION

Contour of sandstone to mudstone ratios, dashed where Chinle Formation eroded, dot and dashed where uncertain. Numerical values are sandstone/ mudstone X 100

Outcrop boundary of favorable area

Subsurface boundary of favorable area

Limit of Petrified Forest Member of the Chinle Formation. Member present on hachured side of line

Town

PLATE 7.--DISTRIBUTION OF ROCK TEXTURE, AND AREAS FAVORABLE FOR URANIUM DEPOSITS IN THE UPPER TRIASSIC CHINLE FORMATION

Compiled by

Robert Lupe, John J. Stevenson, and Rodger A. Hooten, U.S. Geological Survey

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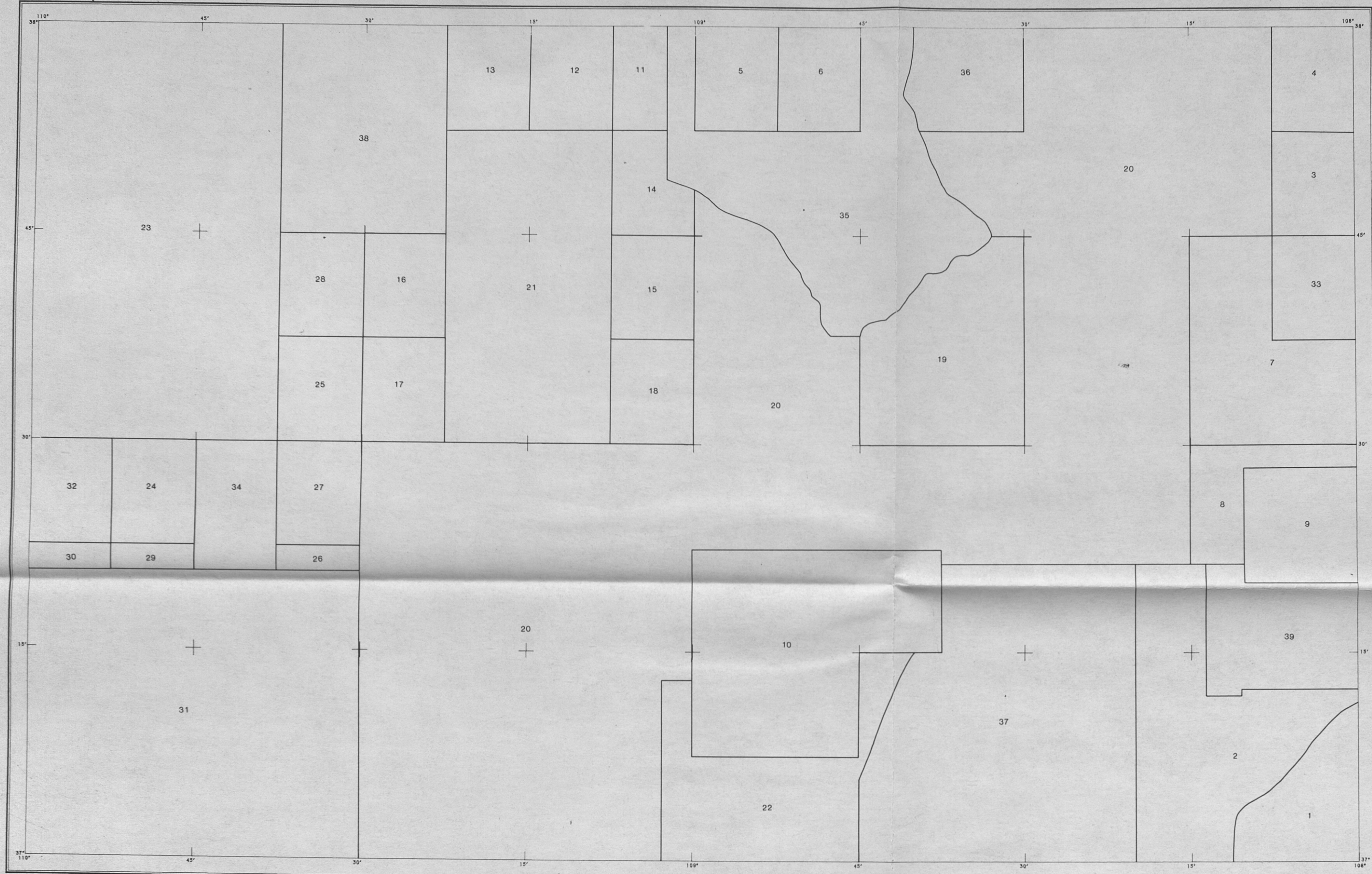

URANIUM RESOURCE EVALUATION
ISSUED BY THE U.S. DEPARTMENT OF ENERGY

BASE MAP CONTROL FROM USGS

5 0 5 10 15 20 25 MILES

5 0 5 10 15 20 25 KILOMETERS

PLATE 11.--GEOLOGIC-MAP INDEX

Compiled by

R. B. O'Sullivan and W. J. Hail, Jr., U.S. Geological Survey

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3. Bush, and Bromfield, 1966, 1:24,000.
4. Bush, Marsh, and Taylor, 1960, pl. 19, 1:24,000.
5. Cater, 1955a, 1:24,000.
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9. Eckel, 1949, pl. 2, 1:31,680.
10. Ekren, and Houser, 1965, pl. 1, 1:48,000.
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19. Hackman, 1959, 1:62,500.
20. Haynes, Vogel, and Wyant, 1972, 1:250,000.
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33. Pratt, McKnight, and DeHon, 1969, 1:24,000.
34. Sears, 1956, pl. 17, 1:63,360.
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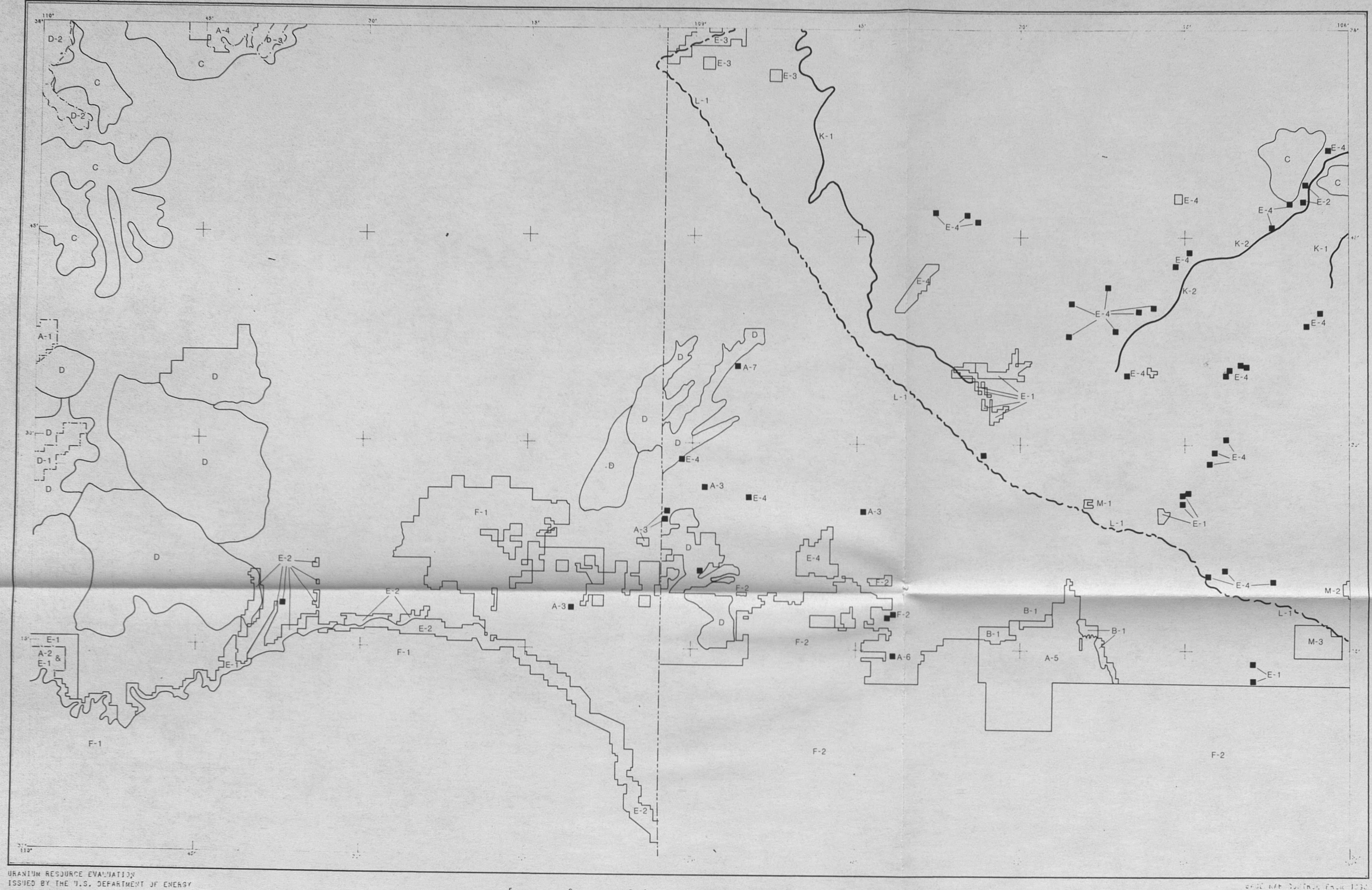
38. Witkind, 1964, pl. 1, 1:31,680.
39. Zapp, 1949, 1:31,680.

CORTEZ, COLORADO/ UTAH



5 0 5 10 15 20 25 MILES

5 0 5 10 15 20 25 KILOMETERS

PLATE 12.--GENERALIZED LAND STATUS MAP

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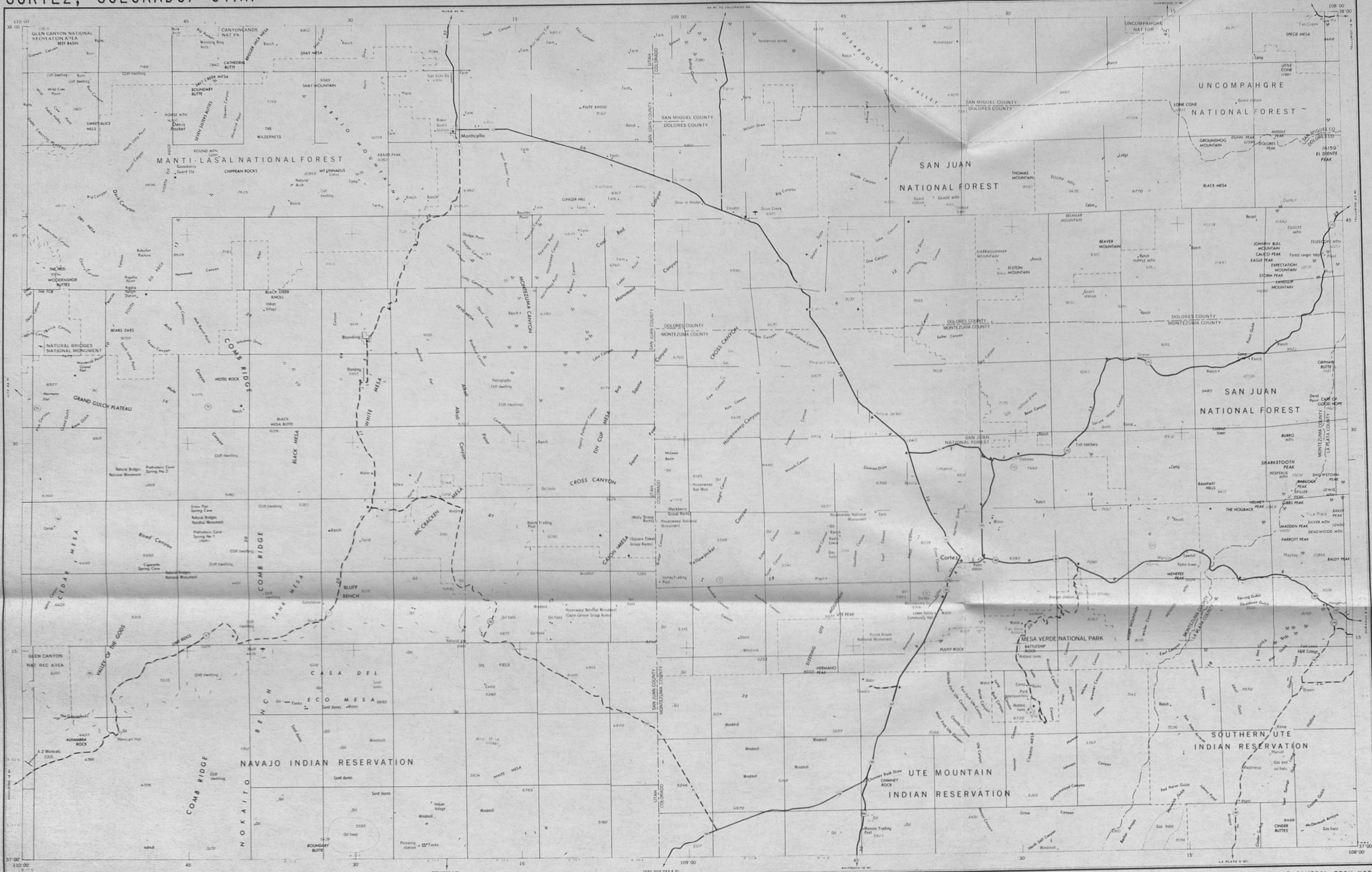
- L-1 Dominguez-Escalante Trail

M. State Withdrawals

- M-1 Colorado Division of Wildlife Withdrawal
- M-2 Colorado Division of Wildlife Withdrawal
- M-3 San Juan Basin Branch Agricultural Experiment Station

This map compiled prior to August 1979

CORTEZ, COLORADO/ UTAH



URANIUM RESOURCE EVALUATION
ISSUED BY THE U.S. DEPARTMENT OF ENERGY

5 0 5 10 15 20 25 MILES

5 0 5 10 15 20 25 KILOMETERS

PLATE 13.--CULTURE MAP

Plate 13.
1979