PGJ/F-022(82)

National Uranium Resource Evaluation

MARBLE CANYON QUADRANGLE ARIZONA AND UTAH

DO NOT MICROFILM COVER

MASTER

Bendix Field Engineering Corporation
Grand Junction, Colorado

Issue Date
May 1982

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

DISCLAIMER

This report is a result of work performed by Bendix Field Engineering Corporation, Operating Contractor for 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.

Available from: Technical Library
Bendix Field Engineering Corporation
P.O. Box 1569
Grand Junction, CO 81502-1569

Telephone: (303) 242-8621, Ext. 278

Price per Microfiche Copy: $6.00

PGJ/F-022(82)

NATIONAL URANIUM RESOURCE EVALUATION
MARBLE CANYON QUADRANGLE
ARIZONA AND UTAH

PGJ/F--022(82)

DE82 015721

Michael T. Field and Robert P. Blauvelt

BENDIX FIELD ENGINEERING CORPORATION
Grand Junction Operations
Grand Junction, Colorado 81502

May 1982

PREPARED FOR THE U.S. DEPARTMENT OF ENERGY
GRAND JUNCTION AREA OFFICE
UNDER CONTRACT NO. DE-AC07-76GJ01664

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.

CONTENTS

CONTENTS (continued)

ILLUSTRATIONS

ILLUSTRATIONS (continued)

Plates in accompanying packet

ABSTRACT

The Marble Canyon Quadrangle (2°), northeast Arizona, was evaluated to a depth of 1500 m for uranium favorability using National Uranium Resource Evaluation criteria. Known mines and prospects were examined; field reconnaissance was done in selected areas of the quadrangle; and a groundwater geochemical survey was made in the southeast third of the quadrangle. The Shinarump and Petrified Forest Members of the Triassic Chinle Formation, which is exposed in the western and northeastern parts of the quadrangle and is present beneath the surface of much of the quadrangle, were found favorable for channel-sandstone uranium deposits. A portion of the Cretaceous Toreva Formation in the southeast part of the quadrangle was found favorable for peneconcordant-sandstone uranium deposits. The western part of the quadrangle was found favorable for uranium concentrations in breccia pipes.

INTRODUCTION

PURPOSE

The Marble Canyon Quadrangle (2°), an area of 20,634 km^2, is in northeastern Arizona (Fig. 1). The quadrangle was evaluated to a depth of 1500 m to identify geologic environments and delineate areas that exhibit characteristics favorable for the occurrence of uranium deposits. Favorable environments, as determined by surface and subsurface investigation, are those that could contain uranium deposits of at least 100 tons U_3O_8 in rocks with an average grade not less than 100 ppm U_3O_8. Selection of a favorable environment is based on the similarity of its geologic characteristics to those found in close association with known uranium deposits (recognition criteria) as described in Mickle and Mathews (eds., 1978). The study was conducted by Bendix Field Engineering Corporation (BFEC) for the National Uranium Resource Evaluation (NURE) program, managed by the Grand Junction Area Office of the U.S. Department of Energy (DOE).

SCOPE

Work on the Marble Canyon Quadrangle began March 6, 1979, and ended February 29, 1980. March through May were spent on preliminary work (5 man-months), June and July in field work by four persons (8 man-months), and August through mid-September in field work by two persons (3 man-months). Mid-September through February were spent on data analysis and folio preparation (8 man-months). A total of 2.0 man-years were expended.

PROCEDURES

Preliminary study indicated that two units appeared much more favorable than the others in the quadrangle, and these were emphasized in the field work. One unit, specifically the Shinarump Member of the Chinle Formation, contains most of the uranium occurrences in the quadrangle. The other unit, a sequence of Cretaceous sandstones and shales known as the Toreva Formation, overlies the Wepo Formation.

Field work consisted primarily of examining and sampling the known occurrences. The Cretaceous formations were traversed by foot and automobile, and over 100 ground-water samples were taken. Some time was spent in studying the Morrison Formation in the eastern part of the quadrangle. Other formations were examined only in reconnaissance, and some ground-water samples were taken in formations other than the Toreva and Wepo.

Three days were spent in helicopter traverses with a spectrometer. These were made along Paria Canyon and the Vermilion Cliffs in the northwest part of the quadrangle, western Monument Valley, the eastern scarp of Black Mesa, and portions of southeast and northwest Black Mesa (Fig. 2). The results of the NURE Aerial Radiometric Survey were not available in time for field checking. No Hydrogeochemical and Stream-Sediment Reconnaissance (HSSR) survey information was available at the time of the writing of this report. Access to the Grand Canyon National Park (Pl. 10) was denied.

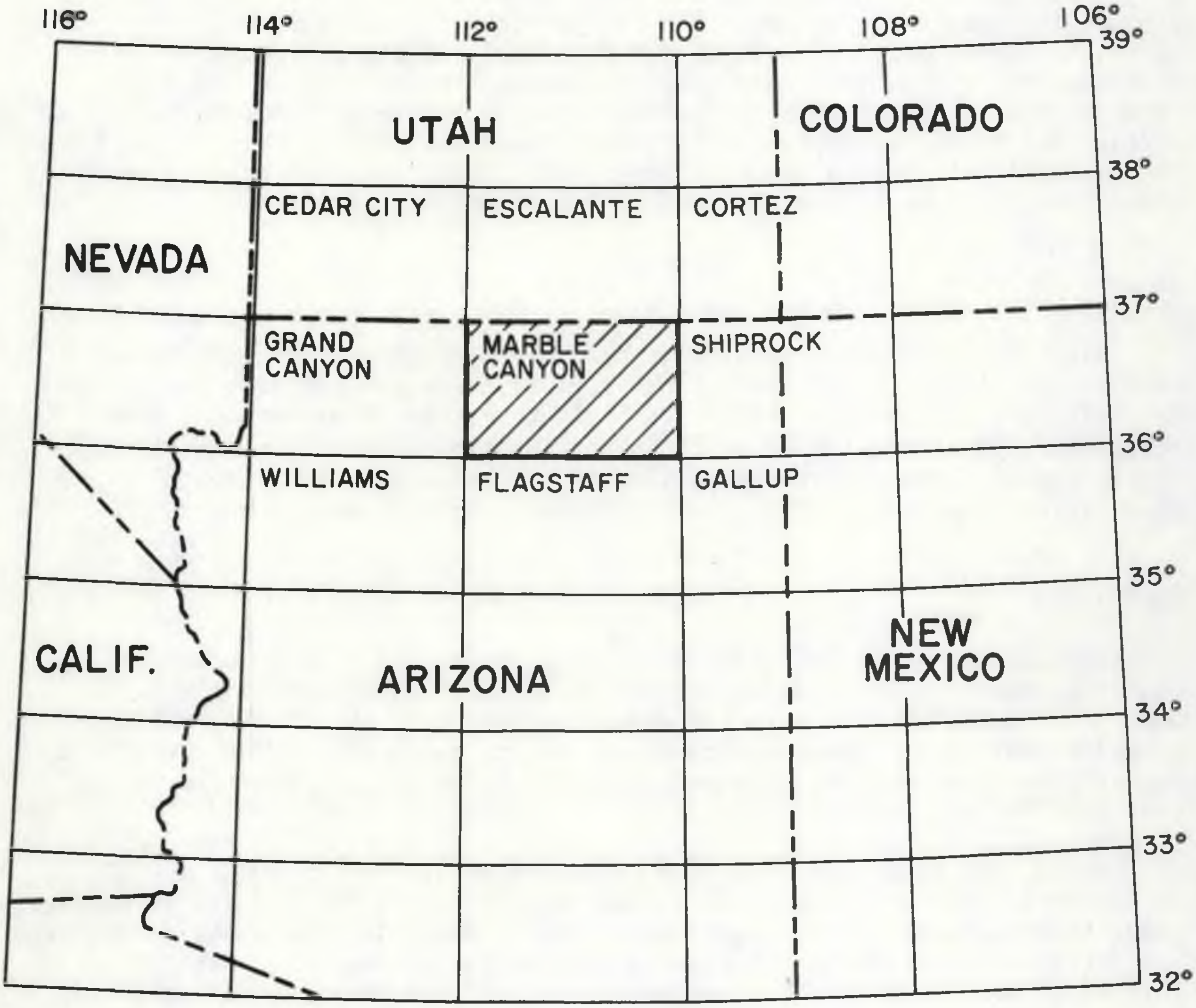


Figure 1. Location of Marble Canyon Quadrangle.

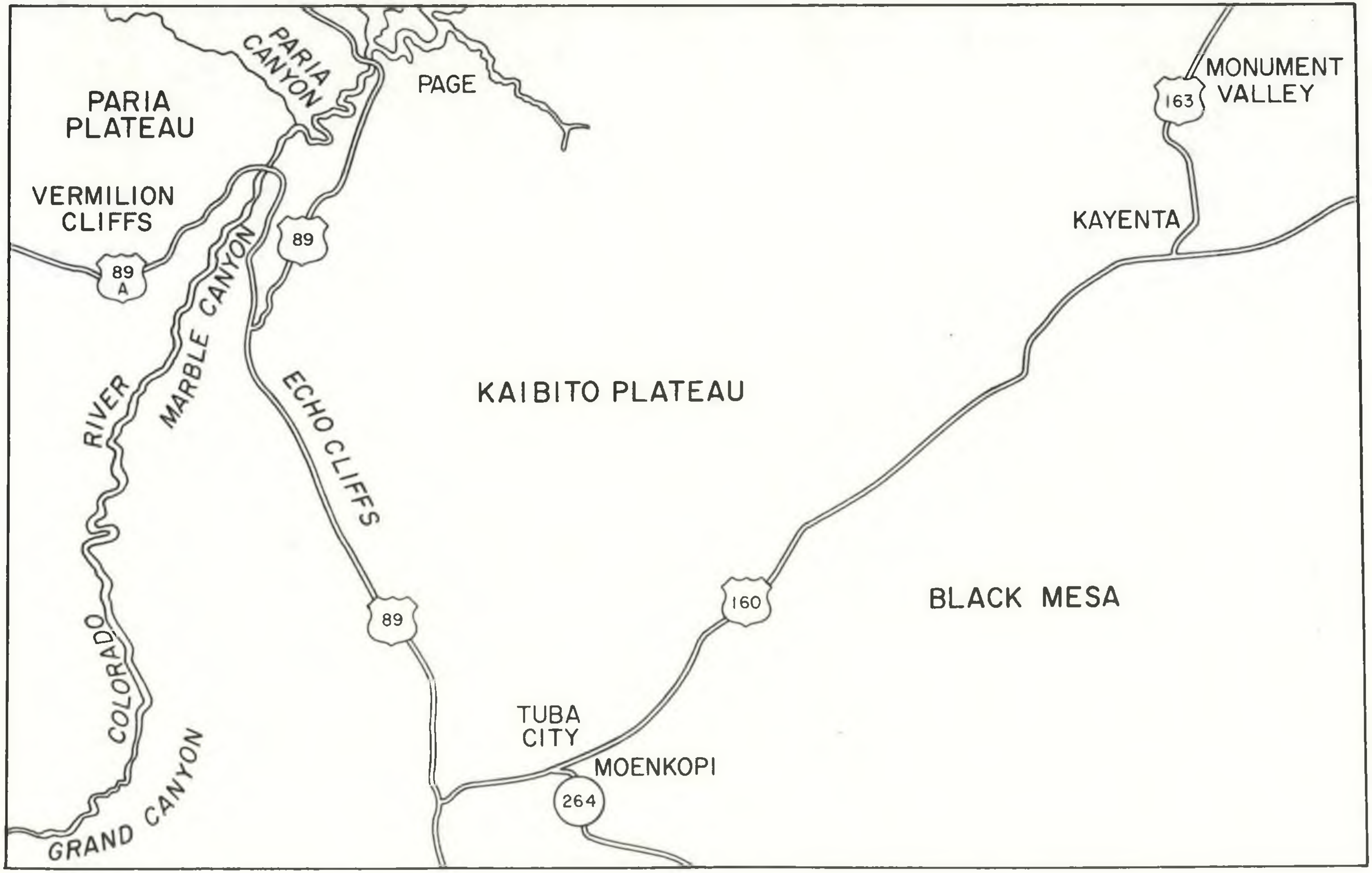


Figure 2. Major physiographic and cultural features of the Marble Canyon quadrangle.

GEOLOGIC SETTING

The quadrangle lies entirely within the Colorado Plateau geologic province and is underlain by a thick series of sedimentary rocks. These are generally flat lying, but a few major monoclines cross the quadrangle (Pl. 8).

The quadrangle, bounded by monoclines to which highways US 89 and US 160 are parallel (Fig. 2 and Pl. 8), may be subdivided into three parts. In the west (except the northwest), a broad platform is developed on top of the Kaibab Limestone. Into this platform is incised Marble Canyon and the upper part of the Grand Canyon of the Colorado River. It is only in these canyons that strata below the Permian Kaibab Limestone are exposed (Fig. 3).

Precambrian schists and gneisses are exposed in a small area in the bottom of the Grand Canyon. Above these are 1700 m of Upper Precambrian carbonates, sandstones, and shales. Unconformably above these is the Paleozoic section, 1000 m of carbonates, sandstones, and shales capped by the 100-m-thick Kaibab Limestone.

The central part of the quadrangle is a plateau formed by Triassic and Jurassic siltstones and sandstones of fluvial and eolian origin, which are overlain by the massive eolian Navajo Sandstone. The southern part of this plateau is called the Kaibito Plateau, and the area in the northwest corner of the quadrangle is called the Paria Plateau. The northern and northeastern parts of this central area are deeply dissected.

Monument Valley occupies the extreme northeastern part of the quadrangle, and it exposes a pre-Triassic section different from that of the western part of the quadrangle. The Kaibab Limestone is absent, and the siltstones and sandstones of the Permian Cutler Formation form most of the mesas of Monument Valley.

The southeastern quarter of the quadrangle is occupied by Black Mesa, which is composed of a series of Cretaceous rocks. The Black Mesa rocks consist of a thick basal marine shale overlain by gray arkosic fluvial and near-shore sandstones. The sandstones contain varying amounts of organic material, which includes mineable coal in the northern part of Black Mesa.

Sandstones of the Jurassic Morrison Formation are exposed east of Black Mesa and south of Monument Valley. Some Pliocene basic intrusive rocks are found in and south of Monument Valley.

ENVIRONMENTS FAVORABLE FOR URANIUM DEPOSITS

In the Marble Canyon Quadrangle, five areas meet the favorability criteria for a deposit of at least 100 tons of U_3O_8 with an average grade of not less than 100 ppm U_3O_8. These are channel-controlled peneconcordant uranium deposits (Subclass 243, Austin and D'Andrea, 1978; Areas A, D, and E, Pl. 1), non-channel-controlled peneconcordant deposits (Subclass 244, Austin and D'Andrea, 1978; Area C), and breccia pipes and vein deposits in sedimentary rocks (Class 730, Mathews, 1978; Area B). Area E is the extension of a favorable area from the Flagstaff Quadrangle and is discussed in that report.

AREAS A AND D

The Shinarump Member of the Chinle Formation, also referred to as the Shinarump conglomerate, meets favorability criteria for Subclass 243, channel-controlled peneconcordant deposits. These criteria are:

- Platform tectonic setting (Colorado Plateau)
- Unconformable contact with underlying impermeable Moenkopi Formation
- Channels cut into the underlying Meonkopi Formation
- Long, sinuous channels
- Bleaching of underlying red siltstones
- Associated minerals of copper and vanadium
- Secondary uranium, copper, and vanadium minerals

Supplementary diagnostic criteria are:

- Organic debris, carbonized and petrified
- Heterogeneous lithology

The Shinarump Member is present at the surface or within 1500 m of the surface in 75% of the Marble Canyon Quadrangle.

Area A includes most of Monument Valley, the dissected area to the west of it, and an arbitrary amount of subsurface area where the Shinarump is at an average depth of 750 m. The southern and western boundaries of Area A are drawn to coincide with the favorable areas in the Shiprock Quadrangle to the east and the Escalante Quadrangle to the north. The eastern portion of Monument Valley has been excluded because the limited outcrop on the mesa tops is thin and barren. Area A covers 1560 km^2.

Area D includes approximately 560 km^2 along the Vermilion and Echo Cliffs. About half of the Shinarump in the area is within 60 m of the surface. The rest is at an average depth of 300 m and a maximum depth of about 1000 m. The southern boundary of the area is based on a lack of channels and a thinning of the Shinarump. The northern and eastern boundaries are drawn between areas where the Shinarump has channels, where it does not, or where there is no subsurface information.

The Shinarump Member of the Chinle Formation is a light-gray sandstone and pebble conglomerate of Late Triassic age. The conglomerate typically contains well-rounded 2-cm-sized pebbles of quartzite, quartz, and black chert. Witkind and Thaden (1963) describe the Shinarump in Monument Valley as consisting of 75% sandstone, 20% conglomerate, and 5% mudstone. It is heterogeneous, and includes some shale, clay galls, and carbonized and petrified wood. Along the Vermilion Cliffs, the Shinarump also contains some granite pebbles and has less mudstone and organic material than does the Shinarump in Monument Valley (Phoenix, 1963). It commonly forms a bench between underlying and overlying red shales and siltstones. The light gray color of the Shinarump stands out in contrast to these surrounding rocks.

The lower beds of the Shinarump fill channels that have been cut into the underlying Moenkopi Formation. The channels generally trend northwest in both the eastern and western part of the quadrangle. The channels vary greatly in size and shape (Fig. 4). The average channel is 100 m wide and 15 m deep, and the largest channel in the quadrangle, in northern Monument Valley, is 650 m wide and 50 m deep. Mineralized channels tend to be relatively deep and narrow.

The red siltstones of the Moenkopi Formation are bleached at the contact with the Shinarump. The zone of bleaching is typically 10 to 30 cm deep but is up to 2 m deep under channels. Bleaching tends to be thicker under mineralized channels. Uranium mineralization often extends into the Moenkopi from the Shinarump.

A wide variety of uranium and vandium minerals are present; these include uraninite, carnotite, autunite, tyuyamunite, corvusite, and uranophane. Associated sulfides include bornite, galena, pyrite, and sphalerite. Additional gangue minerals are apatite, calcite, gypsum, limonite, and quartz.

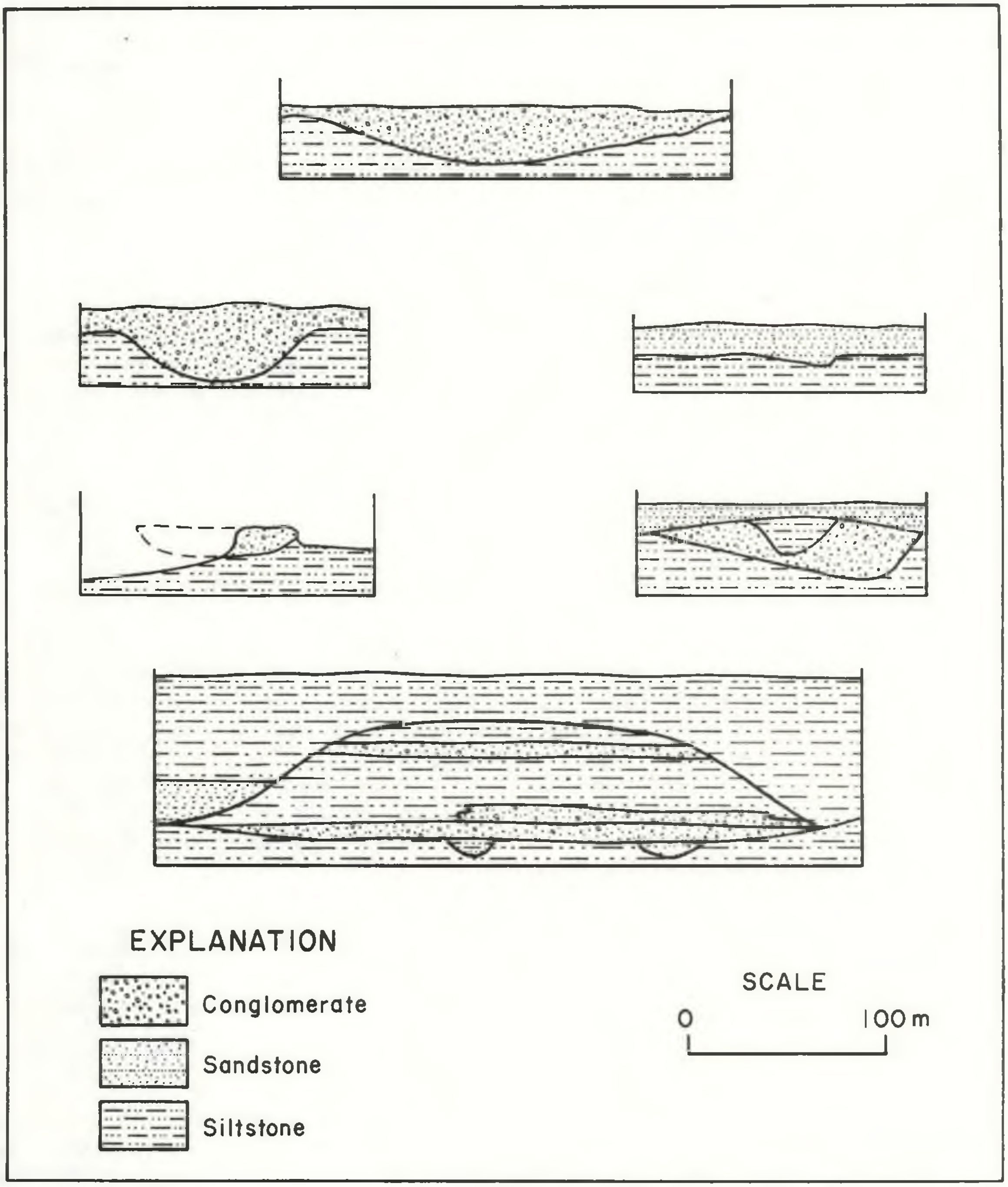
The ore bodies may be rodlike, tabular, or irregularly shaped (Witkind and Thaden, 1963). Tabular ore bodies have been found that are 20-40 ft wide, 60 ft long, and 6 ft thick (Witkind, 1961). Rod-shaped ore bodies are between 2-8 ft in width and may be up to 30 ft long.

All uranium deposits in the Shinarump are found in channels. Within the channels, the uranium deposits are sporadic; and, the presence of one deposit does not necessarily indicate that another is nearby. Finding these deposits within the channels has been the subject of considerable discussion. Most investigators conclude that ore is associated with carbonaceous plant material. It appears to collect in that part of a channel where the flow of ground water is restricted because of facies changes, changes in regional dip (Thaden and others, 1964), channel bends, potholes, and deep scours (Lewis and others, 1959; Gray, 1957; and Young, 1964), or heterogeneous lithology (Gray, 1957; Young, 1964).

Uranium-bearing fluids have been restricted to the Shinarump because it is a permeable unit between impermeable siltstones and shales. The source of uranium is not known but may be tuffs in the overlying Petrified Forest Member of the Chinle (Austin and D'Andrea, 1978).

Witkind and Thaden (1963) report 62 channels on 40 square miles of Shinarump exposure; seven of these channels contain uranium minerals. Along the Vermilion Cliffs, the Shinarump contains 10 channels over a length of 20 miles (Phoenix, 1956); three of these show enrichment.

Young (1964) suggested some changes in classification of the Shinarump Member and its channels, which may be of some help in finding the mineralized



From Witkind and Thaden(1963) and Young (1964)

Figure 4. Cross-sections of Shinarump channels.

portions. He feels that the term Shinarump should be restricted to the sediments within the channels. There is an unconformity approximately at the top of these channel-filling sediments, and the Monitor Butte Member covers the Shinarump and is the basal member of the Chinle away from the channels (Fig. 5). Some shallow, unmineralized scours filled by Monitor Butte sediments may have been mistaken for Shinarump channel fillings. Young also observes that some small features have been mapped as channels. These features are actually scours within a broad channel. Moreover, this broad channel may be traced for many miles. These channels are a better guide to the location of the small ore-bearing scours because the small scours cannot be traced for any distance. It is not known if any exploration has been done using Young's model.

There appears to be a systematic variation in channel configuration from northeast to southwest across the region (L. M. Roe, pers. comm., 1980). In the vicinity of the San Juan River, north of Monument Valley, the Shinarump forms small lenses that are surrounded by mudstone (Lewis and Trimble, 1959). In Monument Valley, individual channels are contained within broad valleys (the broad channels of Young) or swales 2-4 mi wide (Witkind and Thaden, 1963) with a channel density of 0.5 channels per mile. In the Grand Canyon Quadrangle near Yellowstone Mesa, the swales containing Shinarump are greater than 10 mi wide, and discrete channels of the type found in Mounument Valley are not apparent.

The occurrence and mines in the Monument Valley area are larger than those found along the Vermilion Cliffs, which in turn are larger than the occurrences found in the Shinarump on Yellowstone Mesa. This suggests that the Shinarump increases in favorability from west to east across the Marble Canyon Quadrangle and that favorability may be related to the size of swales and to the density of individual small channels. If this is true, it might be possible to extend Area A westward to include Area D. The channels in both Areas A and D trend northwest-southeast, and it may be that the Shinarump in the subsurface is favorable to the northwest and southeast of Area D for a considerable distance. However, because of the lack of evidence of channels in the subsurface, we have elected to place most of the subsurface Shinarump in the unevaluated category.

In Area A, the land is on the Navajo Indian Reservation and includes a small portion of the Navajo Tribal Park, Mounument Valley. The area is accessable by a single paved road, U.S. Highway 163, but there are numerous dirt roads and trails that are usually passable in dry weather.

The northern and western parts of Area D contain BLM land, the Vermilion Cliffs Natural Area, the Paria Canyon Wilderness Area, and parts of the Glen Canyon National Recreation Area. The eastern part of the area is on the Navajo Indian Reservation. The main access to the area is along U.S. Highway Alternate 89. While there are numerous dirt roads and trails in the area, travel is limited by the rugged topography of the Vermilion Cliffs.

AREA B

Area B is considered favorable for vein-type deposits in sedimentary rocks (Class 730), specifically breccia pipes. Only a few are known in the

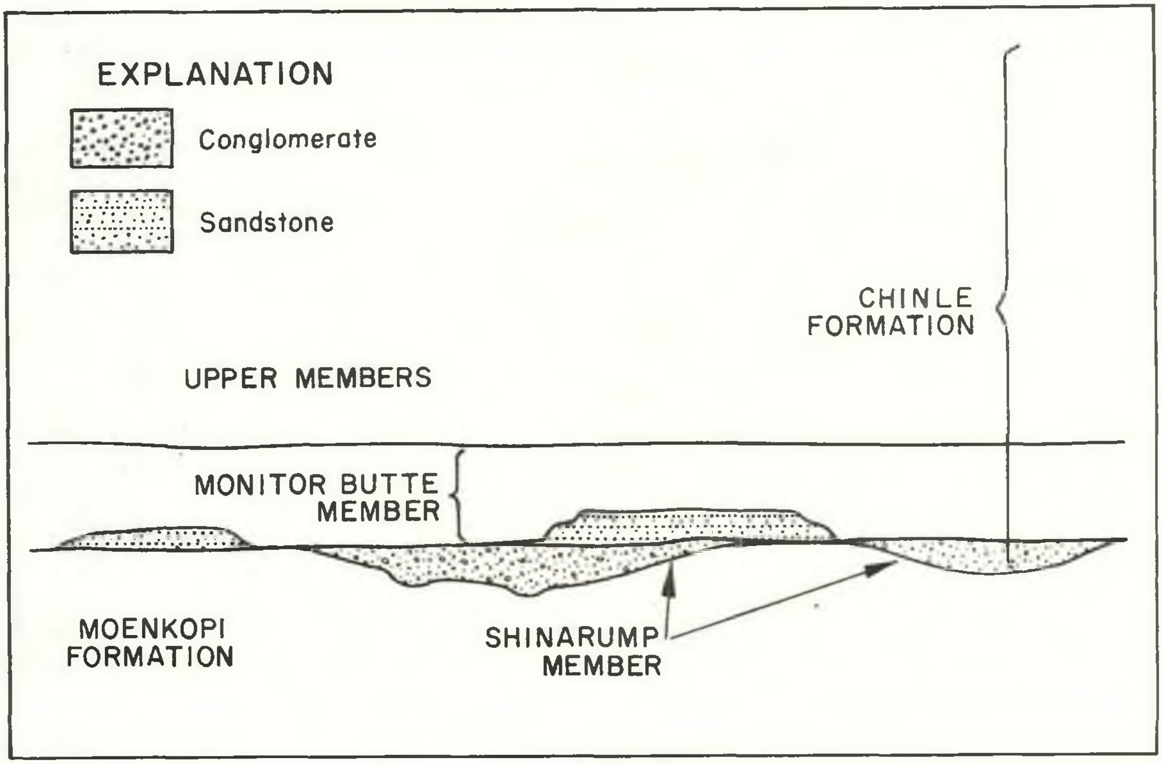


Figure 5. Shinarump stratigraphy as interpreted by Young (1964).

Marble Canyon Quadrangle, and all are within the Grand Canyon (Grand Canyon Natural History Association, 1973) except for one collapse structure in the south, west of Route 89. However, many are known in the adjacent quadrangles (Grand Canyon, Flagstaff) to the west and south, and several of these contain uranium deposits. The Orphan Lode Mine, which has produced 2,000 tons of U_3O_8, is only 13 km west of the Marble Canyon Quadrangle.

It is believed that the favorable area for breccia-pipe uranium deposits continues into the Marble Canyon Quadrangle from the Grand Canyon Quadrangle (Baillieul and Zollinger, 1980). The density of these breccia-pipe uranium deposits is one or more pipes per 128 km^2. The favorable area in the Marble Canyon Quadrangle is 3,429 km^2. This implies a minimum of 27 breccia pipes in Area B.

The Redwall Limestone, in which caverns control the formation of the known breccia pipes in the Grand Canyon and Marble Canyon Quadrangles, is present under the entire Marble Canyon Quadrangle (Irwin and others, 1971). The eastern boundary of Area B is drawn along the eastern exposure of the Kaibab Limestone; east of the Kaibab exposure the pipes cannot be detected because of the thick cover. The Redwall is commonly more than 1500 m below the surface. In the favorable area, the top of the Redwall is typically 500 m below the ground surface. It has been found that the breccia pipes in the Grand Canyon Quadrangle may extend upward as much as 400 m above the top of the Redwall. Therefore, breccia pipes in Area B may be from 100 to 500 m below the ground surface.

AREA C

This is a portion of the Toreva Formation in southeastern Black Mesa. The Toreva Formation meets the following criteria for non-channel-controlled peneconcordant deposits (Subclass 244):

- Platform tectonic setting (Colorado Plateau)
- Clean, quartzose to feldspathic sandstones containing scattered carbonaceous material
- Siltstones, mudstones, and coal providing local permeability control
- Metatyuyamunite present

The presence of other criteria is uncertain. Sandstones in the Toreva are gray, and it is not apparent if this is the original color or if they have been bleached. It is not known if any of the sediments are derived from tuffs or if the ore follows trends related to depositional drainages. No primary uranium minerals were identified.

The Toreva Formation is composed largely of gray sandstone. In some parts of Black Mesa, there is a middle shaly or carbonaceous unit. The lower sandstone portion of the Toreva is massive and rests on the impermeable Mancos Shale. All uranium mines are in the lower sandstone, and most of the springs in the area are at the Toreva-Mancos contact.

The favorable area of Toreva in the Marble Canyon Quadrangle has been delineated on the basis of structure and ground-water sampling. There are several uranium mines in the Toreva Formation just east of the Marble Canyon Quadrangle, and ground-water anomalies imply that the zone of mineralization extends into the quadrangle (Fig. 6). The largest mine, Claim 28, produced 9 tons of U_3O_8. The total for all mines was 28 tons (Chenoweth, 1973). We believe the deposits in the Marble Canyon Quadrangle are no larger, but the Toreva in the southeast part of the quadrangle is favorable for deposits of 10 tons U_3O_8 each with grade of at least 100 ppm U_3O_8.

An aerial radioactivity survey was made for approximately twenty miles west of the mines (Clinton, 1954), and the area has been prospected. However, no mines were opened in the Marble Canyon Quadrangle. The sandstone at the mines contains more carbonaceous material than is commonly found in the Toreva. The reason for this difference is not known.

An explanation for the distribution of the mines may be seen in Figure 6. To the east of the mines is a steady upgrade to the Defiance uplift near the New Mexico border. Uranium-bearing water could have moved down this long homocline, meeting the first interruption to its flow in the syncline, which now contains the mines. It appears that the uranium was precipitated in and near this syncline and did not move far west or north.

The Toreva Formation in Area C occupies an area of 472 km^2. Uranium deposits have been found only in the 40-m-thick, lower part of the lower member. In Area C, this member crops out or is buried under less than 100 m of overlying Wepo Formation.

AREA E

Area E, favorable for channel-controlled peneconcordant sandstone uranium deposits, Class 243, is located in the Petrified Forest Member of the Chinle Formation. The area covers 324 km^2 and is a small extension of a larger favorable area in the Flagstaff Quadrangle. The reader can refer to the National Uranium Resource Evaluation, Flagstaff Quadrangle, Arizona, by Wenrich-Verbeek and Spirakis (1980) for details.

Area E is entirely within the Navajo Indian Reservation. U.S. Highway 89 runs through the area, but access is limited by the Echo Cliffs.

ENVIRONMENTS UNFAVORABLE FOR URANIUM DEPOSITS

There are many unfavorable environments for uranium deposition in the Marble Canyon Quadrangle. The marine limestones, eolian sandstones, and fluvial sedimentary rocks (except Areas A and C) are not considered favorable for limestone (Class 230, Jones, 1978) or sandstone (Class 240, Austin and D'Andrea, 1978) uranium deposits. The marine shales and near-shore and tidal-flat sediments of the quadrangle also fail to meet recognition criteria for marine shale (Class 130, Jones, 1978) or sandstone (Class 240) uranium deposits. The basic dikes and flows do not meet the criteria for plutonic

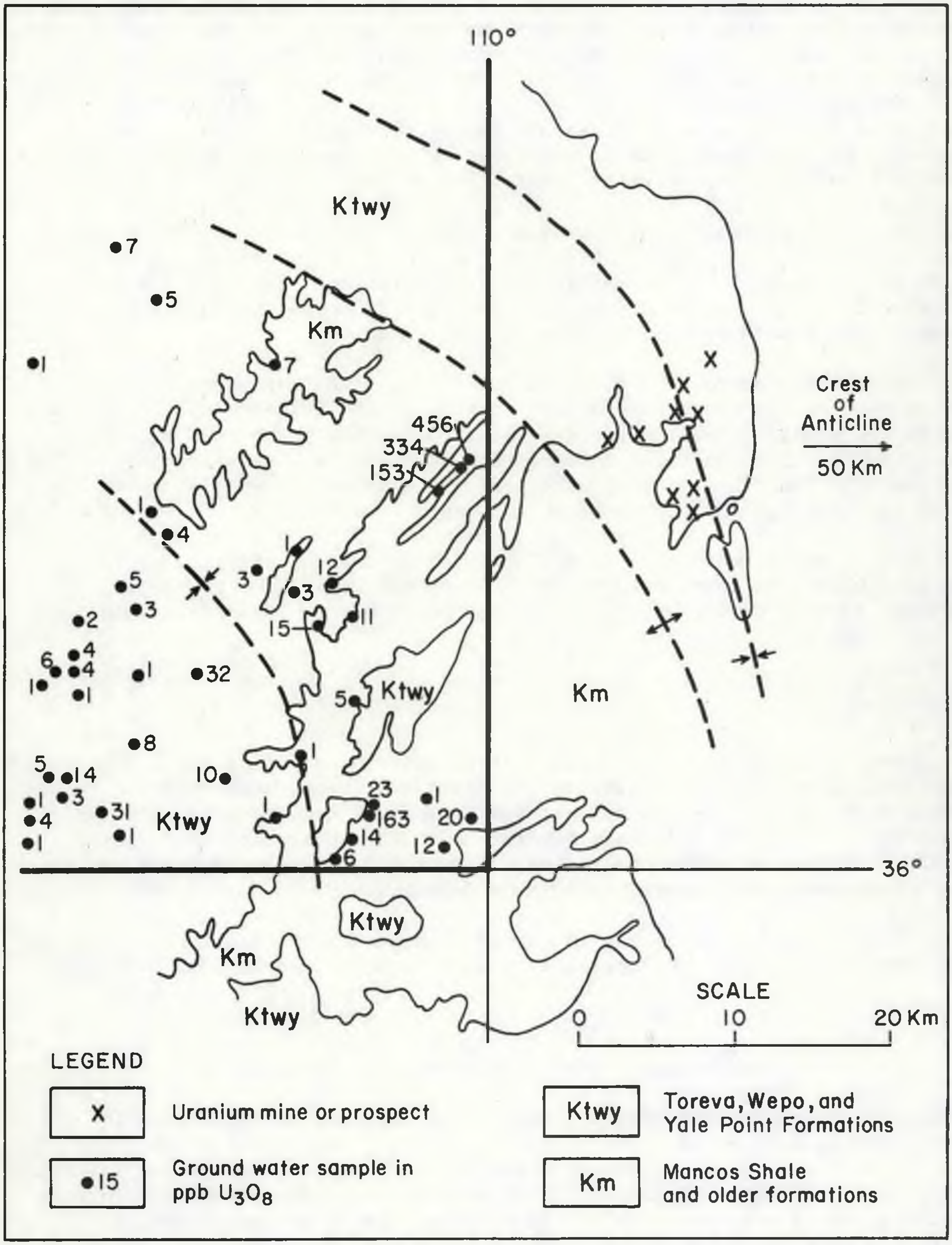


Figure 6. The Toreva Formation in southeastern Black Mesa

(Class 300, Mathews, 1978a) or volcanogenic (Class 500, Pilcher, 1978) deposits.

EOLIAN SANDSTONE

The eolian sandstones are unfavorable host rocks for sandstone uranium deposits (Class 240). This depositional environment is represented in Marble Canyon by the following formations: the Permian DeChelly Sandstone and Cedar Mesa Members of the Cutler Formation and the Coconino Sandstone; the Lukachukai Member of the Upper Triassic Wingate Sandstone; the Triassic-Jurassic Navajo Sandstone; and the Upper Jurassic Cow Springs Formation.

All of these units are composed primarily of very fine- to medium-grained quartz sand and exhibit large-scale cross-bedding. The Coconino Sandstone is cemented with silica. The others are weakly cemented with calcite and, in places, iron oxides. Accessory minerals are rare, and all these units are lithologically uniform. They are mature, homogeneous, clean sandstones; there is little visible alteration and no obvious reductants. Local permeability and concentrating controls are lacking. No anomalous radioactivity was detected in numerous air and carborne traverses. The only mineralization found in these rocks is the copper mine in the Navajo Sandstone about 30 km south of Page, which is discussed under unevaluated environments.

MARINE SHALES

The marine and marginal-marine shales of the quadrangle are the Hakatai Shale, Bright Angel Shale, and Mancos Shale. The Precambrian Hakatai is an orange-red mudstone deposited in shallow water. The Cambrian Bright Angel Shale is dominantly a green mudstone. Both of these are exposed only within the Grand Canyon. The Mancos Shale, a Cretaceous, dark marine shale with thin sand ledges, is exposed around the rim of Black Mesa and at some places in the interior of the mesa. None of the shales contain enough organic material and pyrite to be considered favorable for uranium deposits in marine black shale (Class 130).

MARINE SANDSTONES

The nearshore marine sedimentary rocks of the Precambrian Shinumo Quartzite, Dox Sandstone, and Nankoweap Formation, and the Carmel, Entrada, and Summerville Formations of the Jurassic San Rafael Group are all considered unfavorable for coastal-plain deposits (Subclass 242, Austin and D'Andrea, 1978). The Precambrian rocks are exposed only within the Grand Canyon. The Shinumo Quartzite is a massive white, red, purple, and brown sandstone. The Dox Sandstone consists of red siltstones and shales with abundant ripple marks and mudcracks. There are a few thin algal limestones. The Nankoweap Formation consists of thick-bedded, ripple-marked, cross-bedded white, purple, and brown sandstones.

The San Rafael Group rocks are exposed along the margin of the Black Mesa Basin and as scattered outcrops throughout the Kaibito Plateau. They are primarily a red, well-sorted, very fine- to medium-grained quartz sandstone.

They are well cemented with calcite, have few or no accessory minerals, and contain little carbonaceous material. Local permeability controls within the formations are lacking. The formations lack the tuff sources, sulfides, and down-to-basin faults of coastal-plain deposits. The Precambrian rocks, deposited before the existence of land plants, could not contain carbonaceous material as a reductant.

High uranium values were found in water samples taken from three springs in upper Bat Canyon, in a sandy white facies of the Entrada (Harshbarger and others, 1957) in the south-central part of the quadrangle. The unit is not considered favorable, and the reason for these anomalous values is not known.

FLUVIAL SEDIMENTARY ROCKS

The fluvial sandstones and siltstones of the Marble Canyon Quadrangle (except for Areas A and C, Pl. 1) have been determined to be unfavorable for sandstone uranium deposits (Class 240). The sandstones will be discussed first. The formations in this category include the Tapeats Sandstone, the Dinosaur Canyon and Springdale Sandstone Members of the Moenave Formation, the Church Rock Member of the Chinle Formation, the Kayenta Formation, the Morrison Formation, the Dakota Sandstone, the Toreva Formation, the Wepo Formation, and the Yale Point Sandstone.

The Cambrian Tapeats Sandstone, exposed only in the Grand Canyon, is a gray to brown, medium- to coarse-grained, well-cemented sandstone with very low permeability.

The Triassic Moenave and Kayenta Formations are exposed along the Echo Cliffs; and the Kayenta crops out near Monument Valley; and the Triassic Church Rock Member is found only in the Monument Valley area.

The Church Rock Member of the Chinle Formation consists of an upper red cross-bedded sandstone (the Hite bed) and a lower red siltstone. The upper, fluvial portions of the slope-forming Dinosaur Canyon Member (the lower part is eolian) consist of coarse- to very fine-grained quartz sand and large amounts of silt. It is poorly sorted and is firmly cemented by calcite. Accessory minerals are rare, and argillaceous materials are locally common.

The cliff-forming Springdale Sandstone consists of laminated, ripple-marked sandstone composed of fine- to medium-grained quartz with scattered claystone lenses and conglomeratic zones. The Kayenta Formation is divided into a sandy facies and a silty facies. Near Kayenta, the sandy facies consists of fine- to medium-grained irregularly bedded calcareous-cemented fluvial sandstones intercalated with beds of shale and arenaceous limestone. In the southern Echo Cliffs area, the silty facies consists of fine-grained sandstones and intercalated siltstone and mudstone. None of the above sandstones are favorable for the occurrence of uranium deposits. They are generally impermeable, well cemented, fine grained, and contain silt. They lack plant material, and no bleaching of these predominantly red rocks was observed.

The Jurassic Morrison Formation crops out only in the northeast part of the Marble Canyon Quadrangle and includes the Westwater Canyon, Recapture, and

Salt Wash Members. Only the Westwater is well exposed. The Morrison thins westward and pinches out in the subsurface of the eastern part of the Marble Canyon Quadrangle. The three members consist of light-gray cross-bedded sandstone with some interbedded mudstone and conglomerate. The Morrison is a uranium-bearing formation elsewhere on the Colorado Plateau. In the Marble Canyon Quadrangle, it meets several favorability criteria for sandstone uranium occurrences but lacks permeability restrictions and reductants.

The Morrison Formation was traversed, and rock and ground-water samples were taken. No unusual radioactivity was noted except for a few places near clay pods or carbonaceous material. It appears that uranium-bearing water flowed through the Morrison Formation in the Marble Canyon Quadrangle but that conditions for its precipitation were present only locally and to a small degree. Small amounts of uranium have been mined just east of the quadrangle from the lower part of the Recapture Member, but nothing has been produced from the Morrison in the Marble Canyon Quadrangle.

The Cretaceous Dakota Sandstone, exposed around the edges of Black Mesa, consists of medium- to fine-grained, cross-bedded quartz sandstone. Local conglomerate lenses are present along with abundant iron-rich concentrations and carbonized plant fragments. Interbedded with the sandstone are thin carbonaceous siltstones and, locally, coal beds. The Dakota is permeable and meets some criteria for sandstone uranium deposits but lacks permeability controls and properly distributed carbonaceous material. Although similar to the Morrison, the Dakota is not mineralized even in areas where the Morrison is mineralized.

Overlying the Mancos Shale on Black Mesa is a thick sequence of fluvial and near-shore sandstones and shales of Late Cretaceous age. From base to top, these are the Toreva Formation, Wepo Formation, and Yale Point Sandstone (O'Sullivan and others, 1972). A portion of the Toreva is favorable and has been discussed above. The rest of the Toreva, and the other units, meet some, but not all, of the criteria for favorability. Medium- to coarse-grained gray sandstones are common, and carbonaceous material is present. However, well-developed fluvial structures, found in many favorable sandstones, are absent; and, the carbonaceous material is largely confined to shaly horizons rather than being distributed through the sandy beds.

The Yale Point Formation is a massive sandstone that caps the highest elevations of Black Mesa. Its extent is very limited, and it may be assumed that it is thoroughly leached. The Wepo Formation is a sequence of siltstones and sandstones and contains large coal deposits. The permeability is less than that of rocks that contain uranium deposits. Numerous traverses were made across the Wepo Formation by car and helicopter, and ground water from springs was sampled (Pl. 5). The radioactivity and uranium values were consistently low.

Several fluvial sedimentary units in the Marble Canyon Quadrangle are predominantly siltstones and do not fit any favorability criteria. They are too fine grained, impermeable, and lack reductants. These are the Supai Formation, Hermit Shale, Organ Rock Member of the Cutler Formation, Moenkopi Formation, Petrified Forest, Owl Rock and Monitor Butte Members of the Chinle Formation, and Rock Point Member of the Wingate Sandstone.

Uranium occurrences are found near the base of the Supai Formation further south in coarser grained facies (Pierce and others, 1977), but the Supai in the Marble Canyon area is too fine grained to be considered favorable. The Moenkopi Formation is commonly bleached at the upper contact with the Shinarump Member of the Chinle Formation, and copper-uranium mineralization in the Shinarump may extend down into the Moenkopi but is part of the Shinarump mineralization.

The Petrified Forest Member of the Chinle Formation is a thick sequence of multicolored shales. It contains small uranium prospects in the Paria Canyon - Vermilion Cliffs area. These are either in massive sandstone beds within the shales or associated with petrified wood.

The Cameron district, just south of the Marble Canyon Quadrangle near Route 89, consists of numerous mines in the lower part of the Petrified Forest Member. There are a few mines in the basal Petrified Forest in the southwest part of the Marble Canyon Quadrangle, but most of this group of occurrences (Pl. 2) are in the Shinarump. The type of occurrences that characterize the Cameron district appear to end rather abruptly just north of the southern boundary of the Marble Canyon Quadrangle, and the small occurrences in the Marble Canyon quadrangle do not indicate that the member is favorable there.

MARINE LIMESTONE

The marine limestones of the Marble Canyon Quadrangle are unfavorable for Todilto-type uranium deposits (Class 230). These limestones are the Bass Limestone, Chuar Group, Muav Limestone, Temple Butte Limestone, Redwall Limestone, Toroweap Formation, and Kaibab Limestone. All except the Kaibab are exposed only within the Grand Canyon. The Kaibab Limestone forms an extensive platform in the western part of the Marble Canyon Quadrangle. All of these limestones lack organic matter and depositional characteristics necessary for them to be considered favorable for Todilto-type deposits.

IGNEOUS ROCKS

The Precambrian Cardenas Lavas and the Pliocene and Pleistocene intrusive dikes and plugs are basaltic; other basic intrusive rocks are too ferromagnesian to meet the criteria for plutonic (Class 300) or volcanogenic (Class 500) uranium deposits. They are not in a mobile belt or basin and range tectonic setting.

UNEVALUATED ENVIRONMENTS

The Precambrian Vishnu Schist and the unconformably overlying Hotauta Conglomerate are unevaluated in the Marble Canyon Quadrangle. Their exposure is very limited, consisting of four linear miles in the bottom of the Grand Canyon in the southwest corner of the quadrangle, and access to this area was denied. These units are considered favorable in the Grand Canyon Quadrangle, west of Marble Canyon, where there is more exposure.

Uranium is found in some of the copper occurrences in and near the old copper mine in the Navajo Sandstone about 30 km south of Page (App. C, Occurrence 14). Most of these copper occurrences have uranium content equal to or double that of the country rocks, but contents on the order of 100 ppm uranium have not been found. The individual copper occurrences, although numerous, are mostly a cubic meter or less. No occurrence pattern could be found. The mineralization appears to be associated with deep-seated fractures, perhaps along the Bright Angel - Eminence Break fault system, or possibly along a hypothetical southeast-trending fracture connecting the copper-mine area with ground-water anomalies in the vicinity of Tonalea (Pl. 5). If these deep fractures are the source of copper and uranium, they probably extend to the basement. It is possible that there are uranium deposits associated with these fractures, but there is no way to estimate their size, depth, or location.

INTERPRETATION OF AERIAL RADIOMETRIC DATA

An aerial radiometric survey was made of the Marble Canyon Quadrangle in 1979 by LKB Resources, Inc. Data from this survey were interpreted by the personnel of Bendix Field Engineering Corporation. The anomalous areas are shown on Plate 3.

The westernmost of the three uranium anomalies is over the Kaibab Limestone, which is considered to be an unfavorable unit. Possibly, uranium was leached from formerly overlying units into fractures in the limestone. This area was not investigated in the field because the aerial radiometric survey was not available until some months after field work was completed.

The two easternmost anomalies are over a broad area of the Shinarump Member of the Chinle Formation. This area was found in the field to have radioactivity a few times background but only in a few small occurrences.

RECOMMENDATIONS TO IMPROVE EVALUATION

No new uranium occurrences will be found in the Marble Canyon Quadrangle without extensive drilling. The outcrops of every unit that might possibly have uranium have been investigated on foot over the last three decades, and the southwest and southeast parts of the quadrangle have been flown in some detail. It can be said with confidence that the uranium reserves of the Shinarump are considerable, but no one has yet found a way to predict where within the Shinarump channels the deposits may be found.

Detailed ground-water sampling of the Toreva Formation in areas not visited in this study might extend the favorable area of the Toreva. Large areas of Toreva are covered by younger formations. Some of these areas, in western Black Mesa, have been deformed into basins (Pl. 8) in which uranium could be concentrated. The presence of uranium in the subsurface Toreva could be revealed only by drilling.

SELECTED BIBLIOGRAPHY

Akers, J. P., Irwin, J. H., Stevens, P. R., and McClymonds, N. E., 1962, Geology of the Cameron Quadrangle, Arizona: U.S. Geological Survey Map GQ-162, scale 1:62,500.

Anderson, R. Y., and Harshbarger, J. W., eds., 1958, Guidebook of the Black Mesa Basin: New Mexico Geological Society, Ninth Annual Field Conference, 205 p.

Annes, E. C., Jr., 1956, Reconnaissance for uranium deposits in the Kaiparowits Plateau region, Utah: U.S. Atomic Energy Commission, Trace Elements Memorandum, Open-File Report TEM-96, 18 p.

Austin, S. Ralph and D'Andrea, R. F., Jr., 1978, Sandstone-type uranium deposits, in Mickle, D. G., and Mathews, G. W., eds., Geologic characteristics of environments favorable for uranium deposits: U.S. Department of Energy, Open-File Report GJBX-67(78), p. 87-120.

Baillieul, T. A., and Zollinger, R. C., 1980, National uranium resource evaluation, Grand Canyon Quadrangle, Arizona: U.S. Department of Energy, Preliminary Open-File Report PGJ-020(80), 316 p.

Baldwin, E. J., 1973, The Moenkopi Formation of north-central Arizona, An interpretation of ancient environments based upon sedimentary structures and stratification types: Journal of Sedimentary Petrology, v. 43, no. 1, p. 92-106.

Beaumont, E. C., and Dixon, G. H., 1965, Geology of the Kayenta and Chilchinbito Quadrangles, Navajo County, Arizona: U.S. Geological Survey Bulletin 1202-A, 28 p.

Black, R. A., 1956, Geophysical exploration for uranium on the Colorado Plateau, in Page, L. R., Stocking, H. E., and Smith, H. B., comps., Contributions to the geology of uranium and thorium by the U.S. Geological Survey and Atomic Energy Commission for the United Nations International Conference on peaceful uses of atomic energy, Geneva, Switzerland, 1955: U.S. Geological Survey Professional Paper 300, p. 721-726.

Chenoweth, W. L., 1973, Mine location map, Black Mountain-Rough Rock area Apache County, Arizona: U.S. Department of Energy Preliminary Map No. 31, Open-File Map, scale 1:62,500.

Chenoweth, W. L., and Malan, R. C., 1973, The uranium deposits of northeastern Arizona, in Guidebook of Monument Valley and Vicinity, Arizona and Utah: New Mexico Geological Society, 24th Annual Field Conference, p. 139-150.

Chenoweth, W. L., and Magelby, D. N., 1971, Mine location map, Cameron uranium area, Coconino County, Arizona: U.S. Atomic Energy Commission Preliminary Map No. 20, Open-File Map, scale 1:62,500.

Chester, J. W., 1951, Geology and mineralization of Hunt's Mesa, Monument Valley, Arizona: U.S. Atomic Energy Commission, Raw Materials Exploration Report, Open-File Report RMO-801, 9 p.

Clinton, N. J., 1956, Uranium reconnaissance of the Black Mountain-Yale Point area, Black Mesa, Navajo Indian Reservation, Arizona: U.S. Atomic Ener Commission, Raw Materials Exploration Report, Open-File Report RME-91, 24 p.

Clinton, N. J., and Carithers, L. W., 1956, Uranium deposits in sandstones of marginal marine origin, in Page, L. R., Stocking, H. E., and Smith, H. B., comps., Contributions to the geology of uranium and thorium by the U.S. Geological Survey and Atomic Energy Commission for the United National International Conference on peaceful uses of atomic energy, Geneva, Switzerland, 1955: U.S. Geological Survey Professional Paper 300, p. 721-726.

Cooley, M. E., Harshbarger, J. W., Akers, J. P., and Hardt, W. F., 1969, Regional hydrogeology of the Navajo and Hopi Indian Reservations, Arizona, New Mexico, and Utah: U.S. Geological Survey Professional Paper 521-A, 61 p.

Evensen, C. G., and Gray, I. B., 1957, Geology of Monument Valley uranium deposits, Arizona and Utah: U.S. Atomic Energy Commission, Raw Materials Exploration Report, Open-File Report RME-95, 38 p.

Evensen, C. G., and Gray, I. B., 1958, Evaluation of uranium ore guides, Monument Valley, Arizona and Utah: Economic Geology, v. 53, p. 639-662.

Finch, W. I., 1959, Geology of uranium deposits in Triassic rocks of the Colorado Plateau region: U.S. Geological Survey Bulletin 1074-D, p. 125-164.

Fischer, R. P., 1956, Uranium - vanadium - copper deposits of the Colorado Plateau, in Page, L. R., Stocking, H. E., and Smith, H. B., comps., Contributions to the geology of uranium and thorium by the U.S. Geological Survey and the Atomic Energy Commission for the United Nations International Conference on peaceful uses of atomic energy, Geneva, Switzerland, 1955: U.S. Geological Survey Professional Paper 300, p. 143-154.

Fischer, R. P., 1970, Similarities, differences, and some genetic problems of the Wyoming and Colorado plateau types of uranium deposits in sandstone: Economic Geology, v. 65, p. 778-784.

Ford, T. D., and Breed, W. J., 1976, The younger Precambrian rocks of the Grand Canyon, in Breed, W. J., and Road, Evelyn, eds., Geology of the Grand Canyon: Flagstaff, Museum of Northern Arizona, p. 21-33.

Freeman, W. E., and Visher, G. S., 1975, Stratigraphic analysis of the Navajo sandstone: Journal of Sedimentary Petrology, v. 45, no. 3, p. 651-668.

Gray, I. B., 1957, Drilling in the Flatirons locality, Monument Valley, Arizona: U.S. Atomic Energy Commission, Trace Elements Memorandum, Open-File Report TEM-126, 9 p.

Grand Canyon Natural History Association, 1976, Geologic map of the Grand Canyon National Park, Arizona: scale 1:62,500.

Harshbarger, J. W., Repenning, C. A., and Irwin, J. H., 1957, Stratigraphy of the uppermost Triassic and the Jurassic rocks of the Navajo Country: U.S. Geological Survey Professional Paper 291, 74 p.

Haynes, D. D., and Hackman, R. J., 1978, Geology, structure, and uranium deposits of the Marble Canyon 1° x 2° Quadrangle, Arizona: U.S. Geological Survey Miscellaneous Investigations Map I-1003, scale 1:250,000.

Irwin, J. H., Stevens, P. R., and Cooley, M. E., 1971, Geology of the Paleozoic rocks, Navajo and Hopi Indian Reservations, Arizona, New Mexico and Utah: U.S. Geological Survey Professional Paper 521-C, 32 p.

Isachsen, Y. W., and Evensen, C. G., 1956, Geology of the uranium deposits of the Shinarump and Chinle Formations of the Colorado Plateau, in Page, L. R., Stocking, H. E., and Smith, H. B., comps., Contributions to the geology of uranium and thorium by the U.S. Geological Survey and Atomic Energy Commission for the United Nations International Conference on peaceful uses of atomic energy, Geneva, Switzerland, 1955: U.S. Geological Survey Professional Paper 300, p. 263-280.

James, H. L., (ed.), 1972, Guidebook of Monument Valley and vicinity: New Mexico Geological Society, 24th Annual Field Conference, 206 p.

Jobin, D. A., 1962, Relation of the transmissive character of the sedimentary rocks of the Colorado Plateau to the distribution of uranium deposits: U.S. Geological Survey Bulletin 1124, 151 p.

Jones, C. A., 1978, Uranium occurrences in sedimentary rocks exclusive of sandstone, in Mickle, D. G., and Mathews, G. W., eds., Geologic characteristics of environments favorable for uranium deposits: U.S. Department of Energy, Open-File Report GJBX-67(78), p. 1-86.

Kelley, V.C., 1955, Monoclines of the Colorado Plateau: Geological Society of America Bulletin, v. 66, p. 789-804.

LKB Resources, Inc., 1979, NURE aerial gamma-ray and magnetic reconnaissance survey, Marble Canyon Quadrangle: U.S. Department of Energy, Open-File Report GJBX-16(80), 2 vol., 214 p.

Lessentine, R. H., 1965, Kaiparowits and Black Mesa Basins; Stratigraphic synthesis: American Association of Petroleum Geologists Bulletin, v. 49, p. 1997-2019.

Lewis, R. Q., Sr., and Trimble, D. E., 1959, Geology and uranium deposits of Monument Valley, San Juan County, Utah: U.S. Geological Survey Bulletin 1087-D, p. 105-131.

Lowell, R. Q., Sr., 1954, Locating paleochannels as opposed to locating uranium ore bodies in Shinarump exploration: U.S. Atomic Energy Commission, Trace Elements Memorandum, Open-File Report TEM-63, 4 p.

Malan, R. C., 1968, The uranium mining industry and geology of the Monument Valley and White Canyon districts, Arizona and Utah, in Ore deposits of the United States, 1933-1967: The Graton-Sales Volume, v. 1, p. 79-804.

Mathews, G. W., 1978a, Uranium occurrences in and related to plutonic igneous rocks, in Mickle, D. G., and Mathews, G. W., eds., Geologic characteristics of environments favorable for uranium deposits: U.S. Department of Energy, Open-File Report GJBX-67(78), p. 121-180.

Mathews, G. W., 1978b, Uranium occurrences of uncertain genesis, in Mickle, D. G. and Mathews, G. W., eds., Geologic characteristics of environments favorable for uranium deposits: U.S. Department of Energy, Open-File Report GJBX-67(78), p. 121-180.

McKee, E. D., 1976, Paleozoic rocks of the Grand Canyon, in Breed, W. J., and Roat, Evelyn, eds. Geology of the Grand Canyon: Flagstaff, Museum of Northern Arizona, p. 42-64.

McKee, E. D., 1969, Paleozoic rocks of Grand Canyon, in Geology and natural history of the Grand Canyon region: Flagstaff, Arizona, Powell Centennial River Expedition, 5th Annual Field Conference, p. 79-90.

Mickle, D. G., and Mathews, G. W., eds., 1978, Geologic characteristics of environments favorable for uranium deposits: U.S. Department of Energy, Open-File Report GJBX-67(78), 250 p.

Minard, J. P., 1956, Photogeologic map of the Tanner Wash NW Quadrangle, Coconino County, Arizona: U.S. Geological Survey Miscellaneous Investigations Map I-193, scale 1:24,000.

Mitcham, T. W., and Evensen, C. G., 1955, Uranium ore gudies, Monument Valley, Arizona district, Arizona: Economic Geology, v. 50, p. 170-176.

Mitcham, T. W., and Evensen, C. G., 1956, Differential strain characteristics, a possible guide to Shinarump channels: U.S. Atomic Energy Commission, Trace Elements Memorandum, Open-File Report TEM-56, 1 p.

O'Sullivan, R. B., 1970, The upper part of the Upper Triassic Chinle Formation and related rocks, southeastern Utah and adjacent areas: U.S. Geological Survey Professional Paper 644-E, 22 p.

O'Sullivan, R. B., Repenning, C. A., Beaumont E. C., Page, H. G., 1972, Stratigraphy of the Cretaceous rocks and the Tertiary Ojo Alamo Sandstone, Navajo and Hopi Indian Reservations, Arizona, New Mexico, and Utah: U.S. Geological Survey Professional Paper 521-E, 65 p.

Petersen, R. G., 1957, East Vermilion Cliffs area, Arizona, in Geologic investigations of radioactive deposits, semiannual progress report, December 1, 1956 to May 31, 1957: U.S. Atomic Energy Commission, Trace Elements Investigation, Open-File Report TEI-690, p. 152-153.

Petersen, R. G., 1959, Preliminary geologic map of the Emmett Wash NE Quadrangle, Coconino County, Arizona: U.S. Geological Survey Mineral Investigations Field Studies Map MF-215, scale 1:24,000.

Petersen, R. G., 1961, Preliminary geologic map of the Paria Plateau SE Quadrangle, Coconino County, Arizona: U.S. Geological Survey Mineral Investigations Field Studies Map MF-196, scale 1:24,000.

Petersen, R. G., Hamilton, J. C., and Myers, A. T., 1959, An occurrence of rhenium associated with uraninite in Coconino County, Arizona: Economic Geology, v. 54, p. 254-267.

Petersen, R. G., and Phoenix, D. A., 1959, Preliminary geologic map of the Paria Plateau NE Quadrangle, Coconino County, Arizona: U.S. Geological Survey Mineral Investigations Field Studies Map MF-214, scale 1:24,000.

Petersen, R. G., and Wells, J. D., 1960, Preliminary geologic map of the Emmett Wash NW Quadrangle, Coconino County, Arizona: U.S. Geological Survey Mineral Investigations Field Studies Map MF-197, scale 1:24,000.

Phoenix, D. A., 1963, Geology of the Lees Ferry area, Coconino County, Arizona: U.S. Geological Survey Bulletin 1137, 86 p.

Pickens, C. M., 1974, Distribution of depositional environments, Dakota Formation (Cretaceous), Black Mesa basin, Arizona [abs.]: Geological Society of America Abstracts with Programs, v. 6, p. 467-468.

Pierce, H. W., and Scurlock, 1972, Arizona well information: Arizona Bureau of Mines Bulletin 185, 195 p.

Pierce, H. W., Jones, Nile, and Rogers, Ralph, 1977, A survey of uranium favorability of Paleozoic rocks in the Mogollon Rim and slope region - east central Arizona: Arizona Bureau of Geology and Mineral Technology Circular 19, 71 p.

Pierce, H. W., Keith, S. B., and Wilt, J. C., 1970, (reprinted 1975), Coal, oil, natural gas, helium and uranium in Arizona: Arizona Bureau of Mines Bulletin 182, 289 p.

Pilcher, R. C., 1978, Volcanogenic uranium occurrences, in Mickle, D. G., and Mathews, G. W., eds., Geologic characteristics of environments favorable for uranium deposits: U.S. Department of Energy, Open-File Report GJBX-67(78), p. 181-219.

Poole, F. G., and Williams, G. A., 1956, Direction of sediment transport in the Triassic and associated formation of the Colorado Plateau, in Page, L. R., Stocking, H. E., and Smith, H. B., comps., Contributions to the geology of uranium and thorium by the U.S. Geological Survey and Atomic Energy Commission for the United Nations International Conference on peaceful uses of atomic energy, Geneva, Switzerland, 1955: U.S. Geological Survey Professional Paper 300, p. 227-232.

Repenning, C. A., and Page, H. G., 1956, Late Cretaceous stratigraphy of Black Mesa, Navajo and Hopi Indian Reservations, Arizona: American Association of Petroleun Geologists Bulletin, v. 40, p. 225-294.

Repenning, C. A, Cooley, M. F., and Akers, J. P., 1969, Stratigraphy of the Chinle and Moenkopi Formations, Navajo and Hopi Indian Reservations, Arizona, New Mexico, and Utah: U.S. Geological Survey Professional Paper 521-B, 34 p.

Shoemaker, E. M., 1956, Occurrence of uranium in diatremes on the Navajo and Hopi Reservations, Arizona, New Mexico, and Utah, in Page, L. R., Stocking, H. E., and Smith, H. B., comps., Contributions to the goelogy of uranium and thorium by the U.S. Geological Survey and Atomic Energy Commission for the United Nations International Conference on peaceful uses of atomic energy, Geneva, Switzerland, 1955: U.S. Geological Survey Professional Paper 300, p. 179-185.

Shoemaker, E. M., 1956, Structural features of the central Colorado Plateau and their relations to uranium deposits, in Page, L. R., Stocking, H. E., and Smith, H. B., comps., Contributions to the geology of uranium and thorium by the U.S. Geological Survey and Atomic Energy Commission for the United Nations International Conference on peaceful uses of atomic energy, Geneva, Switzerland, 1955: U.S. Geological Survey Professional Paper 300, p. 155-170.

Stanley, K. O., Jordan, W. M., and Pott, R. H., Jr., 1971, New hypothesis of Early Jurassic paleogeography and sediment dispersal for western United States: American Association of Petroleum Geologists Bulletin, v. 55, no. 1, p. 10-19.

Stewart, J. H., Williams, G. A., Albee, H. F., and Raup, O. B., 1959, Stratigraphy of Triassic and associated formations in part of the Colorado Plateau region: U.S. Geological Survey Bulletin 1046-Q, p. 487-576.

Thaden, R. E., Trites, A. F., Jr., and Finnell, T. L., 1964, Geology and ore deposits of the White Canyon area, San Juan and Garfield Counties, Utah: U.S. Geological Survey Bulletin 1125, 166 p.

Visher, G. S., 1971, Depositional processes and the Navajo sandstone: Geological Society of America Bulletin, v. 82, p. 1421-1424.

Wells, J. D., 1960, Stratigraphy and structure of the House Rock Valley area, Coconino County, Arizona: U.S. Geological Survey Bulletin 1081-D, p. 117-158.

Witkind, I. J., 1956, Channels and related shales at the base of the Shinarump Conglomerate, Monument Valley, Arizona, in Page, L. R., Stocking, H. L., and Smith, H. B., comps., Contributions to the geology of uranium and thorium by the U.S. Geological Survey and Atomic Energy Commission for the United Nations International Conference on peaceful uses of atomic energy, Geneva, Switzerland, 1955: U.S. Geological Survey Professional Paper 300, p. 233-237.

Witkind, I. J., 1961, The uranium-vanadium ore deposit at Monument No. 1 - Mitten No. 2 mine, Monument Valley, Navajo County, Arizona: U.S. Geological Survey Bulletin 1107-C, 24 p.

Witkind, I. J., and Thaden, R. E., 1963, Geology and uranium-vanadium deposits of the Monument Valley area, Apache and Navajo Counties, Arizona with sections on Serpentine at Garnet Ridge, by H. D. Malde and R. E. Thaden, and Mineralogy and paragenesis of the ore deposit at the Monument No. 2 and Cato Sells mines, by D. H. Johnson: U.S. Geological Survey Bulletin 1103, 171 p.

Wright, J. C., and Dickey, D. D., 1969, Relations of the Navajo and Carmel Formations in southwest Utah and adjoining Arizona: U.S. Geological Survey Professional Paper 450-E, p. E63-E67.

Wright, J. C., 1969, A tuff clast from the Bidahochi Formation at Tonalea, Arizona: U.S. Geological Survey Professional Paper 650-D, p. D144-D147.

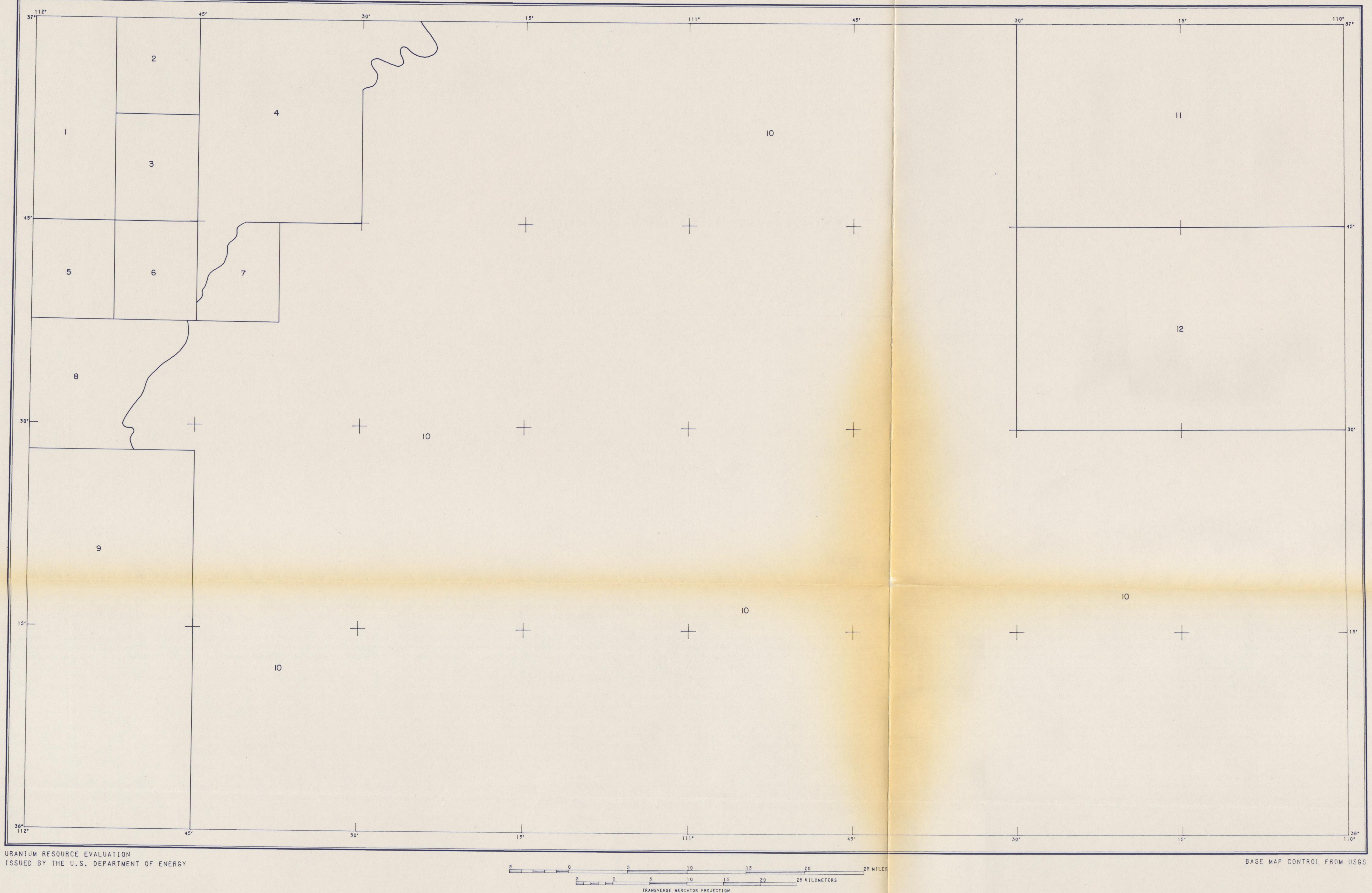
Wood, H. B., and Grundy, W. D., 1956, Techniques and guides in exploration for uranium in Shinarump channels of the Colorado Plateau, in Page, L. R., Stocking, H. E., and Smith, H. B., comps., Contributions to the geology of uranium and thorium by the U.S. Geological Survey and Atomic Energy Commission for the United Nations International Conference on peaceful uses of atomic energy, Geneva, Switzerland, 1955: U.S. Geological Survey Professional Paper 300, p. 651-658.

Wright, R. J., 1955, Ore controls in sandstone uranium deposits of the Colorado Plateau: Economic Geology, v. 50, p. 135-155.

Young, R. G., 1964, Distribution of uranium deposits in the White Canyon - Monument Valley district, Utah-Arizona: Economic Geology, v. 59, p. 850-873.

30

MARBLE CANYON, ARIZONA/ UTAH



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

BASE MAP CONTROL FROM USGS

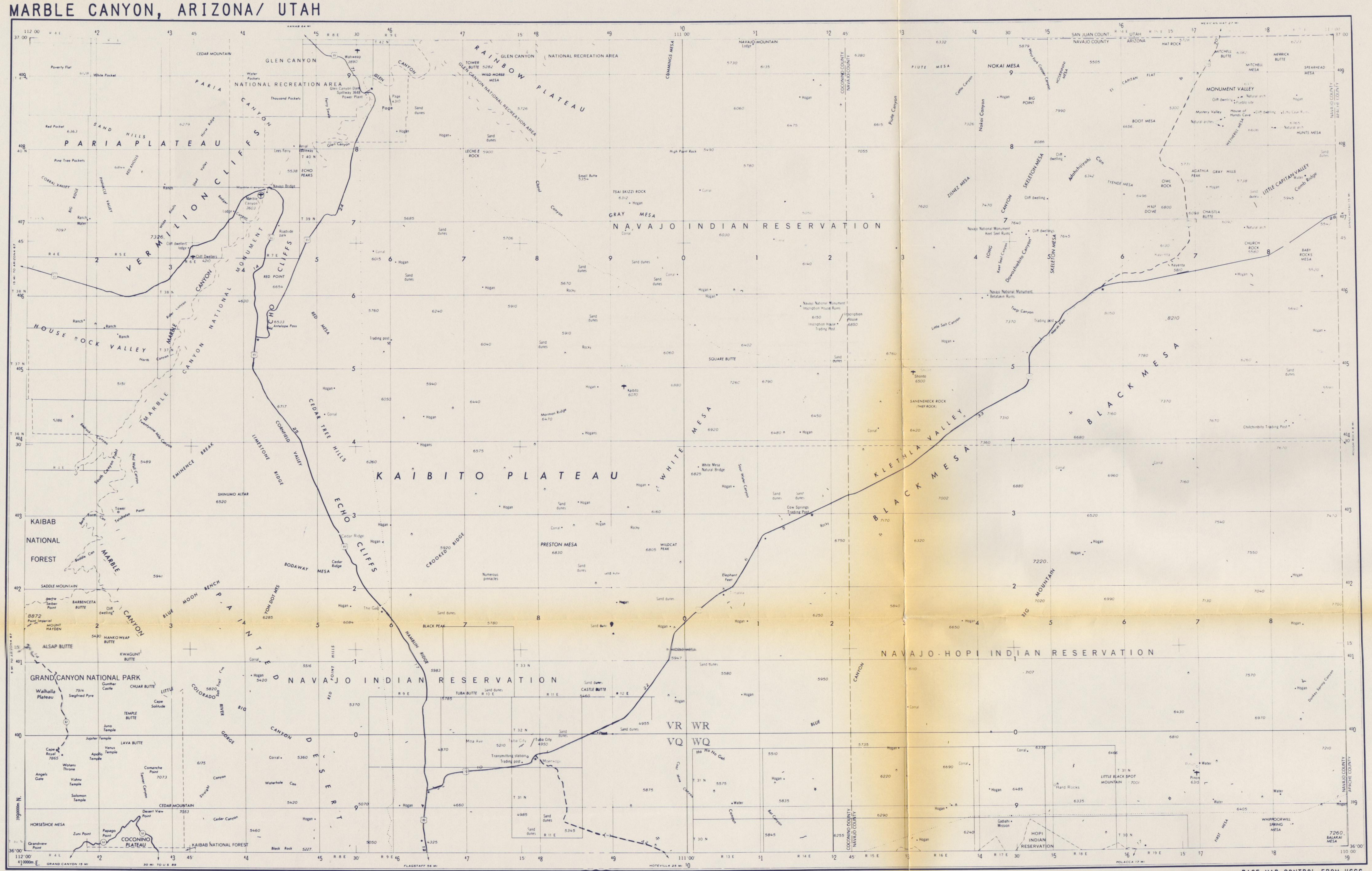
INDEX

1. Wells, 1960, scale 1:62,500.
2. Petersen and Phoenix, 1959, scale 1:24,000.
3. Petersen, 1961, scale 1:24,000.
4. Phoenix, 1963, scale 1:24,000.
5. Petersen and Wells, 1960, scale 1:24,000.
6. Petersen, 1959, scale 1:24,000.
7. Minard, 1956, scale 1:24,000.
8. Haynes and Hackman, 1978, scale 1:250,000.
9. Grand Canyon Natural History Association, 1976, scale 1:62,500.
10. Cooley and others, 1969, scale 1:125,000.
11. Witkind and Thaden, 1963, 1:62,500.
12. Beaumont and Dixon, 1965, 1:62,500.

Plate 9. GEOLOGIC-MAP INDEX

FEBRUARY 1
Pla

MARBLE CANYON, ARIZONA/ UTAH



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

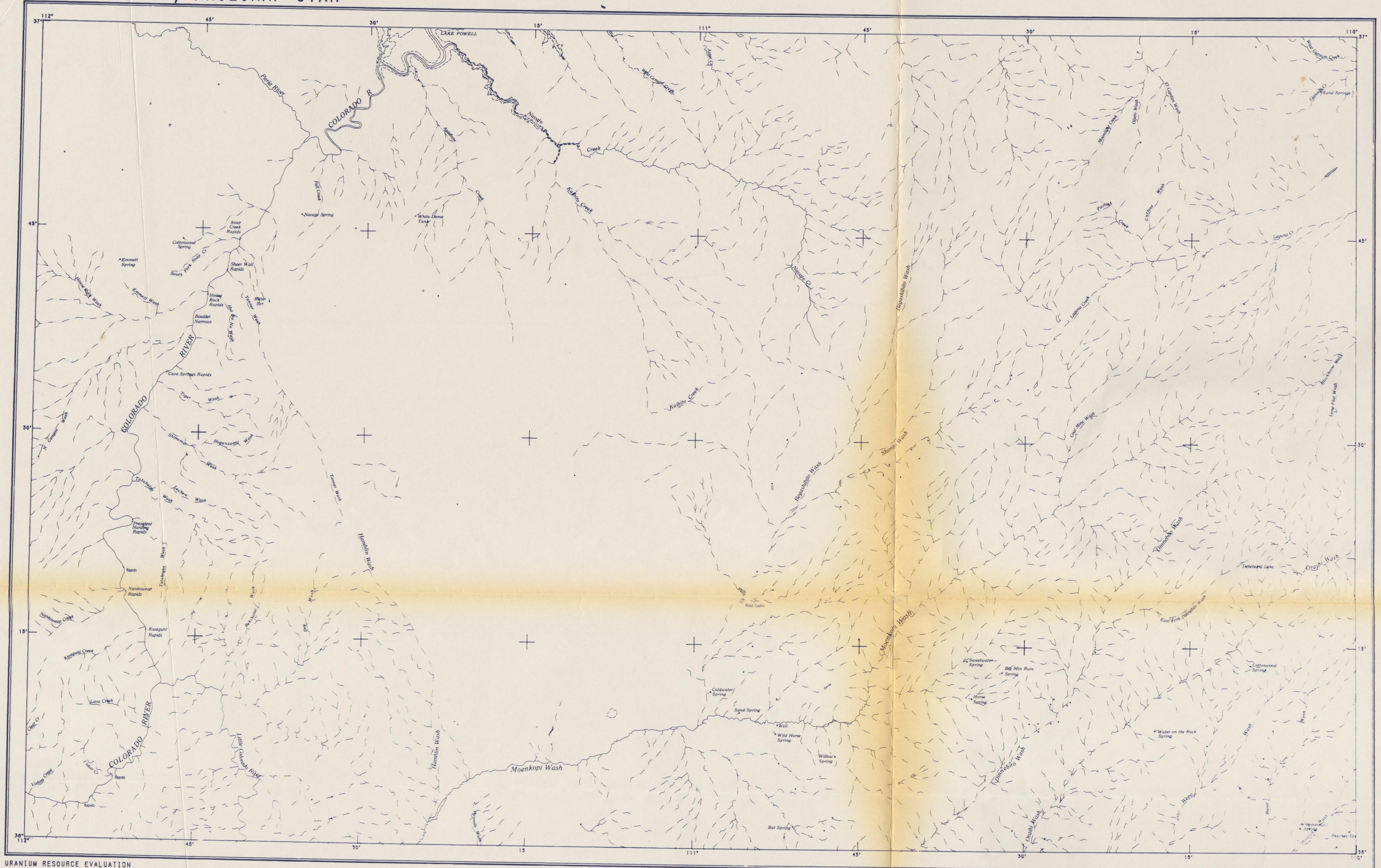
BASE MAP CONTROL FROM USGS

5 0 5 10 15 20 25 MILES

5 0 5 10 15 20 25 KILOMETERS

Plate 7. CULTURE

MARBLE CANYON, ARIZONA/ UTAH



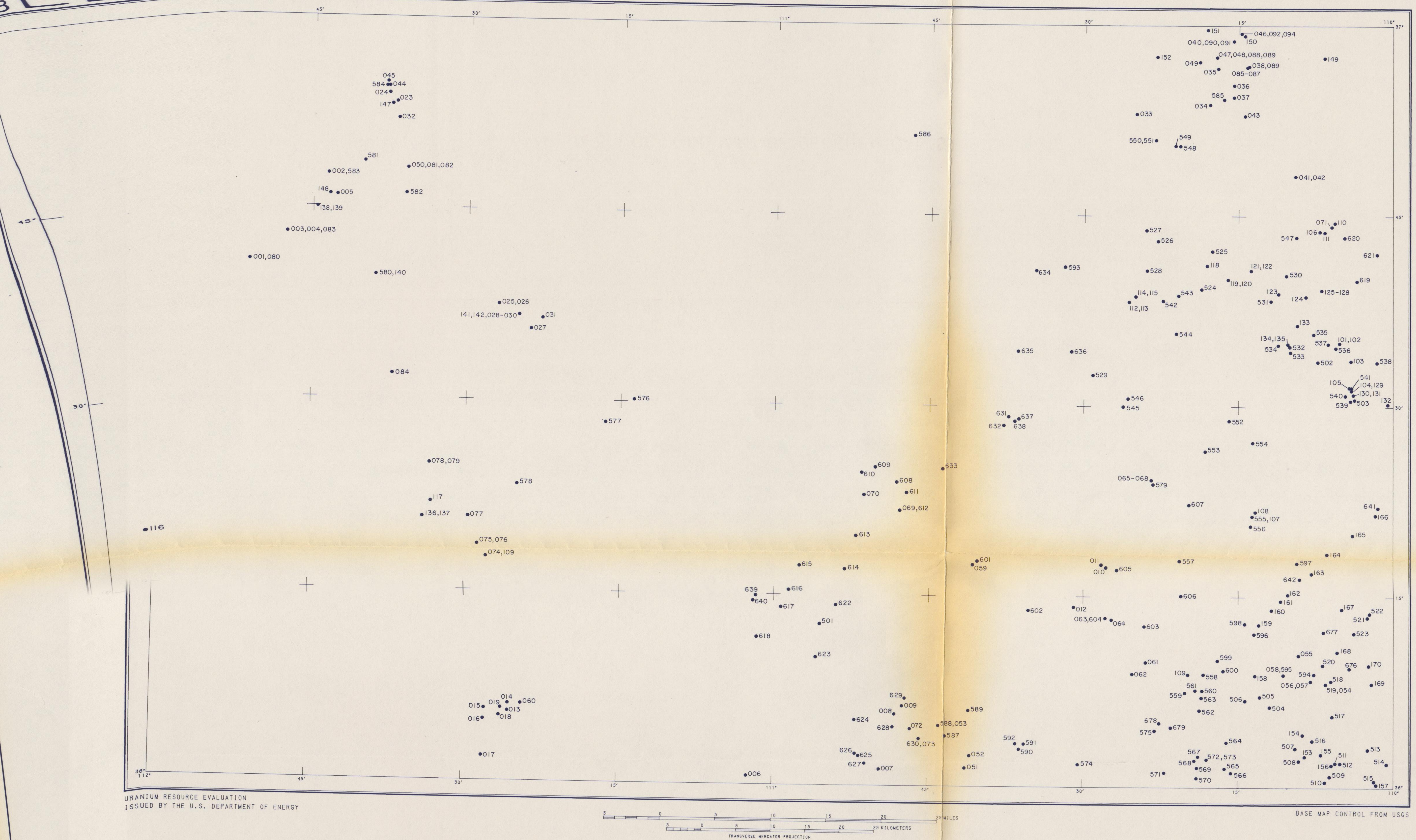
URANIUM RESOURCE EVALUATION
ISSUED BY THE U.S. DEPARTMENT OF ENERGY

BASE MAP CONTROL FROM USGS

5 0 5 10 15 20 25 MILES
5 0 5 10 15 20 25 KILOMETERS

Plate 6. DRAINAGE

BLE CANYON, ARIZONA/ UTAH



NOTE:

All samples are MJM.

MJM 001-170 — Rock samples

MJM 501-642 and 676-679 — Ground water samples

Plate 5. LOCATION MAP OF GEOCHEMICAL SAMPLES

FEBRUARY 1980

Plate 5.

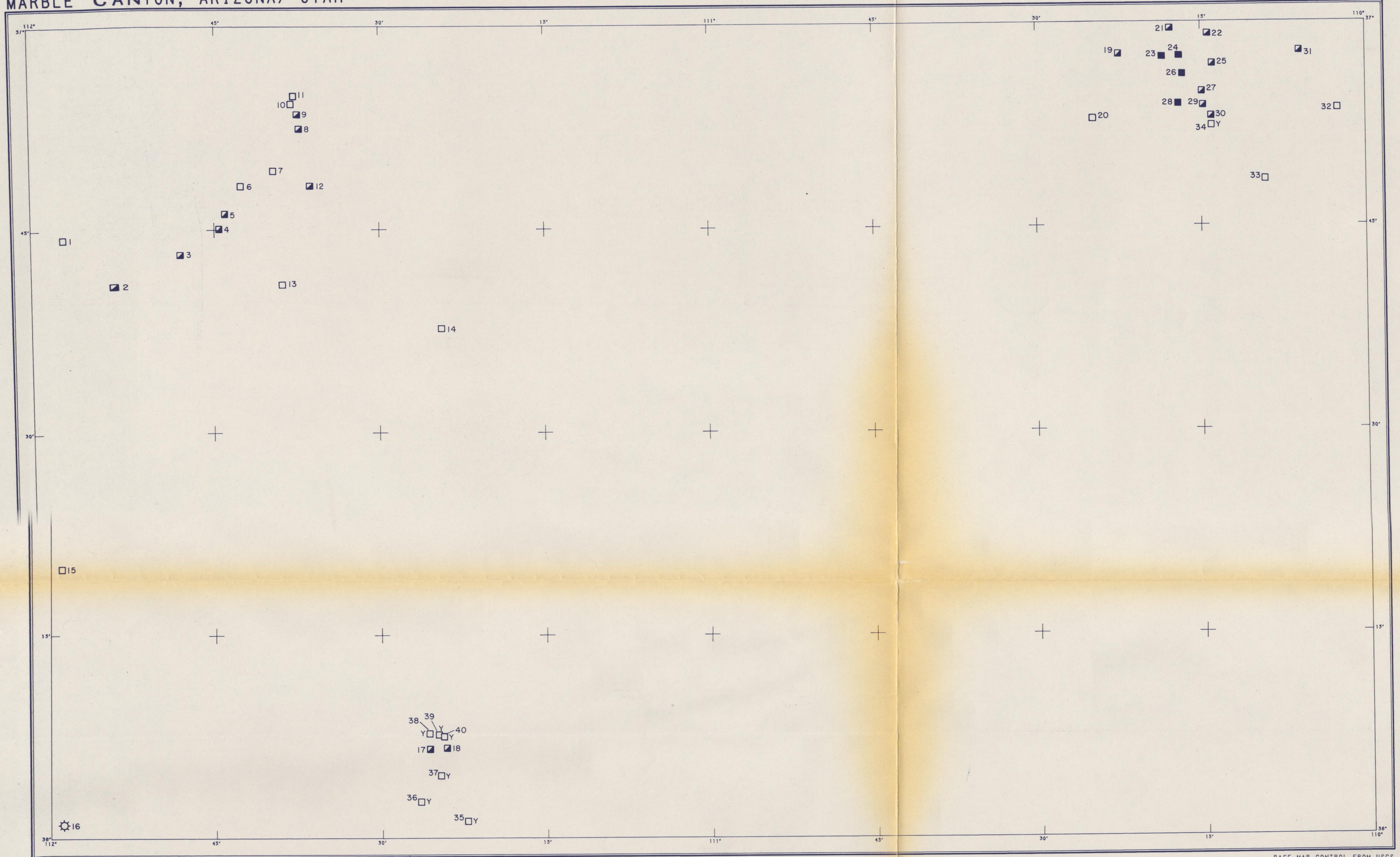
ARBLE CANYON, ARIZONA/ UTAH

Aerial radiometric data from LKB Resources, Inc., 1979

Plate 3. INTERPRETATION OF AERIAL RADIOMETRIC DATA

FEBRUARY 1980
Plate 3.

MARBLE CANYON, ARIZONA/ 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
TRANSVERSE MERCATOR PROJECTION

EXPLANATION

URANIUM OCCURRENCES

	CLASSIFICATION			
	Sedimentary	Plutonic	Volcanic	Other
Minor prospect or mineral occurrence	□	△	⬠	☼
Prospect or mine, production unknown	⬓	▲	⬟	✹
Significant prospect or mine reporting minor production	◩	◭	⬟	✹
Mine having production over 200,000 pounds U_3O_8	■	▲	⬟	✹
Not visited	□Y	△Y	⬠Y	☼Y
Not found	□X	△X	⬠X	☼X
Mining District	( )			

Plate 2. URANIUM OCCURRENCES

FEBRUARY 1980
Plate 2.

MARBLE CANYON, ARIZONA/ UTAH

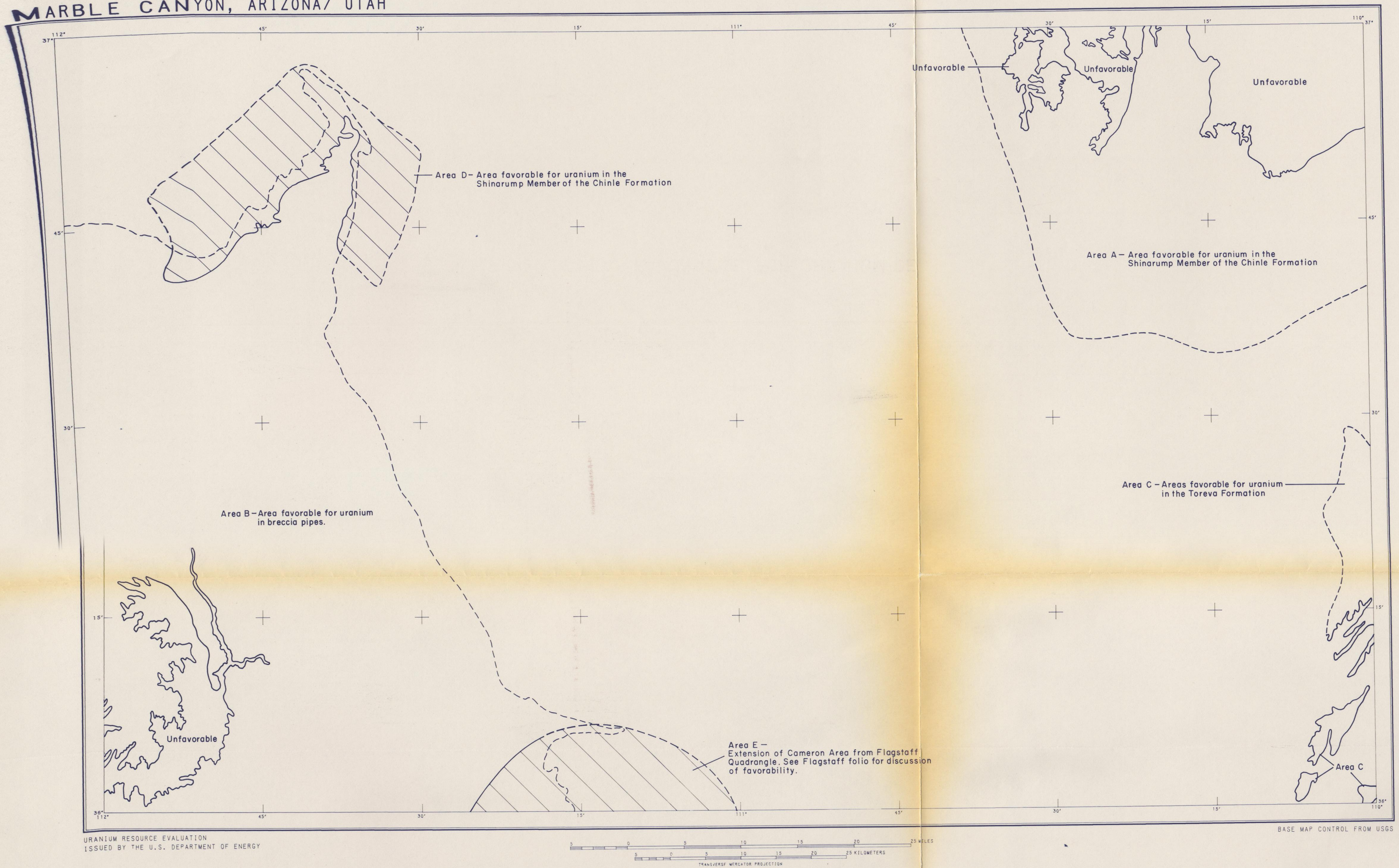


Plate I. AREAS FAVORABLE FOR URANIUM DEPOSITS

FEBRUARY 1980
Plate I.

AGE	FORMATION	MEMBER	THKNS. (M)	DESCRIPTION
HOLOCENE AND/OR PLEISTOCENE	ALLUVIAL AND EOLIAN DEPOSITS	ALLUVIAL AND EOLIAN DEPOSITS (INFORMAL)	—	Stream deposits and windblown silt and sand on benches, small terraces and in broad valleys. Reworked by running water.
		ALLUVIAL DEPOSITS (INFORMAL)	—	Silt, sand, and gravel along streams, in broad valleys, and flood plains.
		DUNE SAND AND EOLIAN DEPOSITS	—	Loess and well-sorted sand; locally includes small dune areas.
	GRAVELS	ALLUVIAL STREAM GRAVELS (INFORMAL)	—	Deposits of pebbles, cobbles, and boulders; locally contained in a sand matrix.
		ALLUVIAL FAN GRAVELS (INFORMAL)	—	Coarse, subangular, poorly sorted, locally derived material.
		PEDIMENT GRAVEL (INFORMAL)	—	Poorly sorted angular to well-rounded pebbles and boulders.
		TERRACE GRAVEL	—	Well rounded gravel on terraces.
	COLLUVIAL DEPOSITS		—	Talus, slope wash, block-rubble, and landslide deposits.
PLEISTOCENE	BASALT			Flows and dikes of fine grained black basalt containing phenocrysts of olivine.
	* BRECCIA PIPE			Silica-cemented and iron-stained pipes composed of breccia and shale fragments, coarse sand, and conglomerate pebbles.
	PEDIMENT DEPOSITS			Poorly sorted angular to well-rounded pebbles and boulders in a sand matrix.
PLIOCENE	INTRUSIVE IGNEOUS ROCKS	MONCHIQUITE (INFORMAL)		Intrusive lamphorphyric rock matrix of principally augite and olivine, small amounts of analcite and biotite; fragments of sandstone and shale.
		MINETTE (INFORMAL)		Intrusive lamprophyric rock matrix of principally biotite and diopside; crystalline xenoliths and sedimentary rock fragments.
UPPER CRETACEOUS	YALE POINT SANDSTONE		122	Coarse-to medium-grained sandstone, interbedded shale and siltstone and sparse coal.
	WEPO FORMATION		40–225	Alternating beds of siltstone, sandstone and coal.
	* TOREVA FORMATION	UPPER SANDSTONE (INFORMAL)	24	Fine-to very coarse-grained, conglomeratic, forms ledge.
		MIDDLE CARBONACEOUS MUDSTONE (INFORMAL)	32	Varicolored mudstone, sandstone and coal.
		LOWER SANDSTONE (INFORMAL)	40	Fine-to medium-grained sandstone.
	MANCOS SHALE		137–204	Marine shale with subordinate fine-grained sandstone and siltstone, marl beds near base.
	DAKOTA SANDSTONE		15–46	Medium-to fine-grained lenticular sandstone with local conglomerate lenses. Thin interbedded carbonaceous siltstone and coal.
	— UNCONFORMITY —			
UPPER JURASSIC	MORRISON FORMATION	WESTWATER CANYON	0–61	Fine-to coarse-grained sandstone containing abundant black accessory minerals and minor shaly mudstone.
		RECAPTURE	0–99	Fine-to medium-grained friable sandstone interstratified with shaly mudstone.
		SALT WASH	0–116	Very fine-to coarse-grained conglomeratic lenticular sandstone interbedded with fissile mudstone.
	COW SPRINGS SANDSTONE			Very fine-to fine-grained eolian sandstone cemented by calcium carbonate; transitional into overlying Morrison Formation.

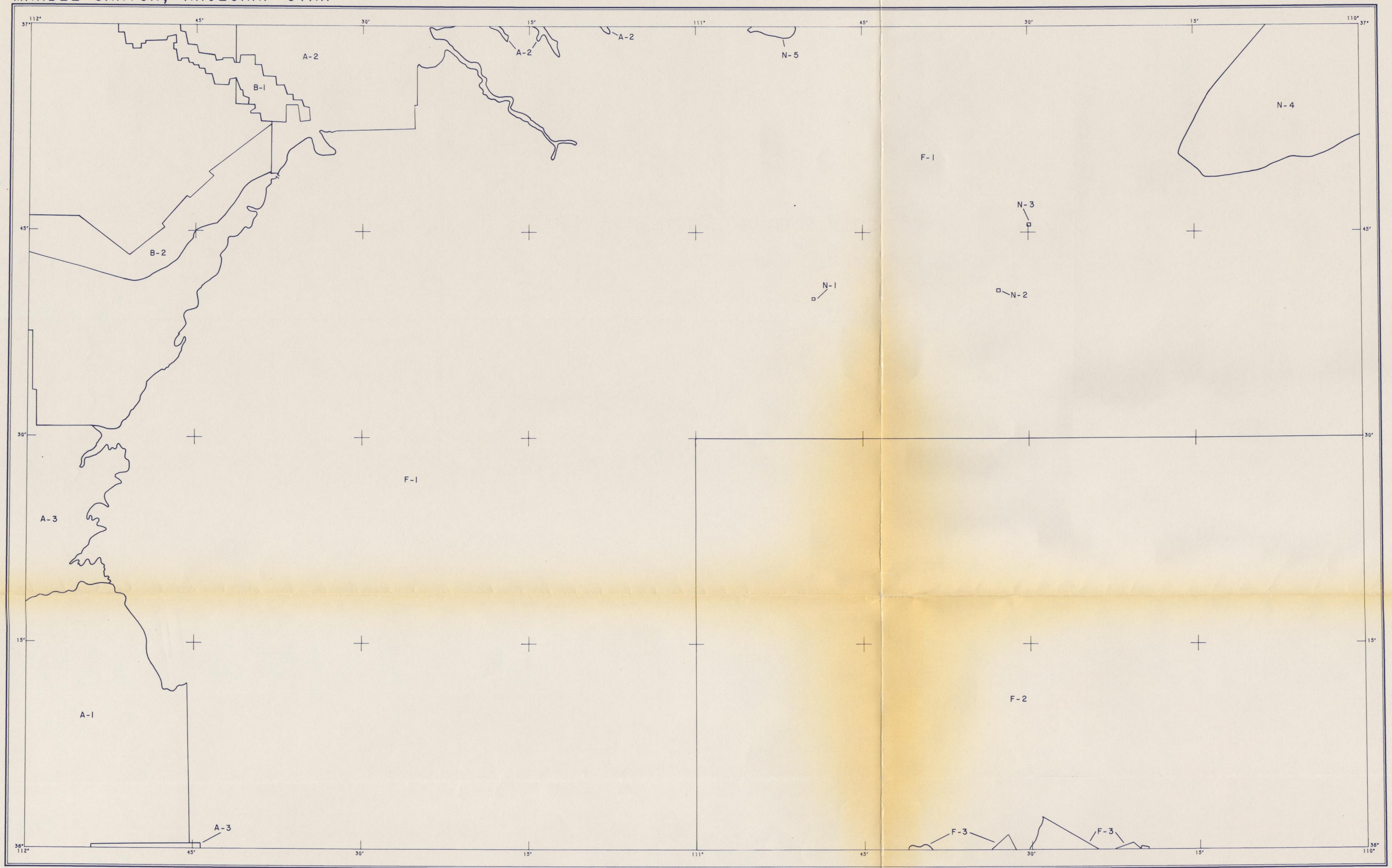
* Favorable for uranium deposit

AGE	GROUP	FORMATION	MEMBER	THKNS. (M)	DESCRIPTION
UPPER JURASSIC	SAN RAFAEL GROUP	SUMMERVILLE FORMATION		37	Very fine-to medium-grained thin-bedded sandstone with silty sandstone beds in upper part.
		ENTRADA SANDSTONE	SILTY MEMBER (INFORMAL)	34	Fine-grained silty sandstone and siltstone.
			SANDY MEMBER (INFORMAL)	229	Fine-to medium-grained sandstone with concentrations of quartz grains along bedding plains.
UPPER AND MID JUR.		CARMEL FORMATION		30–122	Fine-to medium-grained sandstone, siltstone and shale.
JUR. AND TRI.		NAVAJO SANDSTONE		518	Fine-to medium-grained eolian sandstone with thin lenticular beds of cherty limestone.
UPPER TRIASSIC	GLENN CANYON GROUP	KAYENTA FORMATION	TYPICAL (INFORMAL)	46–152	Irregularly bedded calcareous cemented fluvial sandstone intercalated with beds of shale and arenaceous limestone.
			SILTY FACIES (INFORMAL)		Mudstone, siltstone, and fine-grained sandstone.
		MOENAVE FORMATION	SPRINGDALE SANDSTONE	67	Crossbedded fluvial sandstone containing claystone and conglomeratic lenses.
			DINOSAUR CANYON	0–95	Fine-grained fluvial and paludal sandstone, siltstone, and mudstone.
		WINGATE SANDSTONE	LUKACHUKAI	0–107	Fine-grained crossbedded eolian sandstone. Intertongues in subsurface with Dinosaur Canyon Member.
			ROCK POINT	0–145	Fine-grained sandstone, silty sandstone and siltstone.
		CHINLE FORMATION	CHURCH ROCK	76	Siltstone, silty sandstone and fine-grained sandstone.
			OWL ROCK (ECHO CLIFFS)	0–76	Mudstone and silicified limestone. Limestone pebble conglomerate, and lenticular coarse-grained sandstone.
			OWL ROCK (MONUMENT VALLEY)	37–50	Shale containing minor lenses of limestone and sandstone.
			PETRIFIED FOREST	152–290	Well indurated siltstone, mudstone bentonite clay and lenticular strata of limestone-pebble conglomerate, sandstone, and conglomeratic s.s.
			MONITOR BUTTE (MONUMENT VALLEY ONLY)	30–55	Coarse-grained sandstone beds with conglomeratic sandstone lenses and claystone and siltstone beds.
			* SHINARUMP	15–23	Conglomerate composed of quartz, quartzite and chert pebbles in sandstone matrix.
		— UNCONFORMITY —			
MIDDLE (?) AND LOWER TRIASSIC		MOENKOPI FORMATION	HOLBROOK (STH. & WST-CENTRAL)	30–152	Interstratified and interfingering lenses of sandstone and siltstone.
			MOQUI (STH. & WST-CENTRAL)		Siltstone containing minor amounts of silty sandstone and gypsum.
			WUPATKI (MONUMENT VALLEY)		Siltstone containing a thin widespread sandstone.
			UPPER (MONUMENT VALLEY)		Slope forming siltstone.
			MIDDLE (MONUMENT VALLEY)		Ledge forming sandstone.
			LOWER (MONUMENT VALLEY)		Slope forming siltstone.
			HOSKINNINI (MONUMENT VALLEY)		Reddish-brown siltstone and sandstone.
		— UNCONFORMITY —			
PERMIAN		KAIBAB LIMESTONE		73–122	Dolomitic limestone containing shale, chert, and thin beds of gypsum and sandstone.
		TOROWEAP FORMATION		0–79	Sandstone, siltstone and cherty limestone.

AGE	FORMATION	MEMBER	THKNS. (M)	DESCRIPTION
PERMIAN	COCONINO SANDSTONE		15–213	Well-sorted, crossbedded eolian sandstone, lateral equivalent of De Chelly Sandstone Member.
	HERMIT SHALE		24–152	Shale, siltstone, shaly siltstone. Lenticular sandstone near base. Lateral equivalent of Cedar Mesa Sandstone.
	CUTLER FORMATION (MONUMENT VALLEY ONLY)	DECHELLY SANDSTONE MEMBER	91–152	Massive, cliff forming eolian crossbedded sandstone.
		ORGAN ROCK TONGUE	198	Even-bedded siltstone containing interbedded sandstone lenses.
		CEDAR MESA SANDSTONE MEMBER	91	Crossbedded sandstone containing thin lenticular beds of limy siltstone.
PERM AND PENN	SUPAI FORMATION		182–244	Shaly siltstone alternating with crossbedded sandstone, limestone, & calcareous sandstone in lower part.
UPPER AND LOWER MISSISSIPPIAN	REDWALL LIMESTONE	HORSESHOE MESA MEMBER	122–182	Gray to brown aphanitic, oolitic coarse grained limestone locally contains siltstone beds.
		MOONEY FALLS MEMBER		Gray to pink coarse-grained aphanitic limestone containing dolomite beds in lower half.
		THUNDER SPRINGS MEMBER		Gray limestone and dolomite with thin elongated lenses of chert.
		WHITMORE WASH MEMBER		Brownish dolomite and gray limestone.
	TEMPLE BUTTE LIMESTONE		23	Limestone filling channels cut into top of Muav Limestone.
	— UNCONFORMITY —			
CAMBRIAN	MUAV LIMESTONE (TONTO GROUP)		91	Thin bedded limestone containing interbedded micaceous shaly mudstone, platy micaceous siltstone, platy silty limestone, and intraformational flat pebble conglomerate.
	BRIGHT ANGEL SHALE (TONTO GROUP)		137	Shaly mudstone containing fine grained sandstone, platy siltstone and friable sandstone beds.
	TAPEATS SANDSTONE (TONTO GROUP)		61	Coarse-to medium-grained crossbedded sandstone.
	— UNCONFORMITY —			
PRECAMBRIAN	CHUAR GROUP	UPPER (INFORMAL)	1829	Shale containing interbedded sandstone and limestone beds.
		LOWER (INFORMAL)		Dolomitic limestone and calcareous sandstone overlying dark shale.
	— UNCONFORMITY —			
	NANKOWEAP FORMATION		100	Purple and reddish-purple massive sandstone containing conglomerate lenses and interbedded siltstone.
	CARDENAS LAVAS (RAMA FORMATION)		305	Sills, dikes, and plugs of diabase and basalt.
	DOX SANDSTONE		945	Thinly bedded sandstone and calcareous sandstone with interbedded red siltstone and shale.
	SHINUMO QUARTZITE		3657	Massive to thick-bedded sandstone which grades into quartzite.
	HAKATAI SHALE		152	Red and vermilion shale and mudstone containing sandstone beds.
	BASS LIMESTONE		61	Reddish gray silty partly algal limestone containing dolomite and interbedded shale in upper part.
	HOTAUTA CONGLOMERATE			Granite and quartz fragments which fill channels cut into Vishnu Schist
	— UNCONFORMITY —			
	VISHNU SCHIST		?	Dark gray and dark green quartz-mica schist containing interbedded hornblende schist. Intruded by dikes of granite.

Figure 3. Stratigraphic column for the Marble Canyon Quadrangle.

MARBLE CANYON, ARIZONA/ UTAH



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

BASE MAP CONTROL FROM USGS

TRANSVERSE MERCATOR PROJECTION

PLATE 10. GENERALIZED LAND STATUS MAP

INDEX

A. Areas Managed by National Park Services.
- A-1 Grand Canyon National Park
- A-2 Glen Canyon National Recreation Area
- A-3 Kaibab National Forest

B. Forest Service Wilderness Areas, Wilderness Study Areas, and Primitive Areas.
- B-1 Paria Canyon Wilderness Area
- B-2 Vermilion Cliffs Natural Area

F. Indian Lands
- F-1 Navajo Indian Reservation
- F-2 Navajo - Hopi Joint Use Area
- F-3 Hopi Indian Reservation

N. Indian Tribal Lands
- N-1 Navajo National Monument - Inscription House Ruin
- N-2 Navajo National Monument - Betakin Ruin
- N-3 Navajo National Monument - Keet Seel Ruin
- N-4 Navajo National Park - Monument Valley
- N-5 Navajo Sacred Mountain

FEBRUARY
P